Business improvement through a structured approach to sustainability in the precast concrete flooring industry

by

Hafiz Elhag

Doctoral thesis Submitted in partial fulfilment of the requirements
for the award of
Doctorate of Philosophy (Ph.D) of Loughborough University

27th October 2006

"The big question about a theory is whether it's right or wrong. Unfortunately, it's impossible to know that a scientific theory is right. The theory may agree beautifully with all the evidence - today. But science isn't like mathematics. There can be no guarantee about what evidence we will discover tomorrow."

Karl Popper

Abstract

Different production and business procurement systems in the precast flooring industry have traditionally been designed to offer products/ services with high quality, within shorter delivery times, and with the lowest cost and expense possible. However, these systems do not account for the different environmental impacts arising from its operations. This thesis explores the environmental performance of precast concrete production systems and evaluates how precast organisations can maintain their business cases within a healthy and sustainable approved practice. A Life Cycle Assessment (LCA) study was carried out for five Hollowcore and pre-stressed beams manufacturers (members of the Precast Flooring Federation – PFF) to identify the main environmental impacts arising from the production of precast flooring. It was found that mineral extraction, carbon dioxide emissions, waste disposal, and transportation are the main sources of environmental impact in the sector. These environmental impacts were linked to specific industry solutions and systems employed in design, production, transport and production management. Ten major areas where specific organisational decisions should take place were identified as the most influential on the products' environmental profiles. After that, 29 different environmental solutions were identified for these problematic decision-areas.

Three focus groups were carried out with the major decision-makers in precast flooring companies to identify the main organisation and perceptual factors associated with the implementation of sustainability in the industry. It was possible to detect a level of unawareness and lack of knowledge of sustainable development, a level of bias and pessimism in dealing with sustainability was also detected. Most of the drivers for sustainability were found to be compelling. Fourteen semi-structured interviews were then carried out to test the applicability of the environmental solutions identified. The results clearly showed a preference to common arrangements and solutions addressing economic, as well as environmental, savings. Using the qualitative and quantitative results received, three main routes (to integrate environmental requirements within the organisations' conventional decision making framework) were identified. All these were developed in a manner that recognises the manufacturers' concerns and responsibilities, and identifies the economic as well as the environmental effects of organisational decisions.

Acknowledgement

I would like to express my sincere gratitude and appreciation to my supervisor, Dr. Jacqueline Glass. Throughout the project period, I continuously received constructive and enriching feedback, this work owes much to her persistent red pen. Special thanks must also go to my other academic supervisor, Professor Alistair Gibb, for his continuous help and guidance. I would also like to thank my industrial supervisor, Clive Budge from British Precast. Clive has been (and still is) my mentor and link to the industry. He offered constructive advice and support throughout the project. Martin Clarke, the Chief Executive of British Precast, also offered much-appreciated advice, support and thought-provoking ideas throughout the project's period.

I would also like to thank Geoff Bailey – From Tarmac Topfloor Ltd. Geoff's help and support has been invaluable. He has a sharp eye for details and superb analytical skill, these have been instrumental in the success of the project.

Special thanks to all colleagues at British Precast and members of the Precast Flooring Federation (PFF) Technical Committee, they have been very helpful and supportive. I am also grateful to fellow colleagues at Loughborough University for their assistance and companionship throughout. Last but not least, I am greatly indebted to my family for their understanding, patience and support during the entire period of my study.

Table of Contents

CHAPTER SEVEN: Results, analysis, findings, and feedback from focus group

CHAPTER EIGHT: Result, analysis, findings, and feedback from semi-structured interviews

APPENDICES

List of Tables

List of Figures

Glossary

The definitions of the different terms used in the thesis were derived and sourced from a number of academic references, publications, and industrial standards; these were included where possible.

- **Autoscrap:** Term used by some precast concrete factories to refer to the concrete waste generated by portions of concrete removed from specific portions of the cast concrete bed to meet design specifications and customisation requirements.
- **Carbonation:** Carbonation is a chemical reaction between atmospheric carbon dioxide and hydrated cement compounds which causes a reduction in the alkalinity of the concrete. The process may lead to the corrosion of carbon steel reinforcement. The rate of carbonation usually depends on the permeability and moisture content of the concrete.
- **CML (Centrum** voor **Milieuwetenschappen Leiden** Onderwijs)**:** Centre for Environmental Studies at Leiden University.
- **Cradle-to-grave:** Cradle-to-grave, Gate-to-gate, and Cradle-to-gate are terms used to define the boundaries of a specific product life-cycle oriented study. **Cradle** refers to the first period within a product system life-cycle (Raw material extraction). **Gate** (factory gate) refers to the period following the manufacture of the product (or part of the manufacture of the product) and prior to its transportation to the following life-cycle stage. **Grave** refers to the end-of-life scenario for the product (which might involve landfill, incineration, recycling, etc.).
- **Cut-off:** In LCA, product systems are assumed to be affected by a range of flows of inputs and outputs. When specific data on one (or more) flows are missing from the Life Cycle Inventory, the inputs and outputs for this specific flow will have to be excluded and eliminated, this process is known as 'cut-off'.
- **Effectiveness:** Effectiveness is very similar to efficiency, but the measure is related to some enterprise objective rather than the technical quality of output. For example, one common indicator of effectiveness is related to customer satisfaction rather than output. Therefore the effectiveness measure of a business process can be indicated by the resource inputs needed to produce a level of an enterprise objective (Darnton and Darnton, 1997).

- **Efficiency:** Judgements of efficiency are based on some idea of 'wastage'. A relatively efficient process either requires fewer inputs or produces more outputs compared to a similar process, to achieve the objectives of the process (Darnton and Darnton, 1997). Technical efficiency = Output quality / Input quantity
- **Environmental intervention:** A human intervention in the environment, either physical, chemical or biological. In particular resource extraction, emissions (including noise and heat) and land use; the term is thus broader than environmental impact (Guinée, 2002). However, in this screened and simplified LCA, the environmental interventions should only include environmental impacts.
- **EMAS – Eco-Management and Auditing Scheme:** EMAS is a voluntary environmental management scheme based on a harmonised scheme throughout the European Union with the objective to improve the environmental performance of organisations by committing themselves to evaluate and reduce their environmental impact. Participating companies employ An Environmental Management System.
- **Environmental Management System (EMS):** A problem identification and problem solving tool that provides organisations with a method to systematically manage their environmental activities, products and services and helps to achieve their environmental obligations and performance goals. ISO-14001 defines an EMS as "the part of the 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."
- **Factor Four:** Weizsacker *et al* (1997) notes that the idea behind FACTOR FOUR is that natural resources can be used more efficiently in all domains of daily life. This is carried out by generating more products, services and quality of life (doubling the wealth) from less resources (halving resources).
- **Factor Ten:** is the idea that per capita material flows caused by OECD countries should be reduced by a factor of ten. Proponents claim that globally material turnover should be reduced by 50%. But because OECD countries are responsible for material flows five times as high as developing countries, and world population is inevitably increasing, the OECD has to set long-term targets well beyond the more conservative Factor Four target (IISD, 2004).
- **Gestalt:** gestalt is a German word meaning shape or form. In the Gestalt Theory, a gestalt is a single entity consisting of multiple independent entities; a being greater than the sum of its parts. The theory proposes that the operational principle of the

brain is **holistic**, parallel, and analog, with self-organizing tendencies. The **Gestalt effect** refers to the form-forming capability of human senses, particularly with respect to the visual recognition of figures and whole forms instead of just a collection of simple lines and curves.

- **Ground Granulated Blast-furnace Slag (GGBS):** Ground Granulated Blast-furnace Slag is a by-product of the iron making industry. It comes from the iron blast-furnace. The slag is quenched, by granulation, and then dried, ground to a fine powder and used as a constituent part of many construction products, including concrete.
- **Halo Effect:** This effect is mainly based on bias. It refers to a person's perception of another being influenced by their appearance (Bowditch and Buono, 1990). It can be used to explain how the manufacturers' perceive sustainability based on their previous experiences with similar concepts and principles (or obligations, governmental regulations, etc.).
- **Industrial Ecology:** This is a concept in which an industrial process is viewed not in isolation from its surrounding system but in concert with them. The concept is based on the shifting of industrial process from open loop systems, in which resource of capital investments move through the system to become waste, to a closed loop system where wastes become inputs for new processes (Jelinsky *et al*, 1991).
- **Kaizen:** A Japanse word that literally means 'to improve'. The term refers to an approach to productivity and continuous improvement (originating in the post war Japanese manufacturing industry). The approach is based on introducing considrable improvements a product (system, process, etc.) through "taking something apart and putting it back together in a better way".
- **Key performance Indicators:** These are national data sets within a comprehensive framework which enterprises (including construction) can use to measure (and benchmark) their performance against the rest of the industry (KPI Working Group, 2000).
- **Muda:** The Japanese term meaning waste of 'fat', this term is repeatedly used by different lean production academics and practitioners (Monden, 1998; Womack and Jones, 1997).
- **Photochemical Ozone Creation Potential (POCP):** This is a measure developed to assess the creation of ozone in the lower parts of the atmosphere, NO_X and VOC can control the rate of the photo-oxidation process and, therefore, levels of ozone.

- **Primary Energy:** Primary energy is the energy value of the fuel at source. In LCA, it is the value for delivered energy corrected to take **account** of the production and delivery losses of energy (Howard *et al*, 1999).
- **Fly Ash (also referred to as Pulverised Fuel Ash):** This is a major by-product in thermal power plants (also known as fly ash). It is formed as a result of burning pulverised coal. The principal contents of fly ash are normally silica (30-60%), alumina (15-30%), iron oxide and carbon (up to 20%), lime, and small quantities of magnesium oxide and sulphate.
- **Recycled Aggregate:** Aggregate resulting from the processing of inorganic material previously used in construction (WRAP *et al*, 2005).
- **SAP (System Application and Product):** SAP is an integrated system (and software application) providing management, financial information, asset, and cost accounting, production operations and materials, personnel, plants, and archived documents for Enterprises worldwide.
- **Secondary Aggregate:** Secondary aggregates are typically by-products of other industrial processes not previously used in construction, such as china clay waste, foundry sand, glass, tyres, and plastic.
- **Soikufu (creative thinking):** Based on a Japanese word meaning 'creative thinking'. The concept is used as a framework for harnessing the creative abilities of employees and '*recognition of the fact that no one appreciates a task better than the person who performs it daily*'. Through implementations such as Quality Circles and Suggestion Schemes, employees are encouraged to continuously think about improvement generation and employment of inventive ideas (Monden, 1998).
- **Thermal resistance:** This is the ability of a material to resist the flow of heat. Thermal resistance in a material will depend on its thermal conductivity (K Value) – this is defined as the quantity of heat (Q) transmitted in a specific time (t) through a thickness (L) in a direction normal to a surface of area (A), the transmittance of temperature will be mainly associated with a temperature difference of ΔT (Boehm, 2005):

$$K = {}^{Q}/_{t} \times {}^{L}/_{A \times \Delta T}$$

- **Three Bottom Lines:** The "Three Bottom Lines" paradigm is a sustainable development concept suggesting that a corporation's ultimate success or health can and should be measured not just by the traditional financial bottom line, but also by its social/ethical and environmental performance.

- **TOX (kg and m^3):** A unit used to measure levels of pollution and toxicity. Institute of Environmental Sciences at Leiden University (known as CML) developed a provisional method of toxicological weighting factors. For human toxicity these are then calculated as (human toxicological classification factor) x (kg body weighting x kg substances). The factors are based on tolerable concentrations in air, air quality guidelines, and tolerable (and acceptable) daily intakes.
- **Triangulation:** triangulation was characterised by Burgess (1984) as a way of implanting methodological rigour to research through the use of cross checking and cross referencing utilising multiple methods, data sources, theories and investigators. The four types of triangulation that Burgess (1984: p145) identifies are;
  1. Data triangulation includes data collected over time, space and by different people or organisations.
  2. Investigator triangulation involves the use of more than one researcher.
  3. Theory triangulation requires the use of competing theories; and
  4. Methodological triangulation incorporating the combination of different but appropriate research methods.

  The one employed in this thesis is methodological triangulation.

CHAPTER ONE: INTRODUCTION

Chapter One: Introduction

1.1 Introduction

During the last few decades, the international community has come to realise that current production systems are not compatible with the planet's eco-system; the level of atmospheric pollution and natural resource consumption is developing at a pace that the planet cannot sustain. This has led to increased concern among practitioners, governments and other organisations. A new culture was required to tackle these issues; this was (and still is) the atmosphere in which the concept of Sustainable Development was first introduced in the "*Our Common Future*" (Brundtland) report as (WCED, 1987):

"*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*".

The concept of sustainable development addresses the need to include new dimensions to current business systems; other than economic criteria, environmental and social aspects need more consideration and attention. As with many other industries, the precast flooring industry will need to incorporate sustainability requirements and adopt an environmentally friendly business approach. However, it is still not clear how this would affect the business case and profit margins of precast concrete manufacturers.

This thesis, entitled; "Business improvement through a structured approach to sustainability in the precast flooring industry", explores the environmental performance of production systems associated with two precast concrete flooring products and evaluates how precast organisations can improve the business case with more sustainable practices. It attempts to identify how the conventional production systems and solutions used in precast flooring affect the environmental performance and profiles of precast flooring products (Hollowcore and prestressed beams). It also explores the links between the industry solutions and environmental impacts and suggests some possible means to understand and solve the problem(s).

1.2 Problem Statement

The problem identified in this thesis is associated with the manner in which precast flooring (hollowcore and prestressed beams) production systems are being operated, and how these could be affected by the introduction of sustainability requirements.

Most production and business procurement systems have historically been designed and shaped to achieve profits through provision of products (or services) with high quality, within shorter delivery times, and with the lowest expenses and costs possible. The conventional decision-making framework in precast flooring production could be considered as the result of decades of collective experience and continuous improvement in the industry. However, sustainable development was never part of such collective knowledge and experience. The concept of sustainable development adds new dimensions to the precast manufacturing scenario because precast manufacturers will have to accommodate social progress and environmental protection as end goals. This may have a considerable effect on the precast organisation as conventional technical or managerial solutions (such as increased cement content) do not align with principles of sustainable development. On the other hand, other economic and technical solutions might have considerable sustainability advantages either in the long-term (e.g. low maintenance requirements), or the short term (e.g. secondary aggregate use or lean production principles).

Concrete is the main material used in construction; it is the largest component of construction's building and waste stream at nearly 53% by volume (Nixon, 2002). One of the main components of concrete is cement, which is an energy intensive and CO_2 producing material. It is estimated that 2.5% of national CO_2 emissions arise from concrete production (Concrete Society, 2001). On the international level, this figure could reach 5% of man-made CO_2 emissions (Pocklington and Glass, 2002), which is a significant figure. The production of concrete (including precast concrete) generates other considerable, harmful emissions. So, there is a need to reduce and manage these environmental impacts. On the other hand, precast concrete manufacturers need to maintain and support their business case.

1.3 Research Aim and Objectives

It should be stressed that this research targeted sustainability improvement in precast concrete flooring organisations, environmental improvement in this research is not considered as a means to achieve saleability, but an objective that needs to be pursued (in addition to economic growth and social progress). This research not only questioned the potential conflict between economic and environmental objectives, but it took this further to offer manufacturers a better appreciation and understanding of the problem. The aim of this thesis was to:

> "***Evaluate the impact of sustainable development and environmental protection measures on the business case of precast concrete flooring production systems***".

Understanding the impact of environmental improvement measures on the business case will require the identification of the relationship and links between the different environmental impacts and measures, solutions, and systems associated with production and operation of precast flooring factories. Moreover, the role and contributions of these measures, solutions, and systems to the business case is another important element that needs to be understood. Only after that, an appreciation of the depth of the problem will be achieved and a resolution assessed and introduced. The solution for the problem will need to account for the various environmental and economic requirements and priorities associated with production.

In order to achieve the stated aim (above), the following research objectives needed to be achieved:

1. **Understand and evaluate the environmental impacts resulting from production of precast flooring products:** In order to define the depth and nature of the problem of compromise and integration between environmental and economic needs, it is necessary to collect useful and sufficient information on the environmental impacts arising during the production of precast flooring. This is carried out using an environmental impact mapping methodology known as Life-Cycle Assessment (LCA).

2. **Determine how managerial, strategic, and technical solutions, measures and decisions affect environmental impacts:** To achieve this objective, it is necessary to understand organisations; understand how the decision making process takes place, and understand how those in marketing, technical and operational departments make and implement decisions. Furthermore, the identified main organisational measures and solutions will need to be linked to the LCA results[1]. It should be noted that this phase mainly concentrates on the main environmental impacts identified in LCA.
3. **Understand the priorities of an organisation and how sustainability can be supported by business decisions:** Following the identification of the problem, it is necessary to understand the characteristics of the most appropriate solutions. The meaning of sustainability to the decision-makers in the industry will need to be assessed and interpreted. One major question is whether sustainability will be accepted or imposed. Given that there are already some legal frameworks imposing specific sustainability requirements, any additional effort will require industry compliance (and maybe enthusiasm). The boundaries between business needs and sustainability needs will need to be identified. This phase concentrates on the main environmental impacts identified in LCA.
4. **Identify the possibility of success and evaluate the most appropriate means of business improvement through the use of sustainability:** The possibility of success of any solution(s) was tested in order to assess the chances of improving general business performance in the precast flooring industry. This phase also concentrates on the main environmental impacts identified in LCA.

The 'problem-solving' and 'action research' approach was chosen as the most appropriate to fulfil the aim and objectives of this thesis. As explained in Chapter Two, the achievement of each objective in turn offered the necessary information and feedback to complete each subsequent objective.

[1] The questions added to this (and other objectives) are included to clarify the intention behind the different objectives.

1.3.1 Main external drivers influencing research

Although this study dealt explicitly with a number of problems and challenges that appear to be associated with a specific industry sector (the precast concrete flooring industry); it was imperative to acknowledge the external drivers behind this research, these consists of a number of factors addressed at different levels across the wider UK and global community;

- **Environmental issues:** As noted earlier, the level of atmospheric pollution and natural resource consumption is increasing at a pace that the planet cannot sustain. Since 1900, the Earth has warmed by 0.7° C (Hadley Centre, 2005). The rate and scale of warming in the 20^{th} Century has been unprecedented for at least the last one thousand years (International ad hoc Detection Group, 2005) and impacts of these environmental concerns are extensive, affecting all of society.
- **Social issues:** Organisations are not only expected to meet environmental responsibilities, but also display a degree of social responsibility toward their local communities, customers, etc. Chapter Three include further discussion on issues relating to social responsibility.
- **Economic issues:** Economic and financial responsibilities are usually accounted for fully by organisations as a matter of course. However, a sustainable organisation needs to pursue economic growth in the context of environmental improvement and social progress.

When looking at the drivers above it is clear that society exerts a major influence; a range of members of the wider community can be identified as main stakeholders in this study – their expectations need to be examined and their requirements addressed carefully. Therefore, it is necessary to recognise the impact of this study's findings on the wider community and examine stakeholder engagement across a range of key issues.

1.4 Scope of the study

In order to maintain consistency in results and control over the different variables in research, it was decided to draw specific boundaries to the scope of the study – these should apply to all the different stages of the research. These boundaries include the following:

- **Products considered for research:** The study was limited to the sustainability impacts of two main types of precast concrete flooring; these are Hollowcore flooring and precast concrete prestressed beams. As explained in Section 4.2, these two products offer an ideal example demonstrating many of the reasons of using precast concrete.
- **Consideration of Sustainable Development:** It should be noted that the thesis concentrates mainly on the '*environmental pillar*' of sustainable development. The triple bottom line concept of sustainable development also proposes social and economic responsibilities for organisations; the other two sustainability pillars are being accounted for in some parts of the thesis. However, the concept of sustainable development can still be considered as novel in the industry, therefore it was decided to look at the most challenging aspect for manufacturers, i.e. the environmental interventions[2] associated with some of the most profitable, value-adding activities in production.
- **Precast flooring manufacturers as main target audience:** This thesis targets precast concrete flooring manufacturers as the subject (and beneficiary) of the research results and findings. This has an effect on all stages and limitations considered for the study; this is why the research concentrated on the *cradle-to-gate* processes (mainly manufacturing activities) in precast flooring products' life-cycles. However, it should be noted that this does not necessarily mean that the study did not look at the wider perspective (e.g. other stakeholders' interests).

These study boundaries have a direct effect on all the different measures considered in research, these include the nature of data collected, study samples chosen, results and findings interpreted, and discussions carried out.

[2] A term used to refer to environmental impact. See Glossary for more definitions.

1.5 Research description: data collection tools and methodology employed

As noted previously, a problem-solving approach was undertaken to fulfil the objectives of the study. Three data collection tools, accounting for quantitative and qualitative data, are employed in the study, these were used in the following sequence.

In order to directly fulfil the requirements for the first and second objectives, there is a need to develop a complete environmental map accounting for all the different environmental impacts associated with the production of precast elements (Hollowcore and prestressed beams). This is carried out using *cradle-to-gate* (and *gate-to-gate*) **Life-Cycle Assessments** (LCA), the primary data collected from LCA, and from two additional surveys carried out within some of the companies involved in the study, was analysed and several findings and results were established. These findings helped in achieving the next objective of the study (identifying the major environmental impacts and linking these impacts to the different decisions undertaken in different departments in the organisation). It is important to stress that the methodology used was the BRE methodology – which is the main methodology used for construction products in the UK. The data collected for LCA was robust and was already recognised by BRE and used for the new edition of the *Green Guide to specification.*

Moreover, an understanding of the manufacturers' appreciation of environmental protection and the introduction of sustainability are established through a series of **focus groups** organised for some of the industry's decision-makers. Moreover, the decision-makers directly/ indirectly affecting the environmental profiles of products are questioned through **semi-structured interviews** to meet the requirements of the third and fourth objectives. The semi-structured interviews explore many of the findings and results (from the two preceding phases) with the decision makers. Moreover, some suggested solutions are assessed by the interviewees. The findings from all these phases of research help to achieve the main aim of the study (by producing a clear case for sustainability measures and the possible effect on the business case of precast flooring manufacturers). A thorough description can be found in Chapter Two.

1.6 Description of Thesis Chapters

This thesis was organised into ten chapters in the following sequence:

Chapter One is an introductory chapter detailing the rationale, aim, and objectives of the study. The chapter also offers a summarised description of research methodology and the data collection tools used.

Chapter Two explains the 'action research' and 'problem-solving' nature of the research. It explains the context in which quantitative and qualitative data will be collected and linked to achieve the different objectives of the study. The chapter also offers an explanation of the three data collection tools used and how the information was analysed and interpreted.

Chapter Three presents a review of literature on the concept of sustainability and the triple bottom line principle. Moreover, the chapter offers information on organisations' reaction and levels of adaptability to the principle of sustainable development, and the main methods and means in which sustainability and environmental improvement requirements and systems are incorporated and addressed within the conventional decision-making framework within other industries.

Chapter Four provides a detailed description of the precast concrete industry (based on literature and secondary information). The chapter also addresses the main economic objectives and principles in the business and the main environmental impacts arising from precast concrete operations.

Chapter Five also reviews literature and secondary information, the chapter explores the nature of decision-making in organisations. The chapter also looks at some of the problem-solving mechanisms employed in different industries and how these can be employed to serve sustainability and environmental objectives.

Chapter Six explores the results and findings established from the LCA study carried out for five of the members of the Precast Flooring Federation (PFF). The study has yielded several findings linking environmental impacts to measures and solutions employed in the industry, which were linked to ten main decision-areas in different levels of management in the industry. The chapter also includes the environmental solutions identified for the problematic decision-areas.

Chapter Seven considers the results and findings established from the focus group sessions. The sessions reveal several findings associated with manufacturers' perceptions of sustainable development and the perceptual drivers limiting their understanding of the relationship between sustainability needs and economic objectives. Some quantitative results (obtained via a survey carried out during the focus group sessions) are included in Appendix M.

Chapter Eight explores the results and findings established from the semi-structured interviews stage. The interviews offer more information on the perceptual, organisational, economic, and functional factors affecting manufacturers' acceptability of environmental improvement solutions.

Chapter Nine reviews the findings established from each phase of the research and looks at the possibility of introducing sustainability into the precast flooring business.

Chapter Ten presents the main conclusions from the research. It reveals the original contribution of the research to knowledge, and suggests some recommendations for further development and research. Limitations to the research are also included.

All the analysis reports and raw data, associated with the different phases of data collection and analysis, are included in the Appendices (A to P).

CHAPTER TWO: METHODOLOGY

Chapter Two: Methodology

This Chapter explains how the research methodology was organised and assembled to fulfil the aim and objectives of the study. The chapter starts with a description of the 'action-research' nature of the study and the collection of approaches and paradigms used to achieve the various research objectives. The study starts with a positivist approach (which was preferred by the author) where a body of primary quantitative information was collected and used to reach findings on specific environmental impacts and decision-areas. These were refined, investigated and interrogated further using qualitative research tools (focus groups and semi-structured interviews). The chapter explains why and how specific tools and techniques were used to tackle different research questions. A description of the sample(s) considered in different stages of the study is provided, and some of the limitations of the methods used, due to several cultural and managerial constraints, are discussed.

2.1 Research methods and paradigms employed

Research, in its widest sense, is considered to be a dynamic and systematic inquiry in which the aim is to produce new knowledge and understanding. It locates and shapes the inquiry within the established existing body of knowledge. It also attempts to offer a justification of any claims made (Silverman, 1985). In order to achieve this, the researcher needs to employ the most appropriate research paradigms, concepts, and methods.

The classification of research differs from one study to another; researchers make a distinction between pure research and the more practical, applied research. Researchers also argue that contribution to knowledge can take different meanings and serve various purposes. There are also classifications for the types of problems that research studies need to deal with, the nature of information collected and modes of data analysis and interpretation. This section discusses the research methods and concepts appropriate for different stages in the study. Although the study seems to be taking a rational, objective, and quantifiable approach in addressing and identifying environmental impacts, the study also deals with other less tangible approaches in handling manufacturers' perceptions and their levels of acceptance and understanding of different measures of environmental improvement.

2.1.1 Problem solving, action research nature of the study

In general, applied research implies solving specific research problems (Fellows and Liu, 2003; Bryman and Burgess, 1999). This study dealt with a complicated problem with economic, as well as social, dimensions. Yin (1994) argues that the research style undertaken is significantly affected by the focus of the research and whether the research is tackling past or current events. The research approach employed for the study is a form of 'action research'. In action research, some open-ended problems are identified during research and, therefore, affecting the course of action in the work. Van Strein (1975)[3] demonstrates a cycle that can be used in action research. This is known as the regulative cycle (Figure 2.1).

This study also employed a problem solving approach (see section 1.2 for problem statement and 5.1.2 on the problem solving process). It should be noted that his 'regulative cycle' (Figure 2.1) bears many similarities with the decision making cycle identified by practitioners and academics such as Adair (1985). Green (1994) also points out that the creative problem-solving cycle (which is very similar to the decision-making cycle) was also used as a structure for the 'job plan'. The 'job plan' is usually used as a basis in value engineering exercises. All this clearly shows that the regulative cycle can be suitably used in problem-solving action research.

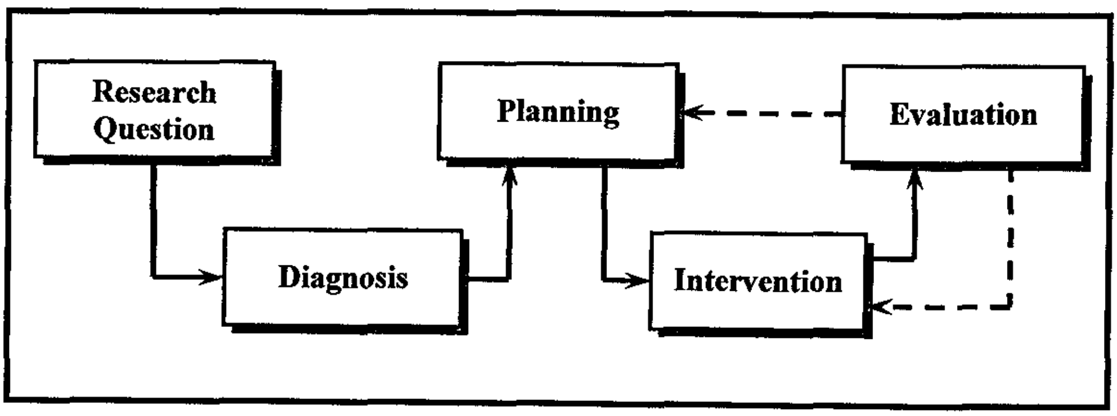


Figure 2.1 the use of the 'regulative cycle' in action research.

Other classifications for research methods and study approaches include study paradigms and research tools (qualitative, quantitative, etc.) employed. These are discussed and explained in the following sections (2.1.2 and 2.1.3)

[3] Cited by Drenth (1998).

2.1.2 Approach and paradigms employed in the study

Another important classification in research is the paradigms used to view events, question results, and consolidate discoveries. Burrell and Morgan (1979) identify two main paradigms that appear to be the most distinct and influential in research studies:

- **Positivist (Functionalist) Paradigm:** This paradigm is influenced by a positivist approach leaning towards natural sciences impelling researchers toward a search for regularities in the social world and for causal relationships among variables which make up the world. This paradigm usually deals with quantitative types of information.
- **Realist and Interpretative Paradigm:** This approach argues that social worlds can only be understood and interpreted from the perspective of its participants[4], offering more emphasis on the depth and qualitative content of information.

Seale (2004), and Fellows and Liu (2003), refer to a conflict or 'warfare' between the two schools of thought and the advocates for each path of interpretation. However, Bryman (1989) notes that social sciences, including organisational studies, do not reveal a level of consensus that would imply the existence of a paradigm at any stage in their development.

It should be noted that the author tended to use more quantified measures to control results and link them firmly to findings. This clearly shows more preference to the positivist paradigm. However, this did not restrict the methodology used in research. Indeed, a combination of quantitative and qualitative information was necessary at each stage of the work to offer different interpretations and allow for different views (as demonstrated in the following sections), this required the use of 'methodological triangulation' (see Glossary).

2.1.3 Nature of information collected in the study

The terms 'qualitative research' and 'quantitative research' are considered in some situations to be competing views about the ways in which social reality ought to be studied and interpreted, and as such are essentially divergent groups of epistemological assumptions. However, this should not be the case; research should be a dynamic process. Therefore, it must be flexible, implying (although not requiring) that a contingency approach would be helpful. This is supported by Bryman (1989) who confirms that the use

[4] The 'social world' in this study does not only refer to the precast industry (see Section 1.3.1).

of more than a single method can greatly enhance the process of fusing problem and method, by allowing the researcher to reap the opportunities presented by two or more techniques. Accordingly, the use of triangulation (integrating qualitative and quantitative research methods) can be an advantage.

Triangulation enables researchers to combine the precision and depth of qualitative information and the uniformity, consistency, and accuracy of quantitative information. (Bryman and Burgess, 1999). However, these integrated (qualitative and quantitative) measures were not used in tackling every single objective in the study. The following section (2.2) explains how a collection of quantitative and qualitative measures were used to achieve different research objectives.

2.2 Research Design (Sequence of research undertaken)

Early in research studies, links between problems, theories, previous findings and methods can be postulated. The links should form a coherent chain, and so may need to be adapted as the work develops and findings emerge. The goal must be to maintain coherence and complementarities; only by such an approach will the results and conclusions be robust (Fellows and Liu, 2003). Yin (1994) notes that the research design must take into account the research questions, determine what data are required, and how the data are to be analysed.

Prior to any explanation of the design of the research, it should be stressed that a distinction exists between knowledge for understanding and knowledge for action (Bryman and Burgess, 1999). The former closely resembles theoretical research as an approach concerned primarily with casual process and explanation, some of the secondary information demonstrated and explored in the Literature Review can be considered as 'knowledge for understanding'. However, it should also be noted that most of the information and findings associated with the first two objectives of the study (see Chapter One) are considered as 'knowledge for action' and inputs to Objectives '3' and '4'.

2.2.1 Sequential nature of the study

As noted by Fellows and Liu (2003) the classification of work in research is difficult, not only due to the use of unclear definitions of relationships between different measures considered in the study but, more importantly, because the work occurs in a continuum. Others, such as Bechhofer, believe that research can be slightly more chaotic than a continuum of investigation, knowledge gain, and interrogation of results; Bechhofer (cited by Paterson, 2000) considered the process of social research to be: "*...not a clear cut sequence of procedures following a neat pattern but a messy interaction between the conceptual and empirical world, deduction and induction occurring at the same time*". Unlike many other conventional studies, the sequence of research stages is important in this study considering that the results and findings of some objectives (and research questions) are considered as inputs to subsequent objectives.

The manner in which each objective is targeted (and findings established) took place in the following sequence:

Objective 1: To Evaluate environmental impacts

As noted in the Literature Review, there is a collection of environmental interventions occurring during the processing and production of precast concrete flooring elements. In order to establish the action research findings from viable and in-depth information, primary data on environmental impact were collected from different manufacturers in the industry (secondary information from the Literature Review is also essential for this research stage). The nature of the data collected is mainly quantitative. However, there are several options for how the data is presented, what environmental interventions are to be considered, and what major environmental impacts are to be specifically targeted to interpret and investigate the other research objectives and eventually achieve the aim of the study. It should be noted that the collected information were analysed, interpreted, and discussed separately prior to the establishment and use of any possible findings or additional raw information in the following stages of research.

Objective 2: To Link environmental impacts (and interventions) to specific mechanisms and measures employed in production

Linking environmental impacts and specific environmental interventions to decisions and solutions employed across precast flooring organisations seems to be an analysis task rather than being a primary data collection task. However, some qualitative empirical information was also collected to help in analysing and understanding the quantitative information and reaching viable results. It was necessary to collect this information from the same manufacturers' population and sample considered for environmental impacts evaluation.

Objective 3: To understand organisational priorities and how sustainability can be supported by business decisions

This objective was mainly associated with the manufacturers' views and perceptions of sustainability and their understanding of how sustainability should be implemented in their businesses (i.e. how far manufacturers would go to implement sustainable development criteria). This could have taken the study to other disciplines (mainly Social Science disciplines) such as sociology and psychology. This is normal when handling research objectives which are associated with organisational research. Bryman (1989) stresses that most organisational research borrows and relies upon concepts and approaches to the conduct of research deriving from the social science disciplines. In order to maintain consistency with the study aim and research questions, the research methods designed to tackle this objective were directly derived from, and linked to, findings and results of the two preceding objectives.

Objective 4: To identify the possibility of success, and evaluate the most appropriate means of business improvement through the use of sustainability

This objective deals with the final research stages where findings are established and suggested solutions are approved. After the identification of measures and decision-areas where environmental impacts occur, and after understanding the manufacturers' perceptions of environmental improvement and its impact on the corporate decision-making process, specific solutions are identified for each problem (or problematic situation/ area). The assessment of these solutions required additional research tools capable of receiving views and feedback from the various decision-makers within precast organisations to see whether these solutions can achieve the final aim of the study. The type of information required for this phase is mainly qualitative. However, the inclusion of a quantitative means (for attitude measurement) may also offer substantial benefits to the study.

2.2.2 The research design structure: A description

The structure of the research was set and organised in accordance with the sequence set out in Section 2.2.1. The research started with the extensive literature review on the subject, followed by surveys (questionnaires) associated with the Life Cycle Assessment (LCA) Methodology to identify the gate-to-gate (and some of the major cradle-to-gate) environmental impacts associated with precast flooring production. The developed environmental impact profiles were then analysed to identify the main measures, solutions, and specific decision-areas associated with the major environmental impacts. These results were then compared with the general perception of the manufacturers and their understanding of boundaries between business needs (and objectives) and environmental needs. Three focus groups were carried out to investigate these aspects and respondents' views were quantified and ranked. Specific quantified environmental solutions were identified and these were assessed via a series of semi-structured interviews with decision-makers in precast concrete flooring production; the interviewees were also asked to offer their views on the most appropriate means of implementing sustainable business improvements. Figure 2.2 shows the framework for the methodology.

Three regulative cycles (with feedback loops) can be identified in the methodology framework; the three dashed-line areas surround the 'regulative cycles' carried out in the study. More details on these are available in sections 2.3 to 2.5.

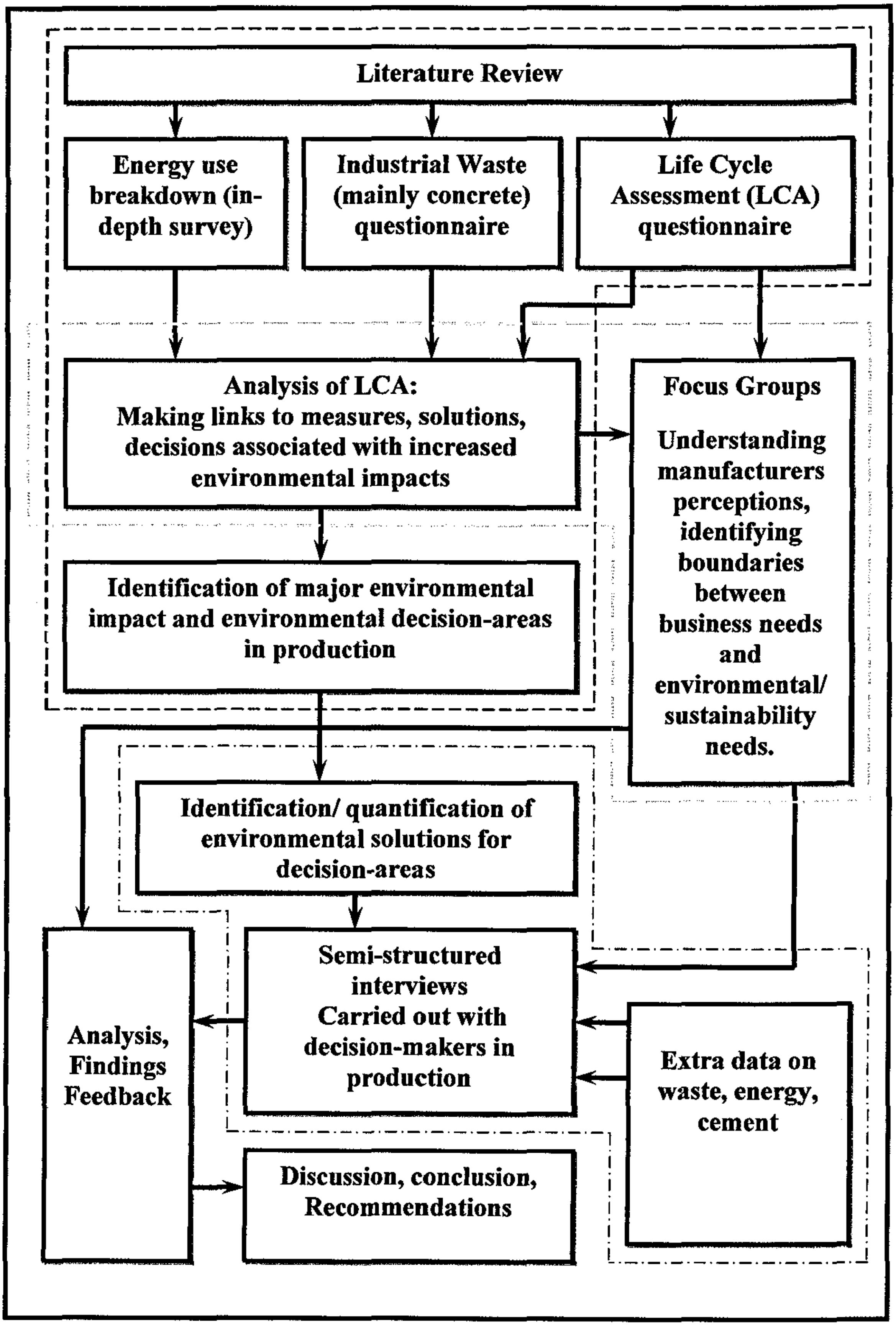


Figure 2.2 Research design and methodology framework.

2.3 Data Collection/ analysis measures: Life Cycle Assessment surveys

As mentioned in 2.2.2, in order to achieve and enable the completion of the requirements of the two first objectives, the BRE Life Cycle Assessment (LCA) methodology was used. This metholodgy was chosen because it is UK focussed and it is based on the most detailed and widely used LCA methodology worldwide – this is the CML Methodology. LCA accounts for the widest range of environmental impacts (Glavind and Munch-Petersen, 2002). A range of data collection tools and data analysis techniques was employed to complete the environmental profiles for hollowcore and prestressed precast beams.

2.3.1 Main research questions

The use of LCA enabled the researcher to tackle very important questions fundamental to the achievement of the aim of this study, these questions included the following:

- What are the environmental interventions associated with the production of precast concrete hollowcore and prestressed beam products?
- What are the major and most important environmental impacts caused by production of precast concrete hollowcore and prestressed beam products?
- What are the major activities, industry solutions, measures, and main decision-areas where most of the environmental interventions and impacts occur?
- What is the contribution of each management department to the levels of environmental impacts associated with precast concrete hollowcore and prestressed beam profiles?

The development of environmental profiles for hollowcore and prestressed beams helped in answering the first question. The use of the Eco-points score environmental scale (see section 6.4.1) helped in answering the second question. The other two research questions can be tackled through detailed analysis and breakdown of Life Cycle Inventory (LCI) information (linking environmental impacts to specific activities and production policies). However, success in answering these questions depended on the design of the survey(s) for LCA.

The BRE Environmental Profile methodology accounts for a collection of environmental burdens and impacts classified in 13 main environmental impact categories – these are detailed in Section 2.3.2. For the purposes of this study, the methodology was used only to assess the gate-to-gate life-cycle environmental impacts directly associated with precast manufacturers' responsibilities: these include the transportation of raw materials to the factory, in addition to the production process at the factory. Other cradle-to-gate impacts were included from secondary data and information from the Literature Review.

2.3.2 Goal and Scope definition for Life Cycle Assessment (LCA)

Guinée *et al* (2002) consider goal and scope definition to be a crucial step in Life Cycle Assessment (LCA). LCA can be conducted for commercial, technical or operational purposes. In the study, members of the Precast Flooring Federation (PFF) were the target audience, they wanted to explore the different environmental impacts associated with precast flooring production (i.e. hollowcore and prestressed beams). With reference to ISO 14040 (1997), clause 5.1.2 (and referred to in ISO 14041, clause 5.3.1), the following parameters define the scope of the PFF LCA study:

- **Temporal and geographical coverage:** the LCA study covered the period between 1st January and 31st December 2002[5]. The study was UK focused. However, some suppliers were based in Spain and Italy, which has affected raw material transport impacts. Moreover, the results were compared to results from several studies in Europe and North America (Chapter Six).
- **System Boundaries:** this study is limited to the factory gate-to-gate phase of the product's life. This does not violate the principles of LCA as the resultant profiles were added to other life-cycle impacts (in the BRE database) to form a complete LCA (González *et al*, 2000). It should be noted that the BRE methodology does not include impacts associated with manufacturing, maintenance and decommissioning of capital equipment. Moreover, the methodology allows for omission of any inputs/outputs that have a marginal impact on the environmental profile.
- **Functional Unit:** among the different functions achieved by precast flooring elements (including structural, fire resisting, thermal and sound insulation functions), only the basic (provision of flooring) function is used. The functional unit is one tonne of precast concrete used for hollowcore/ prestressed beams flooring with a thermal resistance of 1.43 m^2 K/W (see glossary).
- **Included data categories:** the study accounted for 12 categories (the Ozone Depletion category was excluded due to lack of significant impacts), these were

[5] Information for PFF3 covered the period between 1st April 2003 to 31st March 2004.

Climate Change impacts (measured in kilograms of CO_2 equivalent), Acid Deposition (kg of SO_2 eq), Ozone Depletion (kg of CFC_{11} eq), Fossil Fuel Depletion (TOE), Human Air and Water Toxicity, and Eco-Toxicity (kg and M^3 of TOX), Photochemical Ozone Creation Potential – POCP (kg of CH_4), Eutrophication (kg of PO_4), Mineral Extraction and Waste Disposal (tonnes), Water Extraction (litres of water), and Transport Pollution (tonnes.km and Eco-points).

- **Data Quality and reliability:** The BRE methodology applies a simplification system developed by SETAC[6] (Christiansen, 1997): Precise, company recorded data are preferred. If not found, company standardised estimations or information from other periods or from similar factories are used. Cut-off and eliminations to some elements were also carried out in accordance with the BRE methodology.
- **Characterisation and conversion factors:** The characterisation and interventions conversion factors used were directly taken from Digest of UK Energy Statistics - DUKES (1997) database. Further updated conversion factors (notably for CO_2 emissions) were taken from the Climate Change Levy guidelines. More information can be found in Appendix C, where one of the studies is fully demonstrated.

2.3.3 Research sample and population

As noted earlier, this study was carried out with members of the Precast Flooring Federation (PFF). Companies associated with the PFF produce nearly 40% of the UK's national production.

The population, i.e. PFF members, producing hollowcore, prestressed beams, or both in Britain was 13 to 15 factories (some factories were not fully operating during the study). It was decided that each member company should nominate a single factory site for the study. With just one PFF member declining to participate, it was decided to carry out the study for hollowcore/ prestressed beams product systems in five precast flooring factories belonging to five different members of the PFF (Table 2.1).

Due to confidentiality requirements, the participating factories (and their companies) are referred to throughout the thesis as PFF1 to PFF5.

[6] The Society of Environmental Toxicology and Chemistry (SETAC) is a non-profit, worldwide professional society comprised of individuals and institutions engaged in environmental research, management, and regulation (see www.setac.org for further information).

Company	Factory/ Site	Products manufactured
Carter Concrete Ltd.	Beeston Regis and Cromer, Norfolk	Four of the factories included manufacture prestressed beams and hollowcore – One factory [PFF5] manufactures prestressed beams only
Hanson Building Products Ltd.	Hoveringham, Nottinghamshire	
Milbank Floors Ltd.	Colchester, Essex	
Cemex UK materials (previously RMC Concrete Floors).	Wick, Avon	
Tarmac Top-floor Ltd.	Ashbourne, Derbyshire	

Table 2.1 Precast Flooring Federation (PFF) factories involved in the research (in alphabetical order).

2.3.4 Life Cycle Inventory (LCI) Questionnaire

To build a comprehensive environmental profile, a Life-Cycle Inventory (LCI) was developed. LCI is the core component of any LCA, indeed the entire Life Cycle Assessment depends on the content of the LCI. An extensive questionnaire, based mainly on manufacturers' records, was carried out to collect the necessary information. The questionnaire was a modified version of the generic BRE Life Cycle Inventory survey (Howard *et al*, 1999). A flow diagram was attached to the questionnaire to enable the respondents to identify the boundaries of activities included in the study. The questionnaire used can be found in Appendix A. All the information received was installed in Excel Spreadsheets designed to carry out LCA conversions, allocations, characterisation, normalisation, and calculation of environmental impact categories and environmental impacts in Eco-points (weighting). Table 2.2 lists some of the main data elements collected to complete the inventory.

More information can be found in Appendix C where one of the LCA studies completed can be found.

Input	***unit***	***Output***	***unit***
Sourced cement	Tonnes	Net production	Tonnes
Sourced aggregates	Tonnes	By products (A)	Tonnes
Sourced reinforcement	Tonnes	By products (B)	Tonnes
Sourced admixture	Tonnes	Products A and B to recycling	Tonnes
Sourced replacement materials (PFA, etc.)	Tonnes	Profits from by-products A and B sold.	GB Pounds
Production: fuel oil used	Litres	Profits from net production	GB Pounds
Production: electricity used	KWh	Water discharged	Litres
Water used	Litres	Emissions to water: silver, zinc, nitrate, nitrite, nickel, etc.	Mg/ Litre
Screws, nails, timber and other consumables	Tonnes	Waste oils disposed	Litres
Lubricating and release oil used	Litres	Concrete waste	Tonnes
Transport: Truck sizes for each raw material	Tonnes	Concrete waste to recycling	Tonnes
Transport distance for each raw material	Km	Other non-hazardous waste	Tonnes
Ship/ train travel distances	Km	Other hazardous waste	Tonnes

Table 2.2 Inventory data handling checklist (modified from Howard *et al*, 1999).

2.3.5 Energy consumption and concrete waste generation surveys

Due to a lack of sufficient information in some categories, the results of LCA were strengthened with two surveys on energy and waste generation. These were extremely useful in the analysis and recognition of the major environmental impacts associated with various important business activities.

A concrete waste questionnaire was developed to quantify the amounts of concrete waste generated weekly during the production of hollowcore and prestressed beams. This was carried out for a period of eight weeks during the first half of 2004 (no major changes were introduced to the factories considered in the period between 2002 and 2005). The questionnaire identified four main concrete waste streams:

- Waste concrete remaining in mixers, concrete delivery and casting systems (S1);
- Discarded cast concrete portions (S2), including customisation waste (waste-by-design);
- Units scrapped in the stockyard (S3); and,
- Site rejects (S4).

The questionnaire was designed to allow three different approaches to the estimation of concrete waste:

- Using gross/ net production information,
- Using estimates based on concrete waste transport information,
- Through quantifying each concrete waste stream separately based on operational managers' own estimations per cast. The concrete waste questionnaire can be found in Appendix B.

In order to eliminate activities not directly associated with energy consumption at factories, and to gain more insight into the specific measures and aspects affecting energy consumption at precast factories, it was decided to carry out a breakdown study for energy consumption at some of the larger PFF production facilities. Primary and secondary information on buildings' energy consumption standards were used to estimate energy consumption for offices, general lighting and welfare facilities. The energy breakdown study also targeted some of the manufacturing activities (such as accelerated curing, sawing, and crane movements) and these were isolated from the overall energy consumption at some sites. The breakdown helped in establishing findings linking environmental impacts to different technical, commercial, and operational solutions and decision-areas.

2.3.6 Consolidation of environmental profiles: Generic environmental profiles

Nine environmental profiles were developed for the PFF members. Two generic environmental profiles (Hollowcore and prestressed beams) were developed from the data collected from the manufacturers. The generic environmental profiles were used to carry out comparisons with similar studies. In addition to the identification of significance in environmental impact results received, the comparisons helped considerably in detecting abnormalities in the results received and established the applicability of study findings to other factories in the UK and elsewhere. The BRE Methodology guidelines (Howard *et al*, 1999) imply that generic products are arrived at by applying an average based on the contribution of each site (factory) by mass of total UK mix of sites (factories) supplied. These guidelines were followed in the calculation of the two generic profiles.

2.4 Data Collection/ analysis measures: Focus Group sessions

In order to understand manufacturers' perceptions on environmental improvement (and sustainable development in general) and in order to identify the boundaries between business needs and sustainability needs, it was necessary to contact different management levels within the industry and collect primary information on their understanding and appreciation of the subject. This section explains why and how focus groups were designed to achieve this aim. Unlike other conventional focus groups concentrating on qualitative accounts of information, the time available for these focus groups sessions was limited. Therefore, a survey with an attitude measurement and ranking mechanism was used during the sessions; this enabled the sessions to account for quantitative as well as qualitative feedback from the manufacturers.

2.4.1 Main research questions

The literature (in Chapter Three) reveals different attitudes, motives, and targets behind the implementation of sustainable development criteria. However, it also opens the door to essential questions in tackling and exploring sustainable development in the precast concrete flooring sector, these may include questions such as: What does sustainability really mean to decision-makers in the precast industry sector? Are precast manufacturers ready to advance to more progressive stages in their quest to become sustainable? Do they have the most appropriate perceptions about their environmental performance? And what are the main factors restricting manufacturers from adopting more sustainable and environmentally-friendly solutions?

In order to serve the aims and objectives of this study, primary in-depth data was collected from the precast concrete flooring sector. This primary data had to cover the following aspects:

- **Explore how manufacturers perceive sustainability:** Recognising the manufacturers' perceptions of environmental improvement and identifying their views toward the introduction of sustainability (and how far they should go to embrace it) is an important research question. The required information is mainly qualitative; the Dunphy model (Dunphy *et al*, 2003) for sustainability (see Section 3.4) was identified as a useful tool in classifying manufacturers' perceptions.
- **Explore the relationship between business needs and sustainability needs:** Identifying the exact relationship between conventional business needs and sustainable development requirements is a challenging task which requires careful planning. By understanding how manufacturers accept or reject specific sustainability principles (and practices), it is possible to understand the boundaries and the nature of the relationship between the business/ production system employed by the precast company and the requirements and needs of sustainability.
- **Identify the major restrictions to implementation of sustainability (economic, technical, etc.):** There are several economic, functional, and technical constraints restricting manufacturers' adoption of environmental solutions. These had to be identified and explored in order to find the most appropriate solutions for the major environmental impacts in hollowcore and prestressed beams production.

Because of the nature of the subject and the nature of data required, 'focus groups' was found to be the most appropriate tool for data collection. The information collected shared the following characteristics:

- **The information required implies use of primary data collection tool(s):** analysis and interpretation of precast manufacturers' responses to sustainability cannot be carried out using secondary information. Primary data collection is required to explore the perceptions and barriers to implementation of sustainability.
- **The information required is mainly qualitative:** This stage dealt with social qualitative information. However, this did not rule out the use of rating tools and statistical instruments: a scaling system can be used – especially in the case of manufacturers' classification in accordance with the Dunphy model (Dunphy *et al*, 2003).
- **The nature of the information required mainly implies use of attitudinal questions:** Attitudes are opinions or basic beliefs which people have about products they buy or tools and systems they use (Hague, 1993). The literature supports the

notion that issues involving manufacturers' perceptions or 'culture' should reflect on their opinions and attitudes. Attitudinal questions can be designed to fit different data collection tools (questionnaires, interviews, focus groups, etc.). However, when a controversial subject is handled (as in implementing sustainability and affecting the conventional business system), the selected data collection tool should allow for discussion, interpretation, and debate.

- **Need for in-depth details:** Some of the information required can be contained in closed questions with a limited and controlled set of answers. However, understanding manufacturers' perceptions required more specific information with a considerable amount of depth. Therefore, the tool used should also allow for open questions.

These characteristics imply the use of highly-structured focus groups with combinations of closed questions and more open questions requiring debate, discussion, and interpretation. Therefore, it was possible to combine the qualitative advantages found in interview conversations with some quantitative advantages found in controlled answers that could allow for categorisation and organisation of results and better links with findings from other work stages in the study. The process of combining qualitative and quantitative methods is always beneficial for the findings of such types of research (Greenfield, 1996).

2.4.2 Research Sample and population

The population targeted in the focus groups included different decision-makers at different management levels in precast flooring organisations. Following the LCA study, specific decision-areas were identified as crucial in terms of environmental impact. Managers responsible for these decision-areas (decision-makers) were the subject of this part of the research. Therefore, they were considered as the research population.

Different literature provides a sufficient description of the characteristics of a potentially successful focus group, these include the following:

- **Size of a focus group:** Krueger (1994) notes that the normal focus group size in marketing-associated research is usually between 10 to 12 members. Barbour and Kitzenger (1999) note that limiting this to six or eight members produces better results.

- **Background and level of knowledge:** Due to the nature of questions for these focus groups, the issues discussed were mainly technical and involved extensive experience and knowledge in precast concrete manufacturing. Unlike other forms of social research, the population for this research was extremely limited and any variation in the group's knowledge and expertise did not benefit the quality of the outcome from the focus groups.
- **Level of homogeneity:** Focus groups are usually characterised by homogeneity with sufficient variation among participants. Clearly, stark differences between respondents were hard to achieve due to the small population within the precast concrete industry. Differentiation was achieved through a different mechanism, such as constructing the group from respondents working for different organisations with different levels of profitability, production systems, and sustainability implementation.
- **Respondents' familiarity with each other:** In order to avoid both the 'polluting' and 'inhibiting' effect of existing relations between group members, it is preferred that those involved in a focus group do not know each other (Barbour and Kitzenger, 1999). However, in a small industry sector where a limited number of managers bid continuously for the same tenders and are members of a limited number of parent organisations, it is impossible to meet this requirement. However, choosing managers working for totally different organisations attempted to mitigate this problem.
- **Level of involvement within the decision making process:** This is another measure restricting choice for respondents for the study. Unlike cement or general contracting organisations, precast concrete manufacturing companies have smaller workforces and flatter organisational structures. It is possible that, in some companies, a manager is involved in all managerial and even technical production decisions; this could have left an even smaller population to choose from. However, the nature of information required to fulfil the objectives of this stage mainly required the participation of those involved in managerial, commercial, or technical decisions within the organisation.

From these characteristics and specifications, the following description is provided on the preferred and appropriate focus groups for this research: 6 to 12 managers with extensive experience/ technical knowledge on precast concrete production systems, those managers should come from different organisations (or different factories). In order to avoid inconvenience and possible delays in preparations and assembly of focus groups, it was decided to use the PFF professional committees (at the time when the research was conducted) for this purpose as most of the professional committees at the PFF met the requirements of the population and the sample group (in terms of number, familiarity, knowledge, and expertise). The PFF has Technical, Commercial, and Strategic committees.

2.4.3 Design of focus groups

Barbour and Kitzinger (1999) define focus groups as group discussions exploring a specific set of issues. They note that "focus" refers to the collective activity that takes place during the discussion of a specific issue within the group (or between the group and the facilitator). It should be noted that it is hard, sometimes, to differentiate between focus groups and other group data collection tools. However, some researchers do not hesitate in defining any group discussion as a *focus group* as long as the researcher is actively encouraging, and attentive to, the group interaction (Barbour and Kitzenger, 1999).

It should be noted that focus groups are more concerned with exploring rather than solving a problem (which coincides with the objectives of this stage). It should also be noted that focus groups do not fit exactly the definition of group interviews as group interaction is the vital data collection instrument. Moreover, the involvement of the focus group facilitator usually takes a different shape; unlike an interviewer, the facilitator has limited control over the results of a focus group discussion. The following section covers the question/ subject categories discussed in the focus groups.

2.4.3.1 Explore how manufacturers perceive sustainability

Each individual within the precast manufacturing sector have his/ her own perceptions of sustainability; there was a need to design the question(s) in a manner that allows for these perceptions to surface. One of the main tools attempting to classify manufacturers' perceptions on sustainability is the Dunphy model; the method used in categorising perceptions and attitudes of companies is based on specific opinions (almost statements) and push/ pull factors derived from Dunphy *et al* (2003):

- **Statements:** Dunphy *et al* (2003) incorporate different opinions within each of the model's categories. These opinions can be shaped into specific statements: such as "*Sustainability is an unnecessary measure that affects the industry*" or "*Sustainability is important, but the industry might need some time to get up to speed*". These statements were used to trigger discussion in the focus groups.

- **Push/ pull factors:** Even within the Dunphy model, companies tend to implement sustainability for completely different reasons and motives (compliance with governmental regulations, technical, marketing, moral). These obviously offer a good insight into how manufacturers perceive sustainability.

Accordingly, it was decided to design two closed multiple-choice questions that dealt with statements and push/ pull factors. The questions were designed to reflect the spectrum of ideas and views demonstrated within the Dunphy model.

I. What is your reaction to the following statements on sustainability?

Details on the statements can be found in the focus group forms (Appendix D). The statements were accompanied by options: *Agree*, *Disagree*, or *don't know*. Following voting, manufacturers were encouraged to explain what they agree/ disagree on for each of the statements.

II. What are the main push/ pull factors for your organisation to seek sustainability?

Details of these factors can be found in the focus group forms (Appendix D). The factors were accompanied by options: *Low*, *Medium*, or *High*. Following voting, manufacturers were also encouraged to justify their choice. The push/ pull factors clearly match those found in the Dunphy model (refer section 3.4).

2.4.3.2 Explore the relationship between business needs and sustainability needs.

The exploration of the relationship between these two broad needs is a challenge that cannot be met in a single focus group session. Sustainability has specific implications for manufacturers (such as energy consumption, health and safety, cement use, concrete waste, etc.). Therefore, stimulus material was offered to participants to remind them of the basic issues and to help them link these to their core understanding of their conventional business needs (Krueger, 1994). This stimulus material was a prompt sheet with a list of potential environmental impacts generated by typical precast production systems. The prompt sheet also included another list containing the major regulations, frameworks, taxes, levies and other measures implemented by the government to improve the environmental and general sustainability performance of the industry.

There were no questions specifically addressing the relationship between sustainability and business needs. However, the answers to all the questions, statements, and opinions involved discussions; these discussions offered a good insight into manufacturers' understanding of advantages, boundaries and the general nature of the relationship between sustainability needs and business needs. For example: Statement 4 of the first category of questions (I) is "*the industry needs time to keep in pace with governmental measures*"; when providing answers the manufacturers were supposed to explain why the industry does/ does not need time to handle modifications associated with sustainability, such explanation should obviously involve managing the relationship (contradiction, harmony) between sustainability needs and profitability needs[7].

2.4.3.3 Identify the major restrictions to implementation of sustainability (moral, technical, economic, etc.)

This question targeted the main obstacles hindering the implementation of sustainable development in the precast flooring industry sector. It is mainly the conflict (between conventional business needs and sustainability needs) that test manufacturers' intentions and level of tolerance towards sustainability.

III. How do you rate these obstacles in terms of their impact on the implementation of sustainability principles in the precast concrete industry?

Details on the obstacles can be found in the focus group forms (Appendix D). The potential obstacles included were accompanied by options (grades of difficulty): *Low*, *Medium*, or *High*. Following voting, manufacturers were encouraged to explain and justify their opinions. The expertise of manufacturers played a major role in the quality of data provided for this objective.

2.4.4 Pilot Focus Group

A pilot focus group was organised at an early stage in the research, the results of this pilot were used later to modify and adjust the structure and questioning of the Focus groups. The focus groups were designed to fit within the 20-30 minutes time-span usually permitted by the PFF committees. The aim was to explore how answers to questions might expand to provide the required depth and even to include areas not targeted by the study. In addition, the pilot study was also intended to explore the nature of the qualitative information and

[7] All answers to the questions on statements, factors and obstacles (I, II or III) should involve the relationship between business needs and sustainability needs.

how these can be recorded and analysed. The pilot group consisted of five Loughborough University research staff members, all of whom had extensive experience either in concrete production or in sustainable development. The results of the pilot were not as reliable. However, the main purpose was to train the author on interviewing skills (see 2.4.3) and test the structure of the questions. Following the pilot focus group, several modifications were carried out to the structure and framework of the sessions to minimise confusion and save time. The modifications also included the forms and prompt sheets used during the sessions.

2.5 Data Collection/ analysis measures: Semi-structured interviews

The content of this research stage depended mainly on the output of the LCA and focus group studies (see Chapters Six and Seven). Analysis of the LCA study should identify specific decisions (undertaken by different tiers of management within precast flooring organisations) that contribute significantly to the environmental profiles and environmental impacts in precast flooring products. Information obtained by the earlier research tools targeted why and how manufacturers do not, or cannot, address sustainability considerations in decisions made by their management. Various internal and external constraints (identified partially in the focus groups) make this difficult to achieve.

2.5.1 Main research Questions

Following the LCA study and the identification of the decisions (undertaken by different tiers of organisation management) that contribute significantly to the environmental profiles and environmental impacts in precast flooring products, the research looked at the conventional decision-making process employed in these organisations. It attempted to tackle two main objectives in the study, to:

- Understand the priorities of an organisation and whether sustainability can be supported by business decisions.
- Explore the possibility of successfully implementing a sustainable, yet profitable, precast business practice.

However, due to the 'action research' nature of the study, several unanswered questions have surfaced from the earlier findings; these are reviewed and analysed in Chapters Six, Seven and Eight. Researchers such as Flick (2002) and Gillham (2000) note that formulating and updating research questions is a central step that helps researchers keep pursuing the same objectives. Accordingly, the new categories for research questions associated with these two study objectives comprised the following:

Understand the nature of the process (decisions, etc.)

Following the links found between environmental impacts and specific decisions undertaken within the organisation, more factual primary data (associated with processes and procedures at some of these organisations) was found to be necessary to fulfil the aim and purpose of the study. This helped in identifying the decision or group of decisions responsible for the environmental impact. It also helped in identifying the parties directly or indirectly involved in these decisions.

Following the identification of the parties involved and the major objectives behind the decisions, manufacturers were asked about the viability of reforming these decisions. These decisions included different issues, depending on the managers interviewed.

Exploring the possibility of reconsideration of manufacturers' decisions

Adair (1985) notes that decision review takes place through monitoring the progress, sensing the effects and redefining the objectives (as part of a continuous improvement cycle). Decision review and subsequent change is a normal process in businesses. However, reviews addressing fundamental strategic decisions are rare. Organisations, in general, are not used to major reengineering and restructuring operations affecting their fundamental strategic decisions (Adair, 1985). On the other hand, other decisions frequently change (notably operational job-based decisions). The possibility of changing a decision is usually subject to the nature of the effects and impacts that may occur. In addition to the basic economic, social, and environmental viability factors that are widely recognised, there are hidden factors that can emerge from implementing a new decision. These could be hard to identify, however, insiders (decision makers) are the most capable of identifying such hidden factors.

Understanding managers' levels of awareness and interest in the subject

This objective was also considered in the Focus Groups stage of the study. In this additional data collection operation, awareness is being sought after as a by-product; there were no questions directly addressing the level of knowledge and awareness of manufacturers. The information received on manufacturers' levels of awareness of environmental impacts was used in understanding how unawareness can play part in creating decision-making areas that adversely affect the environment.

Lack of interest is a major problem in organisations unable to embrace sustainable practice. If manufacturers had clear negative views on sustainability and the implementation of environmentally and socially responsible systems, it would be very hard to address most of the other options for the study. The 'why' question can be answered through discussion of possible scenario options in addition to the identification of manufacturers' priorities in the implementation of decisions. The levels of interest can be related to the levels of awareness (See Section 3.4[8]). Failure to differentiate between specific gate-to-gate impacts and decision-based long term upstream (or downstream) impacts could severely affect manufacturers' judgements. For example, precast concrete production has low environmental impacts and emissions. However, decisions undertaken on cement content or a product's ability to be recycled can have a considerable effect on different cradle-to-grave impact levels for precast products (CO_2, energy, mineral extraction, etc.). As noted by Fielding and Fielding (1986), there is a strong link between a person's point of view, and the world (or in this case the business circumstances) in which he/ she acts.

The questions in these sections were more related to the subjective theory. This theory refers to the complex stock of knowledge possessed by the participants (managers) about the topic under study. This knowledge includes assumptions that are explicit and immediate and which a manager expresses spontaneously in answering an open question.

Understanding managers' priorities in production

Managers should be aware of the purposes behind the tasks they undertake; they should know the exact objectives and value coming from a specific task and how it is being performed. If changes are to be carried out in the process, managers are the ones capable of identifying how and when these changes can be made.

Therefore, it was imperative to understand the "priority setting" for some of the activities and decisions carried out by some departments: For example, a marketing department's customisation decisions, operational department's job organisation and machine operating decisions, and a technical department's concrete mix decisions (see sections 6.6 and 6.7).

[8] Reference to Dunphy model - first and second stages (Dunphy *et al*, 2003).

Identifying the priorities can help in categorising the conflicting criteria and the solutions or options available for every specific problem within a decision-area.

Understanding Managers' preferences for a solution

In addition to 'priority setting' within decisions, manufacturers base their decisions on specific objectives, which are employed to make preferences between decision options. The bases of these preferences are very hard to capture and document as these depend on a wealth of operational and managerial empirical information. Therefore, it was more appropriate to present the solutions or options directly to managers so they can state which option is most appropriate and why.

2.5.2 Research sample and population

The population of the semi-structured interviews was very similar to that associated with the focus groups. However, in this stage of research the targeted group was mainly decision-makers in some specific departments and levels of management associated directly with 10 decision-areas where major environmental impacts occur (see Section 6.6.3). It was found that four main decision-maker categories were directly associated with the 10 decision-areas as follows[9]:

- Strategic managers.
- Technical managers.
- Marketing and financial managers.
- Operational managers.

Due to the small population of managers working in these capacities in precast concrete flooring organisations within the UK, it was necessary to arrange for a quota sample specifically targeting these categories. The final list included 11 interviewees, as shown in Table 2.3. In addition, a second interview with PFF1 Technical Manager, a brief interview with and an interview with an Environmental Manager working for the parent company of PFF1. More details can be found in Chapter Eight.

[9] In addition to these, the views of one environmental manager were taken in another interview. The environmental manager offered feedback on the replies of managers from the main quota sample.

Managerial posts	Number of interviewees	Companies/ factories involved
Senior strategic managers	2	PFF2, PFF3
Operational managers	3	PFF1, PFF2, PFF3
Technical managers	3	PFF1, PFF2, PFF3
Marketing/ financial managers	3	PFF1, PFF2

Table 2.3 Details of managers included in the interviews (sample).

2.5.3 Identification of environmental solutions for problematic decision-areas

In order to identify the most appropriate approach to solving environmental impact problems in production decision-areas, a number of different environmental solution options (totalling 29) were identified and quantified (see Appendix E). The solutions targeted environmental impacts associated with the problematic decision-areas (see Chapter Six). It should be noted that the solutions only identify the approach and could account for a range of very specific applications and techniques.

2.5.4 Design of semi-structured interview questions

Oppenheim (1992) identifies three main types of questions that can be used in surveys (either interviews or questionnaires); these are factual questions, attitude and opinion questions, and classification questions. All these types were used in the questions made for the decision-makers in the semi-structured interviews, which were organised in the following sequence (shown in Figure 2.3).

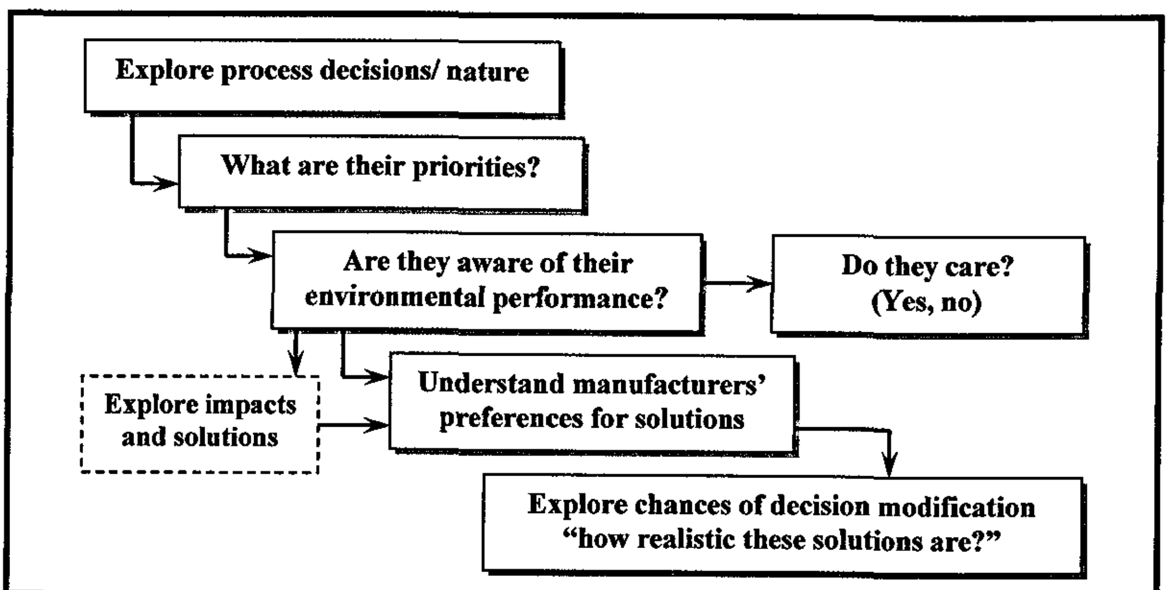


Figure 2.3 Questioning sequence – in terms of topics.

First general questions

Flick (2002) notes that unstructured (more general) questions are usually asked first and increased structuring is introduced only later during the interview. That is to prevent the interviewer's frame of reference being imposed on the interviewee's viewpoint. The first group of questions handled the general tasks and decisions made by the interviewee. These were essential factual questions that can help in tackling the first objective and research question identified in this specific stage of study.

Business objectives priorities questions

There was a need to quantify the question associated with manufacturers' preferences between different business objectives. A ranking system with three categories (*Very important*, *Important*, and *Not important*) was provided to the interviewees. The interviewees were also asked to offer their qualitative views on the different business objectives mentioned in the interviews (refer Appendix E).

Awareness and care toward specific environmental impacts

Two main questions were set to identify specific manufacturers' perceptions and eagerness to tackle environmental impact problems. In the first question, the different environmental impacts associated with the decision-areas were shown to the managers (decision-makers). They were asked if they were aware of the level and type of environmental impacts caused by their decisions. The other question tested their eagerness to tackle the problems identified.

'Preferences for solutions' and 'decision modification' questions

A ranking system was provided for the interviewees to classify the environmental solutions presented, the ranking included three main categories:

- *Doable*: This is for environmental solutions that they can implement (or have already implemented).
- *Likely*: This is for environmental solutions that they may consider currently (or in the future).
- *Never*: This is for environmental solutions that they would never consider within their production systems at any stage.

The semi-structured interviews also included questions to the managers exploring their opinions on the reasons for and the opportunities of success for the different solutions presented, together with the possibility of modifying their decisions to allow for more sustainability and an improvement in environmental performance. The quantified savings in environmental impacts and emissions were also presented to the interviewees. Their judgements and comments should offer an idea about their preferences for trade-offs between environmental and economic measures in decision-making.

2.5.5 Feedback interview (with a company environmental manager)

Another separate category was established for expert opinion on sustainable development from within the precast flooring industry itself. Due to the lack of a sample of environmental managers in the study, and due to the small number of environmental managers directly responsible for precast flooring, the views of one environmental manager were taken. The views of the environmental manager were important in assessing the internal policies within the precast concrete flooring organisations and their understanding of the relationship between general environmental needs and specific company and business requirements.

2.6 Summary

In this study, an 'action research' problem-solving approach was undertaken to achieve the different objectives of the research. In order to evaluate the impact of sustainability and environmental improvement measures on the business case of precast concrete manufacturers, a body of qualitative and quantitative data were collected from the precast concrete flooring industry. The study included three main research *regulative cycles* with appropriate feed-back loops for information (refer Figure 2.2). This was carried out in the following sequence:

A Life Cycle Assessment (LCA) study was carried out to identify the main environmental impacts associated with hollowcore and prestressed precast concrete beam production: two questionnaires and an energy breakdown study were carried out to complete the LCA. A wealth of quantitative and qualitative information was collected in the various stages of the LCA. The environmental profile information for the hollowcore and the prestressed precast concrete beams was analysed to identify the major environmental impacts and the main solutions, measures, and decisions associated with these environmental impacts. The methodology allowed for the identification and quantification of the main decision-areas where significant environmental impacts occur.

Three focus group sessions were arranged with different PFF professional committees. The aim of the focus groups was to understand manufacturers' perceptions and views regarding sustainable development and their understanding of the boundaries between business needs and sustainability needs. The tool targeted qualitative information, but it was also possible to quantify some of the replies using Oppenheim's (1992) methods of attitude measurement from the rankings obtained for perception and awareness measurements.

The findings of the focus groups and LCA studies were used to investigate the possibility of introducing environmental solutions and adjusting the conventional decision-making process in the industry to allow for more sustainable development criteria. A group of semi-structured interviews were carried out with managers involved in the main decision-areas. There were a few limitations to the research tools used in the study. It should be noted that many of these limitations were addressed and challenged in Chapter Ten.

CHAPTER THREE: LITERATURE REVIEW – CORPORATE SUSTAINABILITY AND ENVIRONMENTAL IMPROVEMENT

Chapter Three: Literature Review- Corporate Sustainability and environmental improvement

The concept of Sustainable Development has arisen at a critical point; never before in the history of the world has the viability of this planet's eco-system been under such threat from humanity. Since 1900, the Earth has warmed by 0.7° C (Hadley Centre, 2005). The rate and scale of the 20th Century warming has been unprecedented for at least the last one thousand years (International ad hoc Detection Group, 2005). This has had a considerable impact as widespread retreats of mountain glaciers have been observed recently (e.g. Alaska – 14 km per annum since 1980, Greenland – 5 km per annum). This is in addition to decreased snow cover and the lengthening of growing seasons in northern latitudes (Intergovernmental Panel on Climate Change, 2001). Organisations, as well as other community sectors, are required to improve their environmental performance and incorporate different sustainability requirements within their conventional decision-making frameworks. The concept of sustainability was first established in the Brundtland report in 1987. Following the issue of the ISO 14000 series and the '*Building a Better Quality of Life*' DETR report in 2000, the features of sustainable development and environmental improvement frameworks became clearer to different construction sectors. However, to date, there is still some confusion within the industry on the concept and applicability of sustainability[10]. This chapter explores the main principles of Sustainable Development, the main systems and frameworks in which sustainability is being incorporated, and the manner in which different organisations respond and react to different sustainability requirements.

3.1 The concept of sustainable development

All meaningful indicators suggest that modern-day patterns of human activity are not sustainable. The international community is starting to realise that current production systems are not compatible with the planet's ability to support its eco-system; the planet can no longer sustain the excessive use of natural resources. Moreover, different harmful gas emissions (such as Carbon Dioxide and Chlorofluorocarbons) have reached levels that the planet's atmosphere cannot sustain.

[10] *Editorial*: Confused message on sustainability, *Construction Products*, March 2005 (pp7, 10-14).

References to the concept of resource efficiency range back to early studies carried out by Lewis C. Gray (1913; 1914) and Harold Hotelling (1931); although their studies mainly covered extraction of resources and effects on value and economics, they both referred to the consequences of resource depletion. Explicit references to negative environmental effects are more modern, ranging back more than four decades and following the publication of the '*Silent Spring*' report (Carson, 1962). However, none of these references (and many other references in the 1960s to the 1980s) suggested a context as broad and robust as Sustainable Development. The concept is supported today by a collection of organisations and environmental lobby groups, including the United Nations Environmental Panel (UNEP), Friends of the Earth and Greenpeace, and dedicated political parties (such as the Green Party in many countries in Europe, North America, and other parts of the world).

The concept of Sustainable Development was defined in the Brundtland report as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987). Agenda 21[11] claimed that the global patterns of production and consumption were excessive and that special attention was necessary to review the demand for natural resources generated by unsustainable consumption, and to use these resources efficiently, to meet the goals of minimizing depletion and reducing pollution. The concepts of 'sustainability' and 'Quality of Life' (also explained in Agenda 21) were broad; covering a collection of aspects and concerns such as eliminating poverty, tackling droughts, preventing famines, and challenging climate change and the rising global carbon dioxide emissions. The concept addressed a radical approach and an action plan to undertake policies and change practices on all levels including influencing individual behaviour and the prevalent production and consumption culture (UN, 1992). Following the United Nations Conference on Environment and Development (UNCED) in 1992, in Rio de Janeiro – Brazil, the Commission for Sustainable Development (CSD) was created to ensure effective follow-up of the conference recommendations.

As the UNCED recommendations covered all production and consumption globally, there has been a need to develop regional and sector-based strategies (and contexts) to address

[11] As part of the Rio de Janeiro Summit recommendations, a comprehensive plan of action (known as Agenda 21) was taken globally, nationally and locally by organizations of the United Nations system, UN member Governments, and Major Groups in every area in which there is human impact on the environment.

the issue properly. Sustainable Development is associated with different sets of meanings and activities for various sectors. Therefore, the concept of sustainable development in the UK construction industry was introduced in a slightly different context; the DETR report 'Building a Better Quality of Life' in 2000 (aimed at the UK construction sector) was adapted from the UK Sustainable Development strategy that generally targeted the UK business, consumer, and infra-structure sectors (DETR, 1999).

The report (DETR, 2000) adopts the broad definition of sustainable development "*ensuring a better quality of life for everyone, now and for generations to come*". This definition implies that Sustainable Development can be achieved by ensuring that all national policies are focused towards increasing people's quality of life. The report also includes a collection of aspects and elements, some of which are not directly associated with environmental improvement. In order to achieve Quality of Life (QOL), four fundamental objectives need to be considered:

- Social progress which recognises the needs of everyone;
- Effective protection of the environment;
- Prudent use of natural resources; and
- Maintenance of high and stable levels of economic growth and employment.

These objectives are consistent with the recommendation of the Brundtland report (WCED, 1987). The first objective identifies social factors and needs in the formation of QOL. These should include some community-associated elements (such as social justice), and corporate-associated elements (contribution to society, Corporate Social Responsibility). The second and third objectives can be considered as environmental concerns, the two objectives represent the two main ecological ends to any economic growth process. The fourth objective (economic growth) is a conventional economic requirement being pursued and sought after by all businesses. Practitioners identify the first objective as the Social Sustainability or '*Social Pillar*' of sustainability, the second and third objectives are the main components of the '*Environmental Pillar*', and the fourth objective as the '*Economic Pillar*' of sustainability. The combination of these objectives is referred to as the 'Triple Bottom Line'.

As noted in the previous sections, the interpretation of sustainability strategies within the context of community and consumers' sectors is different to that implemented in the industry and different corporate sectors. The following sections look at each of the three pillars of sustainable development and how these may link to corporate activities and interests.

3.1.1 Social Sustainability

The consideration of Corporate Social Responsibility (CSR) is relatively new in business. Nowadays, many organisations account for such responsibility as part of their Mission Statements and as an essential element within their corporate culture. However, some of the roots of Social Sustainability (and corporate responsibility) can be traced back to the 19th Century following the works of Henry Fayol (1841 – 1925) in management in '*Administration Industrielle et Generale*'. There are also earlier applications including the planning and construction of villages such as Saltaire, Copley, and New Lanark.

The first attempt to consider and account for human factors within production systems was in the 20th Century. Although this recognition was bound to human relations and factors within the internal fabric of the corporation, it was a dramatic change from Taylor's Scientific, Ford's mass-production, and Weber's bureaucratic-based approaches where all production systems and principles were built around productivity and organisations' prosperity. Elton Mayo's work, in what became known as the '*Hawthorne studies*' (between late 1920's to early 1950's), identified the impact of groups' behaviour on production (Cole, 1996). The Human Factors concept became clearer after McGregor's theories *X* and *Y*, the two theories recognised the impact of positive (*X* Theory) and negative (*Y* Theory) schools of leadership and management. Following further works in this field the concept of Human Resource Management became a recognised discipline. However, the concept of CSR is much more recent, and is described as "*the voluntary actions that business can take, over and above compliance with minimum legal requirements, to address both competitive interests and the interests of wider society*" (DTI, 2004a). This definition takes corporations' responsibility into new boundaries addressing responsibilities toward the local, regional, national, and international communities (DeGeer *et al*, 2002).

The concept has already proved successful. Bennett (2005) notes that CSR can yield not only social benefits, but it can also be a positive force for business growth in terms of engaging the community, forming business networks, and promoting local employment growth. CSR can even have benefits on the broader strategic level (since it affects almost all functions and activities of a business organisation), improving a firm's competitiveness and market value (Bissacco *et al*, 2005). Although many believe that social sustainability only accounts for aspects such as values, health and safety, labour standards and information security, other issues such as efficient and just use of energy and other resources can be included as part of social sustainability. This is because excessive use of resources conflicts with the principle of CSR. Unfortunately, there still seems little (in terms of the broad understanding of Social Sustainability) in the way of stakeholders' dialogue to this approach (Raynard and Henriques, 2001). Indeed, the broadness of sustainability can be considered a disadvantage given that several cases have emerged where businesses were accused of disregarding their responsibilities, prompting governmental bodies and international organisations (such as the EU) to demand businesses to adhere to their stated social responsibilities. Therefore, CSR remains an elusive concept, as evidenced by the lack of consensus about what it is and why it might be a worthy objective (Fairbrass *et al*, 2005).

It should be noted that some Social Responsibility issues are not being directly addressed in this thesis (See section 10.4.4). However, CSR is still widely covered given that most organisational efforts to embrace sustainability and environmental improvements are considered (directly or indirectly) as part of CSR.

3.1.2 Economic Sustainability

Economic Growth is the most recognisable sustainability pillar for an organisation. As explained in Section 4.4, economic performance is the industry's predominant concern, indeed all management and production systems are usually built around economic growth and profitability. Unfortunately, most economic models and financial tools used by industries do not recognise the other main sustainability principles (such as '*mutual benefits*' or '*prosperity for all*'), as these are usually taken as moral and ethical principles with limited influence on daily activities and operations. Economic sustainability includes the economic and accounting mechanisms that an organisation undertakes to improve its performance and profits and the contribution to the national economy and the value added to the client through a specific service or product. The concept even expands to include the impact of the provided service or product on local economies and communities, the economic impact of operational and maintenance costs, general satisfaction, health and safety, and productivity.

DeGeer *et al* (2002) note that the construction industry has been lucky in terms of economic sustainability as these changes (to the concept of economic sustainability) have already been in place for the last decade. DeGeer *et al* (2002) point out that changing the adversarial nature of the construction industry through partnering, open-book accounting, target costing and prevention of set-offs have helped it to adapt to economic sustainability and the principle of '*mutual benefits*'. This explanation rules out the notion that sustainable development is limited to environmental protection and improvement. Indeed, any aspect that can relate to or influence an individual's quality of life is considered as a component of sustainable development. However, it should be stressed that the level of contribution of each of the three pillars of sustainability remains something that organisations can specify (Glass and Gibb, 2003).

3.1.3 Environmental Sustainability

Environmental sustainability is a new concept to most practices worldwide and therefore requires more explanation. Concerns about environmental degradation started in the early 1960's; the first major effort to explore the impact of a production system on the environment and society on the long term was in 1962. The report known as 'Silent Spring' (Carson, 1962) gave an account of the toxicological and ecological impacts of agricultural pesticides used in the United States. However many believe that environmental issues only started to attract national interest during the oil crisis in 1972 when the vulnerability of the international economy (to conventional sources of energy) seemed very significant. The threat of global environmental degradation became more imminent when Ozone Depletion and Climate Change issues were raised during the late 1970's and early 1980's. There are several environmental criteria and concerns being addressed by different practitioners and industries worldwide, including:

3.1.3.1 Climate Change

Climate Change has become a fundamental issue during the last two decades, and is defined as "*change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*" (International Panel for Climate Change, 2001). Human activities, in particular activities requiring the combustion of fossil fuels for industrial or domestic purposes, produce 'greenhouse' gases which affect the composition of the atmosphere. These gases form a layer within the planet's atmosphere causing what is known as radiative forcing that causes global warming and several other suspected downstream impacts (Figure 3.1).

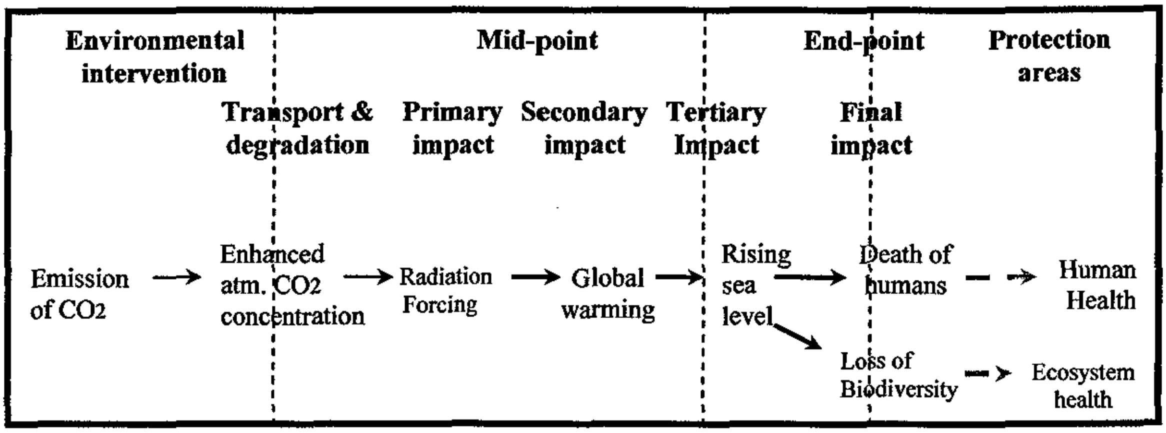


Figure 3.1 The intervention-effect chain, with global warming as an example (Tukker, 2000).

3.1.3.2 Ozone Depletion

According to the United Nations Environmental Programs (UNEP), it is believed that excessive use and production of Chlorofluorocarbons (CFC), and other similar compounds, has caused a significant impact on the ozone layer (Stratosphere). Unlike many of other compounds that include Chlorine, CFCs have the ability to reach the Stratosphere levels. CFCs usually disintegrate (when exposed to Ultra-Violent light) into atoms of Chlorine, which have a great ability to break down ozone molecules (O_3-O_2):

$Cl + O_3 \rightarrow ClO + O_2$, $ClO + O \rightarrow Cl + O_2$ (EPA, 2003)

Chlorine can considerably reduce the ozone quantity within the Stratosphere. One Chlorine atom can destroy 100,000 atoms of Ozone. The destruction Ozone exposes people and Earth to higher levels of Ultra Violent radiation known with wavelength from 280-320 nanometres (known as UVB). UVB has been linked to many harmful effects, including various types of skin cancer (Sugihara *et al*, 2005), cataracts, and harm to some crops, certain materials and some forms of marine life (EPA, 2003).

3.1.3.3 Minerals Extraction

Every year, more than 214 million tonnes of virgin aggregates (QPA, 2003) and 125 million tonnes of cement, concrete, plaster and other cementitious material (Smith *et al*, 2002) are consumed in the UK construction industry. With increased economic growth, these amounts can increase significantly; this is a pressure that no national reserve can sustain for ever.

3.1.3.4 Wastes

The construction industry produces vast quantities of waste. In 1999, it was estimated that 72.5 million tonnes of construction and demolition waste, including clay and subsoil, were produced annually[12] (Symonds Group, 2001). This represents some 17.5% of the total waste produced in the UK. With increased rates of consumption, the amounts of wastes would naturally rise. This would put tremendous pressure on available and planned landfill capacities. Elimination of production waste at source, finding suitable means of recycling, and reuse of demolition and production waste are main objectives for environmental sustainability.

3.1.3.5 Energy and Fossil Fuel Depletion

The search for a renewable energy source has always been a challenge for the global industry. The UK energy source composition includes several sources of energy (see Figure 3.2). This is different to other European countries such as France where 78% of electricity used is generated by nuclear power, or Denmark where 15% of electricity produced is generated by wind power (Griffin and Fawcett, 2000).

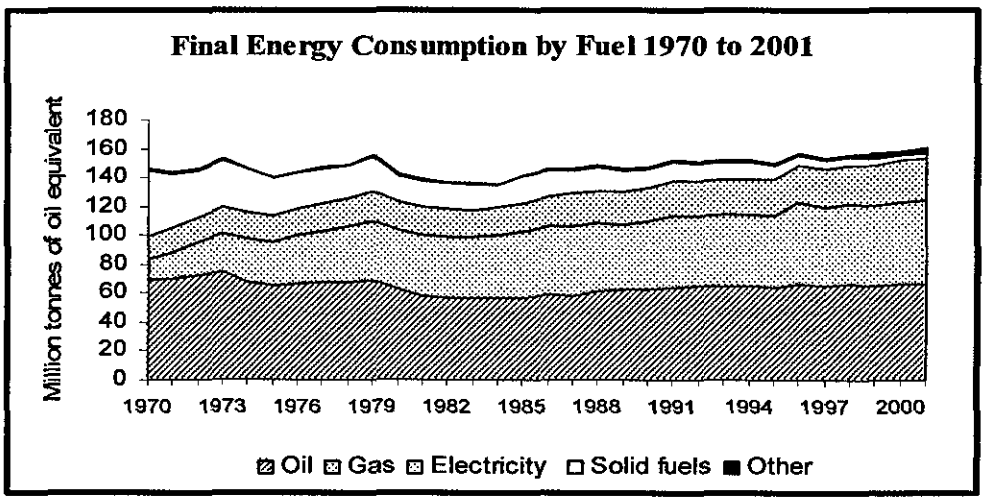


Figure 3.2 UK energy breakdowns (DTI, 2004b).

[12] The 2003 State-of-the-Nation report reveals that the construction industry now produces 103.2 Mt of waste every year (revealed in NCE journal, 17th June 2004).

3.1.3.6 Transport Pollution

Impacts of transport might exceed most expectations. It is estimated that cars and lorries are directly or indirectly responsible for roughly 80% of different products' life-cycle carbon dioxide emissions within Western Europe (EU, 2003a). The direct impacts from transport might be less than that, but it is still a major polluter.

3.1.3.7 Water

Water is a renewable resource, vital for public health and the environment. Safeguarding resources and ensuring affordable supplies are essential for sustainable development. The UK does not face severe problems of water availability and quality, but there are marked regional variations. Overall demand and household use is likely to grow (DETR, 1999). The latest DEFRA figure on water use in corporations (mostly office-based) is 8,110 litres per employee per annum[13].

3.1.3.8 Human Toxic Air Pollution and Acid Deposition

Harmful emissions causing human toxicity (and other health complications), and arising from different means of manufacturing or transportation are one of the basic concerns of Sustainable Development. These emissions have decreased considerably since the 1970's (see Figure 3.3). It should be noted that there are other environmental impacts that can also be added, these include impacts generated by radiation, dust and particle emissions, and acoustic pollution.

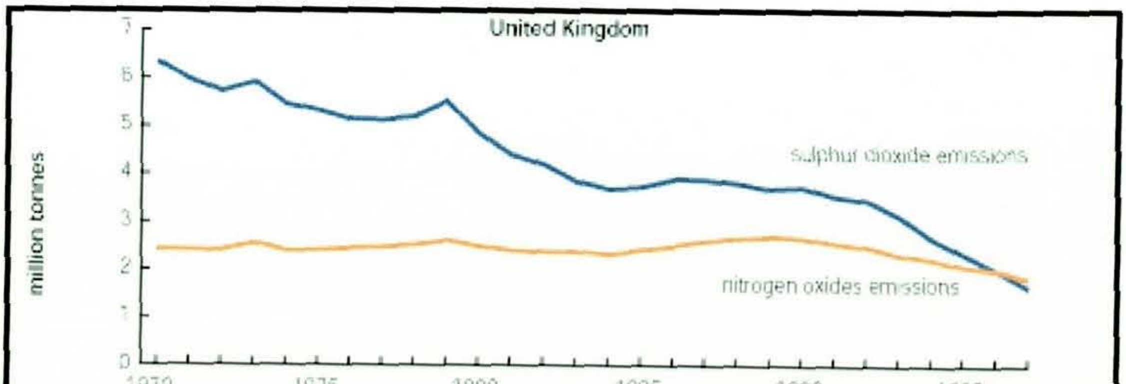


Figure 3.3 Nitrogen oxides and sulphur dioxide emissions (DETR, 1999)

---

13 http://www.defra.gov.uk/corporate/sdstrategy/operations/partc.htm

The implementation of sustainable development principles vary from one sector or industry to another because different manufacturing processes have different effects and influences on the environment. Therefore, there are substantial differences between the actions and activities adopted by, and the regulations imposed on, organisations to improve sustainability performance.

3.1.4 Sustainability and stakeholder engagement

When implementing sustainability improvements, it is important to recognise the main drivers behind the principle. One of the main drivers to incorporate sustainability is the expectations of society at a local and more general level. As noted in the preceding sections, organisations have a combination of environmental and social responsibilities toward society. BS 8900 notes that society's expectations of both public and private sector organisations continue to expand and deepen. Organisations are therefore faced with the challenge of meeting the requirements and expectations of their communities (BSI, 2006).

BS 8900 (BSI, 2006) identifies a number of areas that can be discussed to add more value to an organisation's sustainable development, one of which is strengthening relationships with community through demonstrating to stakeholders that the organisation is operating in an economically, environmentally and socially responsible way that will benefit stakeholders in the short and long term and to engage them in feedback. Engagement of different stakeholders from the community is an important aspect that can take place through annual reports, reviews, and many other ways and means such as community liaison groups. BS 8900 specifically encourages the use of innovative methods in engaging stakeholders.

3.2 Persuading organisations to adopt a sustainable approach

Section 3.1 demonstrates the moral case for sustainable development and the need for environmental improvement. However, industry practitioners and business leaders usually build their business case around other objectives, usually associated with profits. This was demonstrated by Milton Friedman more than 30 years ago:

'There is one and only one social responsibility of business – to use its resources and engage in activities designed to increase its profits' (Friedman, 1970).

Moreover, there is a prevalent view in the industry that environmental activities hurt an organisation's performance (Clemens, 2005). However, in spite of the potential conflicts between sustainability needs and business needs, many organisations are persuaded by several factors to look at and adopt sustainability measures. These factors are discussed in this section (with emphasis on specific measures affecting precast concrete flooring manufacturers).

3.2.1 Local Authority and Governmental actions: Regulations, taxation, and levies

The UK Sustainable Development Strategy clearly justifies the use of economic measures (such as taxation) in regulating and driving different sectors' adoption of sustainability and environmental protection measures (DETR, 1999). The UK government now imposes a range of different levies and taxes mainly focusing on the concepts of resource efficiency or pollution prevention. Some of these were introduced under the new Pollution Prevention and Control (PCC) regime. These regulations, taxations and levies discussed below.

3.2.1.1 New regulations and regimes

Most of the Environmental Protection regimes (including the Environmental Protection Act 1990) were replaced by the new Pollution Prevention and Control (PCC) regime. The new regime implements the EU's Integrated Pollution Prevention and Control (IPPC) Directive in the UK. PCC part A(1) and A(2) in England and Wales includes new issues not previously covered by IPPC, such as energy efficiency, waste minimisation, vibration and noise (Environment Agency, 2005). The new regime requires the implementation of an effective system of management to insure that all appropriate pollution and control measures are taken. Special emphasis is placed on the application of Best Available Practice (or Best Available Technique – BAT) to reduce the environmental impact of the process.

3.2.1.2 Landfill Regulations and Tax

In England, Scotland and Wales, landfill sites were subject to a licensing regime established under the Environmental Protection Act 1990 and the waste management Licensing Regulations 1994. These regimes were replaced in order to comply with the requirements of the European Directives on Integrated Pollution Prevention Control and Landfill. Precast manufacturers currently pay landfill tax of £2 per tonne on the waste they dispose of in landfills. The standard rate of landfill tax for hazardous waste was increased to £10 per tonne in April 1999, it has been increasing annually by nearly £1 per tonne for the last five years (DETR, 1998)[14]. This rate applies only to hazardous waste generated during production (HMCE, 2004). The cost of £2 per tonne is still a considerable cost that needs to be considered by manufacturers. Therefore, instead of taking waste to landfill, precast manufacturers usually crush their concrete waste and sell it as recycled aggregate, or they pay contractors to undertake the concrete waste and avoid the tax. Currently, around 23% of aggregate used in the UK is either secondary or recycled (Valuation Office Agency, 2004).

3.2.1.3 Climate Change Levy

Precast manufacturers pay for the Climate Change Levy in accordance with the energy they consume. The levy varies according to the type of energy used (and its potential emissions of carbon dioxide). However, this levy has been criticised widely by practitioners.

Many believe that the levy is unjust because it simply considers the manufacturing period of a product and does not refer to the service life performance. In the case of concrete or cement, long-term carbonation and the energy savings in buildings due to the thermal mass of concrete plays a major role in offsetting the carbon dioxide emitted during cement manufacture. The Climate Change Levy does not raise or address these issues. Furthermore, the scheme is complex in its formulation, the negotiation of the agreements, and their monitoring. This has significant cost implications to both industry and regulators (more dedicated working hours and employees) and the extent to which eligible Small and Medium Enterprises (SMEs) participate in the scheme (Pocklington and Glass, 2002).

3.2.1.4 Aggregate Levy

Precast manufacturers pay a standard Aggregate Levy at a rate of £1.60 for every tonne of virgin aggregate they use. The charge is usually channelled to them from their suppliers in the prices of aggregates bought. Having been introduced by the UK government in 2002, the main purpose was to influence the industry to look for other solutions where secondary and recycled aggregates can be used. The levy had a considerable impact on the industry; many companies and trade associations have already complained that the levy would

[14] In April 2006, landfill tax is set to rise again by a further £3 per tonne taking the total price per tonne to £21.00 (Brown, 2002).

severely affect their markets and business case. Figures show that the use of recycled aggregate has been increasing by an average of two million tonnes per annum since 1989), which indicates that the levy never had a real impact on recycled aggregate consumption level. The only effect of the levy was a slight decrease in the virgin aggregates market by 3.5% (QPA, 2003), one reason for this was due to the action taken by some of the companies to stockpile materials in 2002 prior to the Levy.

The decision to use recycled aggregate is still fraught with difficulties. One problem is the limited amount of recycled aggregate which can be reused within products (no more than 20% for precast flooring). A project, partly funded by the PFF, explored the use of recycled and reclaimed content (including a 10% replacement of fine and 20% replacement of coarse material) within prestressed flooring. The results of the project were encouraging and it was possible to establish a technical basis to allow reclaimed product to be used in prestressed concrete flooring (up to the amounts mentioned above). The project partners (also including BRE) produced a protocol to allow the use of reclaimed product, the protocol dictates that production using reclaimed/ recycled content should be carried out under a quality scheme (Bailey *et al*, 2002). Similar findings were established in another study in the Netherlands (Addtek, 2000).

3.2.2 Influences within the supply chain

As a supporting industry, the precast industry is required to satisfy and fulfil the needs of those in the downstream part of the supply chain. Zinkhan and Carlson (1995) note that organisational actions relative to environmental issues should consider the organisation's relationships with numerous stakeholder groups – not all stakeholder groups will be pleased concurrently with management actions. However, stakeholder influence can also work positively; Carlson *et al* (1993) claim that consumers tend to respond more favourably to organisations with environmentally-conscious images. With the emergence of a new generation of long-term contracts and managerial arrangements (such as Partnering, PFI, Prime contracting, Procure 21)[15], manufacturers are required to meet new unconventional supply-chain targets and objectives. In such cases, market pressure could force suppliers to implement environmental innovations in products and production processes (Van Berkel *et al*, 1999).

[15] See Glossary.

Other influences include potential for marketing (Addtek, 2000), the potential of sustainability and social responsibility issues in improving the corporate image and avoiding the risk of reputation damage due to adverse publicity , and improving the ability to attract and retain the best stakeholders and employees (Crossley, 2002).

3.3 Sustainability systems employed within manufacturing organisations

As noted earlier, the implementation of sustainable development principles usually takes a different form from one sector to another. Manufacturers comply with different regulations and implement various systems and tools in accordance with the type and magnitude of their environmental effects. Moreover, there are several environmental or resource efficiency principles that organisations implement within their different management levels. In this section, different means for implementation of sustainability efforts were classified into three main categories:

- Basic standardised efforts for environmental monitoring,
- Advanced environmental performance and improvement efforts,
- Advanced efforts to include environmental principles into the companies' business model/ strategy.

3.3.1 Basic Standardised Efforts (monitoring of environmental performance)

The most basic and standardised efforts carried out by organisations to monitor, maintain, or improve environmental performance are those associated with compliance with local authorities' and governmental regulations and controls. However, these efforts are usually part of larger and more comprehensive frameworks known as Environmental Management Systems (EMS). Prior to the ISO 14000 series standards, or the EMAS scheme within the European Union, many organisations used to carry out their own environmental reviews and audits. Standardised EMSs were developed to give the industry more efficient ways to record and implement change.

Meeting ISO 14000 standards requires the development of an environmental policy that shows what aspects are to be monitored (and then tackled), after which a plan is developed to meet the policy requirements and targets, followed by implementation. The entire process is subject to feedback, revision and continuous improvement (BSI, 1996).

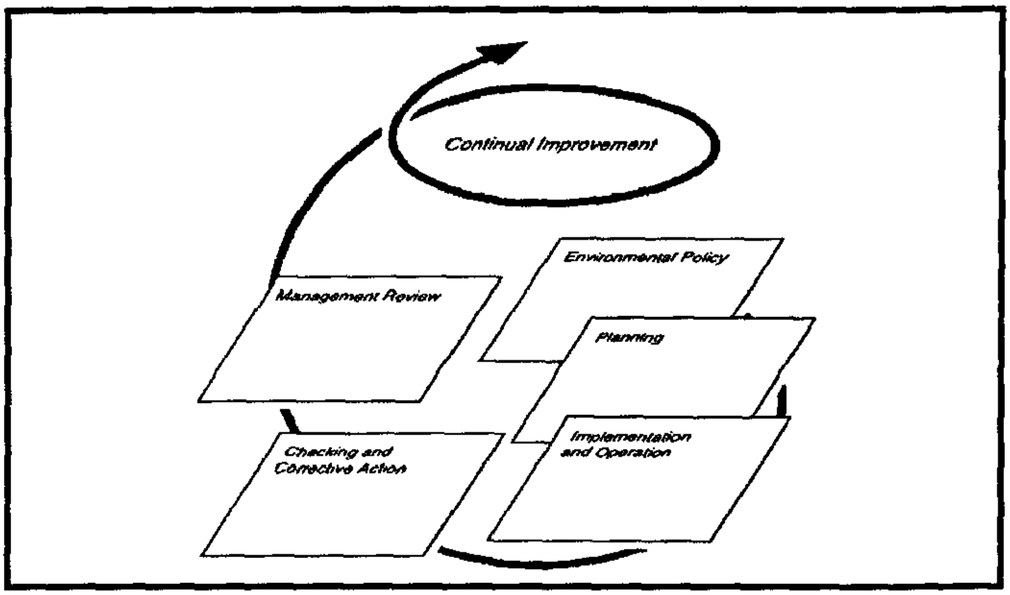


Figure 3.4 The Environmental Management System model in ISO 14001 (BSI, 1996)

However, there are still differences between large organisations and SMEs in terms their of implementation of ISO 14001 and EMSs in general. Hillary (2003) notes that the uptake of Environmental Management Systems by SMEs has been patchy at best and miserable at worst. Johansson (2002) identifies a number of barriers limiting ISO 14001 implementation to larger national/ multinational organisations. These include aspects such as lack of awareness (identified as the biggest hurdle), cost associated with certification, and lack of time (or human resources) to manage the system. Johansson (2002) believes that this could be overcome by more industry-wide initiatives and efforts addressing the need and potential benefit of EMS. However, Hillary (2003) criticises the increased dependency on 'best practice' demonstration case studies, as these might mislead SMEs on the expected levels of business gains and losses. It was found that many of those who implemented the system suffered problems associated with lack of resources and lack of business rewards (Hillary, 2003).

3.3.2 Advanced efforts (improvement of environmental performance)

There are other managerial efforts, systems, and philosophies (these can also be part of an EMAS framework) that can be considered to reduce environmental impacts and dramatically improve organisations' performance. The following tools are main components in organisations' environmental improvement measures:

- **Life Cycle Assessment (LCA):** This is a decision-support tool that can be used to build a comprehensive environmental map for all the different environmental interventions and impacts associated with the production, processing, and use of a specific product. LCA is considered by many practitioners as the ultimate and most advanced environmental tool that can explore a product's or organisation's performance from the widest perspective (Glavind and Munch-Petersen, 2002). Many manufacturers today use a range of simplified or more complex implementations of Life-cycle Assessment (LCA). See section 5.3 for more detail.

- **Environmental Impact Assessment (EIA):** In principle LCA and EIA share the aim of objectively making an inventory of the inputs/ outputs and assessing the environmental impacts of the object of study, but they differ in one fundamental sense (Figure 3.5). In EIA the focus is put on assessing the actual environmental impacts of an object located in a given site and in a given context (Crawley and Aho, 1999), whereas LCA targets a product throughout its life-cycle regardless of its location.

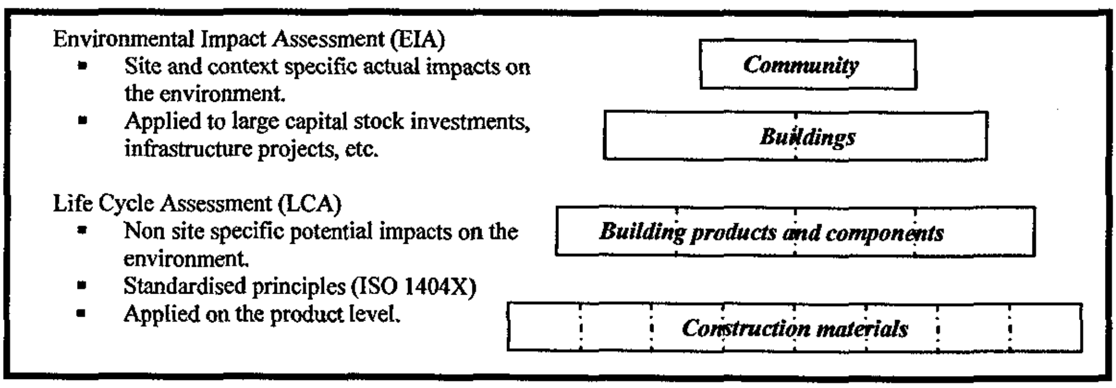


Figure 3.5 Conceptual differences between EIA and LCA (Crawley and Aho, 1999).

- **Benchmarking using Key Performance Indicators (KPI):** Another tool that can be employed to improve environmental performance is benchmarking. Benchmarking offers comparitive measurement frameworks for the purpose of continuous improvement and competition. Gray (2002) notes that benchmarking focuses on the search for improvements in business processes through the quantification of gains achieved by the industry. Following the '*Rethinking Construction*' report (Egan *et al*, 1998), the DTI has encouraged the production of national data sets, Construction Key Performance Indicators (KPI), against which a project or a company can compare (and benchmark) its performance. In 2005, national KPI on environmental issues were introduced to help industries and companies track their performance (TruCost, 2005). These should offer an incentive to organisations to compete and improve their environmental performance.

There are several philosophies built around the concept of environmental improvement. One of the main fundamental philosophies is the concept of Industrial Ecology. This concept offers a context in which industrial activities and dealings between different organisations (through the supply chain) can be employed to improve environmental performance, achieve mutual benefits, and enhance resource efficiency. In nature, ecological systems operate through a web of connections in which organisms live and consume each other and each other's wastes. The concept of Industrial Ecology (Figure 3.6) explores the possibility of implementing this within industry; a component can be manufactured or assembled from another component's waste and this reduces the amount of industrial wastes and provides an ecological atmosphere within the entire industry sector (Frosch, 1992). One example is the use of an energy generation by-product (such as fly ash) as a component in another industry (concrete industry).

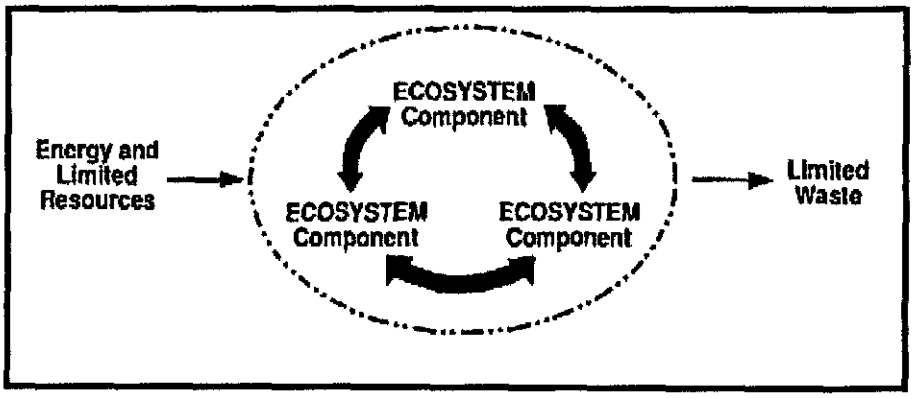


Figure 3.6 The concept of Industrial Ecology (Jelinski *et al*, 1992)

3.3.3 Efforts to incorporate environmental criteria within the companies' business strategies

These efforts also target environmental monitoring and improvement. However, the manner in which improvements are introduced is different; this is carried out through the incorporation of environmental improvement measures within the conventional decision-making framework (more information on the conventional decision-making process is available in Chapter Five). There are several tools that can be used to achieve such requirement, amongst them Environmental Accounting and the principle of Eco-balancing.

Environmental Accounting is used by corporations to give an economic value to different environmental aspects (such as energy consumption, wastes or specific environmental activities) so these are dealt with within the corporation conventional business system as functions within profit and loss accounts (Howes, 2002). Many companies (in Europe and North America) have started implementing a further concept known as Sustainability Accounting to identify, evaluate and manage social and environmental risks by identifying resource efficiency and cost savings and link improvements in social and environmental issues with financial opportunities and targets.

However, such integration (for environmental and economic principles) can be achieved using several other frameworks. Some of these are organisation-based (bespoke). A good example is found in Arup's. Sustainable Project Appraisal Routine (SPeAR) system; the system sets progression to sustainability in six major steps (Arup, 2006)[16]. These are illustrated below (see Figure 3.7).

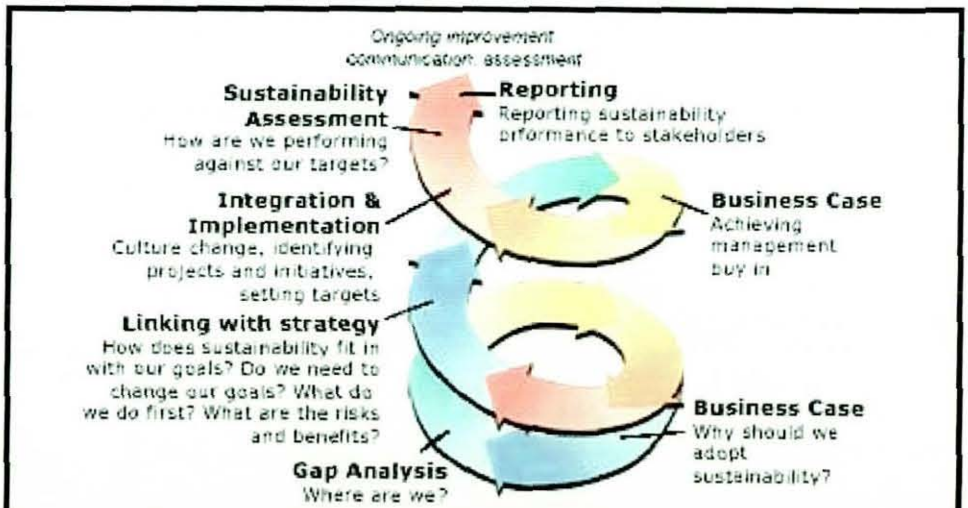


Figure 3.7 Diagram illustrating the framework adopted by manufacturers for self-assessment and sustainability progress[17].

1. **Sustainability gap analysis:** As part of an improvement continuum, Arup assesses its sustainability performance in a specific area using various tools. The efficiency gap that needs to be closed is measured.

[16] Arup first started with systems addressing building products. The system (and experience) was later used to develop a corporate version.
[17] http://www.arup.com/sustainability/services/services.cfm

2. **Linking sustainability assessments with organisations' strategy:** Integrating sustainability objectives to the main organisational strategy is a tough step that needs to be carried out. However, there is insufficient information on how this integration is to take place; a possible route is through the introduction of sustainability measures into the routine managerial structure (Gabel and Beckentein, 1986), another is through the use of cross-functional teams (Avadikyan *et al*, 2001).
3. **Making the business case for sustainability:** If the business case for sustainability is passed by the management, then it becomes an integral part of the business. This shows that the Arup framework might hold some of the elements employed for Dunphy model phases of '*Efficiency*' and '*Strategic Pro-activity*' (Section 3.4).
4. **Integrating and implementing sustainability within the organisation:** This is the actual implementation of change phase. There is no clear information on how such change should take place and whether any activities and organisational divisions could be affected.
5. **Sustainability performance assessment (using SPeAR and Corporate SPeAR):** This is another self-assessment/ benchmarking stage where a customised managerial tool (SPeAR) is used.
6. **Preparation of sustainability reporting:** Following assessment, a sustainability report is prepared. This sets the parameters for any further continuous improvement or additional tasks.

There are several philosophies and principles that have tried to build the case for sustainability and environmental improvement through the use of economic contexts. One of these philosophies is Factor Four.

Factor Four is simply a new way of thinking: this resource efficiency concept was developed by Weizsacker *et al* (1997) and takes a radical approach in redefining some major business objectives (such as redefining productivity in terms of resource as well as labour or working-hours). The concept handles resource efficiency from an economic point of view because profit is the main objective and sustainability is a co-product of resource efficiency. The concept also addresses continuous improvement: doubling the wealth while halving environmental impacts (see Figure 3.8). Although many of the aspects and examples offered by Weizsacker *et al* (1997) are economically motivated, he clearly demonstrates how sustainability and environmental improvements can be made and addressed using an unconventional context.

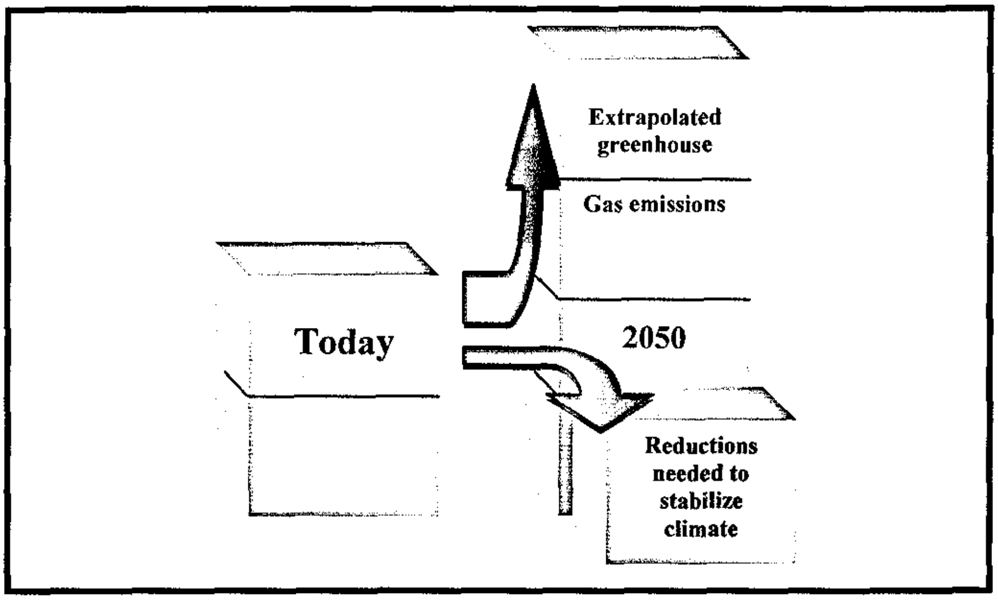


Figure 3.8 Factor Four efficiency concept (Weizsacker *et al*, 1997)

There are many other strategies, concepts and tools used by organisations worldwide to implement and address sustainable development. As noted, many manufacturers and corporations tend to develop their own practices and initiatives. Some European companies use the concept of Eco-Balance, which is a benchmarking system that measures products and processes in terms of the financial cost of environmental problems, including problems such as emissions and landfill taxing (Miyazaki, 1998). Moreover, there are attempts to employ Quality Function Deployment (QFD) and value engineering tools; these include measures based on value trees or fuzzy logic to measure different social, environmental and economic consequences (Bovea and Wang, 2002; Dong *et al*, 2003). Section 5.4.2 offers additional details.

3.4 Manufacturers' reaction to sustainable development

Manufacturers across the supply chain have different interpretations of appropriate sustainability efforts, energy, and resource efficiency activities. These usually depend on several aspects such as the nature of the manufacturing processes and the impacts arising from these processes (this is covered in Chapter Four). However, it also depends on corporate culture and manufacturers' perceptions and views on sustainable development. The following section covers the main push/ pull factors affecting organisational implementation of sustainability requirements, it also looks at various classifications for organisations (or manufacturers) suggested in the literature.

3.4.1 Sustainability: Main push/pull factors

There are several measures and influences that affect organisations' acceptance and implementation of sustainability and environmental improvement measures, including the following:

- **Governmental Measures:** Manufacturers are required to comply with regulations restricting levels of pollution and emissions, and promoting health and safety and workforce welfare. Moreover, manufacturers are also required to deal with economic tools designed to force businesses to be more sustainable (Landfill Tax, Aggregate Levy, and Climate Change Levy). Shipworth (2001) confirms that these economic tools have always been the main factor behind most environmental efforts within organisations. Section 4.4 offers more information on how economic measures can dominate organisations' operations.

- **Profitability:** Some environmental solutions, such as use of pulverised fly ash as a replacement for cement, can have a positive economic advantage.

- **Marketing and Corporate Image:** Some manufacturers might consider credentials, such as ISO 14001, EMS, or other various environmental certificates and management systems, as a bonus to corporate identity and image[18]. Roberts (2003) reports that a high number of companies have found to their cost that corporate reputations can be significantly affected by organisations' management of sustainability issues.

[18] Refer to precast organisations' annual reports; e.g. Marley Ltd, Consolis Ltd, Tarmac, RMC (Cemex).

- **Competitive Advantage:** Nowadays, sustainable and environmentally-friendly products and processes can offer a major competitive advantage for manufacturers in the construction industry (Crossley, 2002).

- **Customer Focus:** With emergence of new forms of Public-Private Partnerships, Partnering, PFI and toll-gate arrangements, clients are becoming more involved in the procurement process; clients are also becoming keener to concentrate on various strands of quality and efficiency including environmental performance. A study reveals that most Finnish manufacturers in the wider industry sector tend to employ waste-management policies as a response to customer demands (Kautto and Melanen, 2004).

- **"Doing the right thing":** Although this is a rare case in profitable organisations, some manufacturers, such as Xerox, the photocopying and printer machines manufacturer, invest heavily in sustainability technologies even though they never have a significant return on the capital invested and employed in this area (Azar *et al*, 1995).

Most environmental policies published by industries do not reveal which of these factors they are pursuing. The best way to understand manufacturers' intentions is therefore through monitoring their efforts to implement different sustainability objectives.

3.4.2 Classifying manufacturers

As mentioned in the previous sections, there are different levels of manufacturer perceptions, appreciation, and understanding of sustainable development. Roome (1998) notes that the way manufacturers perceive environmental management differs from one organisation to another; an increasing number of companies have moved from the view that environmental management requires compliance with current laws and regulations, to positions based on an understanding that environmental management is a legitimate business function driven by, among other things, legislation, markets and long-term profitability, relationships in the supply chain, investors, local communities, and activist organisations – the same group identified by Zinkhan and Carlson (1995) as stakeholders.

The BRE's Managing Sustainable Companies (MaSC) Chart offers a classification for manufacturers' efforts and compliance with environmental management and sustainability requirements (BRE, 2003a). The matrix includes five different phases using the sequence offered in Table 3.1.

Increasing Compliance →	Strategy	Responsibility	Planning	Communication	Implementation	Auditing
1	No written policy.	No one responsible	No integration into business planning	No awareness or internal dialogue	Compliance with regulated issues only	No management audits of performance
2	Informal guidelines	Some informal support	Ad-hoc planning in some parts of the business	Ad hoc awareness raising	Informal ad hoc procedures	Add hoc audits with little follow up.
3	Written statement without targets	Delegated responsibility but authority unclear	Formal planning in some parts of the business	Piecemeal internal communication and training	Formal procedures without benchmarking	Most aspects of business audited with some follow-up
4	Internal statement with some targets	Clear delegation and accountability	Formal planning throughout the business	Comprehensive internal communication and training	Formal procedures with routine benchmarking	All aspects of business audited with some follow-up
5	Published policy with targets, reviews and active commitment	Fully integrated into general management	Outcomes regularly reviewed against annual plan	Comprehensive internal and external communication and training	Procedures and benchmarking promoted and updated.	Company-wide audit scheme linked to review of annual plan

← Increasing Level of Engagement ←

Table 3.1 The Managing Sustainable Companies (MaSC) matrix (BRE, 2003)

The MaSC model offers a profile of the explicit activities of an organisation rather than exposing the implicit perceptions and culture of its workers and employees. It therefore allows companies to plot progress and/ or benchmark against others.

A more relevant model, although concentrating more on corporate culture and attitude, is the one developed by Dunphy and Griffiths (Dunphy *et al*, 2003). Through reviewing a collection of models in the ecological and management literature in addition to research results on the development phases of the movement towards human sustainability in corporations, Dunphy developed a comprehensive model of the development phases through which a corporation progresses towards both human and ecological sustainability (see Figure 3.9).

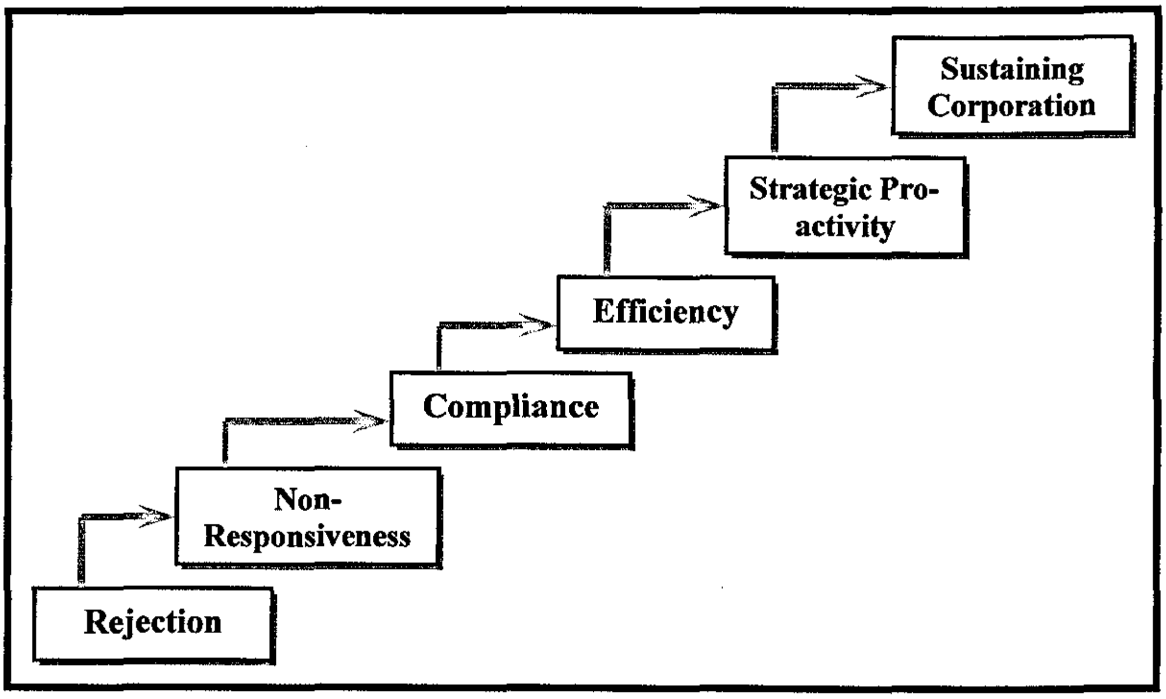


Figure 3.9 Model of the sustainability development phases (Dunphy *et al*, 2003).

Both models can be used to trace the historical trajectory that an organisation has taken in getting to where it is and to chart possible paths forward. However, Dunphy claims that his model can be used to characterise an organisation's way of treating the human and natural resources employed. Dunphy's model includes six main phases:

1. **Rejection:** Involves an attitude on part of the corporation's dominant elite that all resources (employees, community, infrastructure and the ecological environment) are there to be exploited by the firm for immediate economic gains. The firm disregards the destructive environmental impacts of its activities and actively opposes any attempts by governments and 'green' activists (trade unions, employees) to place constraints on its activities.

2. **Non-Responsiveness:** This usually results from lack of awareness or ignorance. Many of the organisations in this category embody the culture of *business as usual* where the human resource strategies, if they exist, focus mainly on creating and maintaining a compliant workforce. Community issues are ignored where possible and the environmental consequences of the firm's activities are taken for granted.
3. **Compliance:** focuses on reducing the risk of sanctions and penalties for failing to meet minimum requirements as an employer or producer. In organisations at this stage, the dominant elite emphasises being a 'decent employer and corporate citizen' by ensuring a safe, healthy workplace. However, the organisation still does not go in for environmental protection for reasons other than process improvement or the avoidance of governmental intervention.
4. **Efficiency:** Reflects a growing awareness on part of the dominant elite in the corporation that there are real advantages to be gained by proactively instituting sustainable practices. In particular, human resource and environmental policies are used to reduce costs and increase efficiency. While moves towards sustainability may involve additional expense, they can also have significant payoffs in terms of generating income directly or indirectly (Dunphy *et al*, 2003). This is the beginning of the process of incorporating sustainability as an integral part of the business.
5. **Strategic Pro-activity:** moves the firm further along the sustainability path by making sustainability an important part of the firm's business strategy. The firm's strategic elite view sustainability as providing a potential competitive advantage. Consequently they try to position the organisation as a leader in sustainable business practices: with advanced human resource strategies, environmentally safe products and services, increased health and safety measures, and 'corporate citizenship' initiatives. The commitment to sustainability, however, is strongly embedded in the quest for maximising longer-term corporate profitability, that is, it is motivated by intelligent corporate self-interest.
6. **The Sustaining Corporation:** the final phase is one where the strategic elite has strongly internalised the ideology of working towards a sustainable world. However, the company still pursues the traditional business objective of providing an excellent return to investors. However, there has been an argument that corporate sustainability management that is uncoupled from core business processes runs the risk of being conceived "luxurious", i.e. something that companies can only afford in times of economic prosperity (Figge *et al*, 2002).

Table (3.2) offers a demonstration of these phases. The descriptions in Table 3.2 show how each phase gives the organisation a specific culture and characteristic. Dunphy *et al* (2003) also notes that this may be an oversimplification as organisations in real life can have different views in each area or department.

Culture / Phase	Response	Attitude, nature of reaction	Core of culture	Env. and H&S systems incorporation	Replies to accusation	Env. impact
Rejection	Negative	Aggressive	Elite	Not available	Denial	Probably severe
Non-responsive	Negative	Ignorant	Corporate Culture/ Elite	Not available (or very limited)	Confused/Denial	Probably severe
Compliance	Positive	Compliant	Elite	Limited to legislative requirements	Required measures taken	Average
Efficiency	Positive	Compliant. Seeking business gains in sustainability	Elite	Available mainly for compliance and business interest means	Required measures taken (continuous improvement)	Relatively low
Strategic Pro-activity	Positively enthusiastic	core part of business case	Corporate culture	Available as part of culture and competitive advantage	Measures taken + continuous improvement	Low
Sustaining Corporation	Positively enthusiastic	core part of business case	Corporate culture	Available, voluntarily seeking sustainability	Measures taken, continuous improvement, spread the word	Very low

Table 3.2 The corporate culture and attitude in different phases of corporate sustainability development, derived from Dunphy *et al* (2003).

It should be noted that there are several classifications found in the literature which are similar to the two systems referred to above. For example, Hahn and Scheermesser (2005) offer a different company classification in a study assessing German companies' approach to corporate sustainability issues; companies were classified into *Sustainability Leaders*, *Environmentalists* and *Traditionalists*. The group of Sustainability Leaders is characterised by a strong commitment to sustainable development, where different environmental issues play a prominent role for these organisations. Hahn and Scheermesser (2005) note that although Environmentalists identify a certain level of moral and ecological responsibility toward sustainability, the main driver for this group is corporate image and economic gains associated with cost savings. As for the third group of organisations (Traditionalists), both standardised management systems as well as corporate environmental, social or sustainability reporting are strongly underrepresented. The main driver for this group is to achieve profits and avoid violation of governmental regulations and directives.

However, the distinction of phases/ categories (and wealth of information offered on them) is more evident in the model created by Dunphy *et al* (2003). The other two models have several disadvantages; the MaSC model does not account for any perceptual information within corporations, and the Hahn and Scheermesser (2005) model is limited to three simplistic categories that might not be effective in breaking down and differentiating between the various practices in industry.

3.5 Conclusion

In order to achieve the aims and objectives of this research, it is imperative to examine and review the broad definition and meaning of sustainability and the different means by which sustainability is being looked at and implemented within the wider industry sector. The concept of sustainability needs to have an evident influence on how different operations are being assessed, and how the wellbeing of the community (as well as the surrounding environment) is being considered. This chapter has addressed these issues, explaining some of the main elements associated with the implementation of sustainable development and environmental improvement requirements within organisations.

The argument in the chapter should raise several questions; these include questions addressing the applicability of these principles and concepts in the precast industry sector (without distorting the way precast production systems operate), the limitations and opportunities available to the industry, the type and nature of the framework required to embrace the new concept of sustainability, and the specific managerial and economic consequences of incorporating sustainability within the precast flooring industry. It is clear that due to the novelty of the issue, it is not possible to reach conclusive results and findings by simply using secondary information. There is still a need for a wealth of primary information to develop answers to these questions.

The following literature review chapters cover previous research and literature offering answers to some of the questions raised in this section.

CHAPTER FOUR: LITERATURE REVIEW – SUSTAINABILITY AND THE PRECAST CONCRETE FLOORING INDUSTRY

Chapter Four: Literature Review- Sustainability and the Precast Concrete Flooring Industry

The manufacture of precast concrete flooring products is part of a £2bn precast concrete industry sector employing 22,000 people and accounting for nearly 28% of the total cement and concrete market in the UK (Smith *et al*, 2002). Like other industries, this sector has always been keen to improve its economic performance and enhance its market position. With the emergence of the new agenda of sustainable development (see Chapter Three), precast flooring manufacturers need to respond and may have to introduce some changes to their systems. This chapter describes the main business aims, objectives, and production requirements within the precast flooring sector (hollowcore and prestressed beams). The chapter also reviews attempts to identify the environmental effects associated with precast production; these are then linked to major business issues identified by earlier research.

4.1 Precast production as an off-site industry sector

The precast concrete flooring sector is a construction-supporting industry that is much closer to other factory-based industries rather than the conventional site-based construction industry. Precast manufacture is part of a larger off-site production industry (Gibb, 1999) which usually involves "*the design and manufacture of units or modules, usually remote from the work site, and their installation to form the permanent works at the work site*". Gibb (1999) identifies four main levels of off-site production, this study is mainly associated with the following two levels:

- **Level 1 (Component Sub-assembly):** These usually include the basic building units such as blocks or kerb stones. These comprise a very large portion of the precast market; building blocks and precast roofing units are also included in this level.
- **Level 2 (Non-volumetric pre-assembly):** These are units and elements that do not enclose usable space. Typical examples include flooring units, partitions, claddings and so forth. All the products considered in this research are included in this level[19].

[19] It is not entirely clear whether precast concrete stairs belong to this or the following level.

The two other categories (Levels 3 and 4) comprise volumetric units that enclose usable space and form parts of the buildings. These are not being considered in this research. Design and manufacturing criteria for each of the levels is different. Unlike precast blocks, precast flooring elements require greater customising and other technical requirements. This affects the manufacturing process of the product and the complexity of its design, manufacture, and maintenance. There are several advantages in using off-site production technologies in the construction industry. The following advantages were identified by Gibb (1999) and others.

- **Fast track construction:** For the last two decades, considerable attention has been given to *fast-track* construction. Precast manufacturing and off-site production are offered as a successful solution where on-site and off-site work packages can operate at the same time and reduce the level of delay and overlap in site working space and time (Richardson, 1991; Gibb, 1999).
- **Introduction of factory disciplines:** Through the introduction of factory discipline, precast organisations have the advantage of repeat production at the same location and under the same circumstances and, therefore, the probability of error is significantly reduced (BIBM, 2002).
- **Off-the-shelf design and manufacture:** The fact that the precast industry employs standardisation and uses equipment/ techniques that enable repetition and off-the-shelf solutions adds value to precast products (Levitt, 1982).
- **Economies of scale:** As with any other industry with a highly standardised content, the precast industry can play a major role in reducing costs through the economies of scale advantage (Gibb, 1999). See Figure 4.3 for an explanation.
- **Advantage of mechanised handling:** The use of precast and prefabricated elements helps to introduce some factory processes to the site. The assembly process is safer and faster than using labour. It is also possible to reduce levels of waste and other ad-hoc construction related consequences (Gray and Fowler, 2000; Richardson, 1991).

These are in addition to other advantages such as reduced disruption to sites, and ability to manufacture complicated products and elements. The introduction of decision-support tools, such as IMMPREST (Blismas *et al*, 2003; Glass and Gibb, 2003), has helped considerably in addressing the benefits off-site and pre-assembly. On the other hand, the industry also has its own challenges; such as high costs of specialised works (Goring,

2002) and additional requirements for expertise and managerial coordination. However, the industry has been the target of some negative publicity, mainly created by the Ronan Point collapse incident in 1968 (Glass, 2000). This has resulted in some unfavourable perceptions of precast products in general.

4.2 The precast concrete flooring industry (description)

As in any other business, all procedures, measures and communication channels are built around the concept of maximum (short and/or long-term) profitability. For conventional precast concrete production this means products should be designed by manufacture to maximum quality, least cost, and within the shortest lead times. The precast sector is part of a large cement and concrete industry in the UK, which produces around 124 million tonnes of concrete and other cementitious material. Precast concrete production accounts for more than 26% of that production (Smith *et al*, 2002); this is around 33.6 million tonnes of precast products – including precast blocks and similar components (see Figure 4.1).

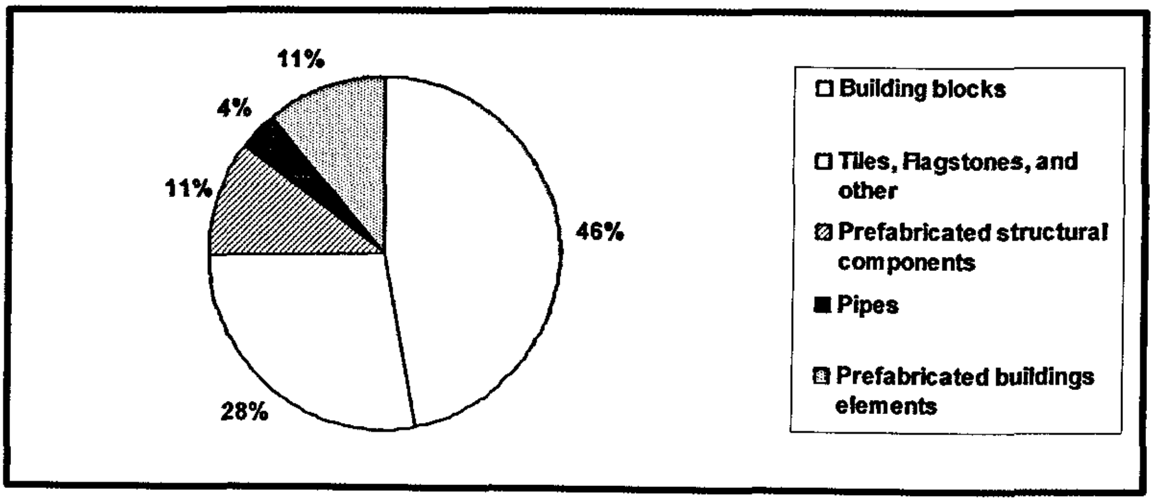


Figure 4.1 Distribution of annual precast production (Smith *et al*, 2002)

The largest market for hollowcore and prestressed beams is the housing sector (Copeland, 2005). However, retail, commercial and industrial applications are also substantial (BRE, 2003b). The following sections (4.1.1, 4.1.2, 4.1.3, and 4.1.4) offer general description of the nature of the industry in terms of products, materials, and production processes.

4.2.1 Precast flooring elements

The precast industry manufactures a range of precast products. Typical products include precast blocks, pavers, lintels, tunnel linings, culverts and other structural elements. Precast concrete products are used widely in buildings as well as in infrastructure projects. However, this research specifically targets prestressed precast flooring products – these include hollowcore and prestressed beams (beam and block) flooring elements. These two products have proved to be particularly popular in housing projects.

A hollowcore floor slab (Figure 4.2) is a precast prestressed concrete element with a longitudinal shape and continuous voids to reduce self-weight and offer an efficient structural section. These are usually manufactured on casting beds or in moulds between 50m and 200m in length, using slipforming, extrusion or wet-casting[20] casting techniques (see section 4.3). Hollowcore slabs can also be solid (PFF, 2001). Beam and block floor systems (Figure 4.2) combine prestressed concrete beams and infill blocks to produce ground and upper floors in housing and other building types. The beams are manufactured on beds or in moulds similar to those used in hollow-core production.

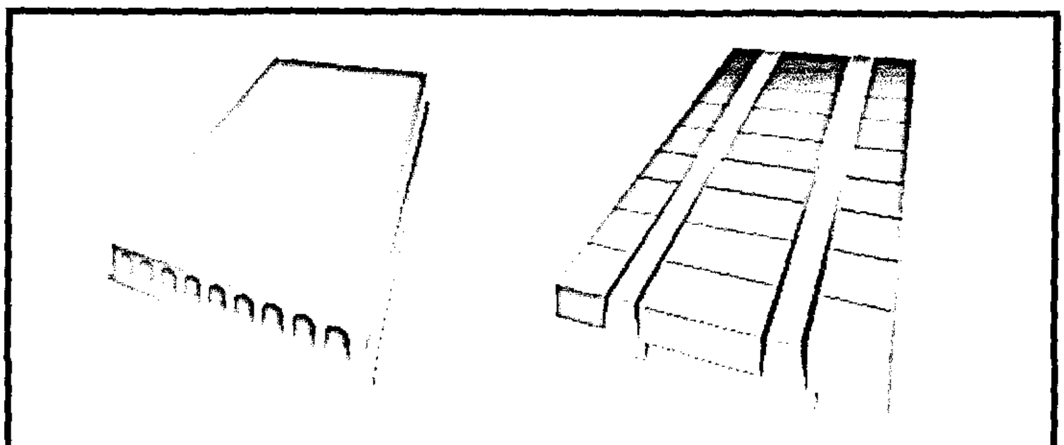


Figure 4.2 Concrete hollowcore slab (left) and precast prestressed beams and blocks (right).

There are several advantages to be gained by using the two flooring systems, including ease and speed of erection, possibility of long spans (mainly for hollowcore), elimination of formwork and propping on-site, high load capacity, fire resistance, and sound insulation (PFF, 2001).

[20] Some manufacturers use wet-casting with ready-mixed concrete to produce hollow-core slabs.

4.2.2 Materials used in the industry

The main ingredients in precast concrete products include Portland cement, fine and coarse aggregates, water, reinforcement steel, and admixtures. Neville (1995) stresses that it is essential that the ingredients are properly blended so as to produce a uniform and homogenous concrete mix. Richardson (1991) notes that the suitable mixes for precast concrete are described in general terms as having a minimum cement content of 320 kg/m^3. However, mixes for extruding or slipforming concrete should have a cement content of at least 350 kg/m^3.

At least 75% of the volume of the concrete is composed of aggregate. Gani (1997) argues that aggregate is known to be cheaper than cement, therefore as much as possible is put into the concrete mix. In prestressed extruded flooring, high density aggregate materials (10 - 14mm) are usually used. The surface texture of the aggregate is also important, a rough texture results in better bonding because of the larger surface area of the aggregate in contact with the cement (Gani, 1997). Neville (1995) also stresses on the importance of different properties of aggregates including porosity, absorption, and moisture content.

5mm diameter high tensile wires or 12.5 – 9.5mm diameter strands (complying with the requirements of B.S. 5896: 1980) are usually used in the reinforcement of prestressed flooring (Bison Ltd, 2006). A study in Finland claims that the use of prestressing helps in reducing reinforcement steel in hollowcore by nearly 7% (Asunmaa, 1999). Manufacturers usually use admixtures (plasticizers and superplasticizers) to reduce the water content in the mix while retaining a level of workability. The main purpose behind such admixtures is to offer more strength and earlier hardening to the produced flooring. Neville (1995) points that the use of such admixtures has revolutionised the use of concrete in many ways, making it possible to produce stronger concrete that can be placed more easily. Precast manufacturers also employ air entraining admixtures, these are typically used to stabilize microscopic air bubbles in concrete and dramatically improve the durability of concrete exposed to moisture during cycles of freezing and thawing (Neville, 1995). However, precast manufacturers mainly use these admixtures to provide some workability for the concrete, enabling them to cast the products successfully (Bison, 2006).

The role of water in an extruded prestressed concrete is mainly to enable hydration[21]. It should be noted that the need for water for workability, currently known as *consistency of concrete*, is very minimal (only in the case of wet-cast concrete flooring). This results in very low (w/c) ratios reaching 0.35 – 0.3 (Schmidt *et al*, 2003), producing concrete with a very low (zero) slump and workability characteristics. The low w/c ratios used contribute to the low shrinkage properties of the concrete[22] and enhance both the efficiency of production and the strength of the product.

Neville (1995) points out that the strength of concrete depends on two major factors only: the water/ cement ratio and the degree of compaction. Coarse/ fine aggregate ratio can also affect strength and durability. Typically, precast concrete elements require 50% to 60% of the 28-day compressive strength at the time of de-moulding (around 28 N/mm^2 to 55 N/mm^2), or removal from the production casting bed. The compressive strength will later reach 35N/mm^2 to 60N/mm^2. However, these figures might differ from one practice to another. Figures from a Canadian manufacturer note that 70% to 80% of the 28 day compressive strength is required prior to de-moulding (Ball, 2002).

Manufacturers are also required to pay attention to the properties of the ingredients as these can have a substantial impact on the properties of the produced concrete. For example, some manufacturers claim that the fineness of cement plays a major role in the speed of curing and the rate of gain of strength. Cement with high alkali content will react with the Silica content of certain reactive aggregates and, therefore, cause cracking (Lyon, 1997; Neville, 1995). This Alkali-Silica reaction can become an issue because of the relatively high cement content used in mixes for prestressed concrete flooring. Excessive aggregate sulphate content can retard the setting time (Levitt, 1982), and chloride content at the mix must not exceed 0.1% (this is to avoid corrosion of the reinforcement).

The strength and quality of the concrete can also be affected by the manufacturing and curing processes. Richardson (1991) notes that excessive loss of water can cause significant loss in product strength. Use of heat during curing needs to be controlled to avoid over-heating during the period of bed curing, which could lead to a product with a continuously decreasing strength (Myers and Shen, 2003). The water in the product must be retained during curing, since almost all of the water used in the mix is required for

[21] Most of the water content in the mix is usually lost to hydration (or evaporation).
[22] Shrinkage reduces the level of the prestress of tendons within the flooring products.

hydration (in the case of extruded and slipform flooring). Moreover, high temperature and humidity are also needed to achieve strength (25 – 35 N/mm^2) within 7 to 14 hours.

The material content of concrete can also affect product appearance. The nature (grading, fineness, texture, etc.) of aggregates used can have an effect on the appearance and surface of concrete. There are many other effects on precast flooring and concrete products' appearance in general (including lime bloom, hydration staining, darkened colour due to the carbon content of fly ash used, etc.).

4.3 The characteristics of precast flooring production

4.3.1 Overview

The manufacturing process in precast plants has experienced major improvements during the last decade. In precast production, there are three main production models used in manufacture, the characteristics of all these models are found in prestressed flooring production. These production models include jobbing production, batch production, and flow-line production (Richardson, 1991). The use of jobbing production (highly customised production) is very rare for precast flooring. Batch production is the most popular as each delivery (or group of deliveries) is considered as a batch. However, it should be noted that precast production systems are basically designed on a flow-line (mass) production basis. Skilled production planners are employed to adopt flow-line techniques for the production of items which usually appear to be more suited to batch production.

Mass-customisation is also a feature in precast production; the automotive industries also use innovative measures such as mass-customisation (Pine, 1993). Gibb (1999) notes that the principle is already being employed in the prefabrication and off-site production sectors. However, it should be noted that the '*Rethinking Construction*' report (Egan *et al*, 1998) gave considerable attention to standardisation and how the concept of repetition in design (and hence in production) can help construction practitioners save significant costs and time and avoid the disruption caused by developing one-off solutions.

4.3.2 Key stages in production

There are substantial differences in the processing systems used in different precast flooring factories. However, all precast manufacturing operations share the same basic steps of concrete batching; reinforcement placing and stressing; casting; accelerated curing; stacking and finally transporting to site and fixing. Figure 4.3 shows the different processes of precast flooring production. Richardson's (1991) description is used in exploring the different processes associated with prestressed precast flooring production:

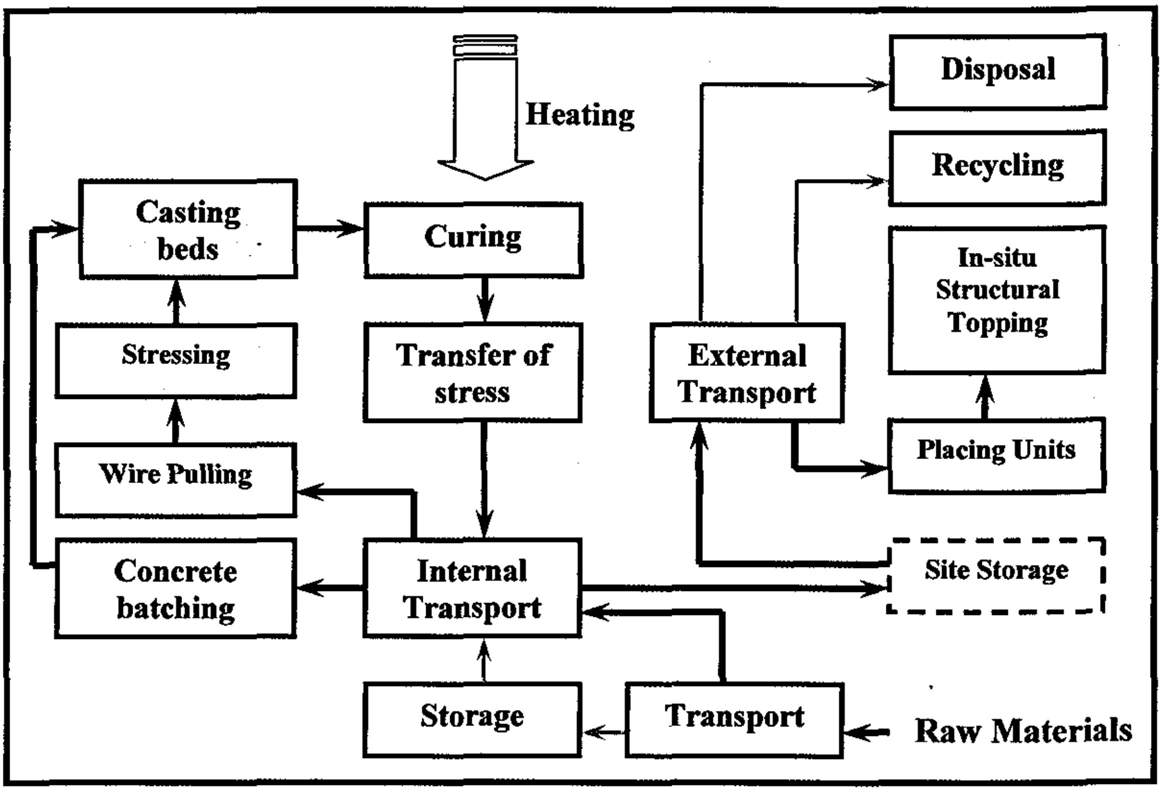


Figure 4.3 Precast flooring production - Diagram based on literature from various sources.

4.3.2.1 Sourcing raw materials

Arrangements for concrete and aggregate supply usually cater for the daily fluctuating demand for production, this is a characteristic of the working shift in the precast works (Richardson, 1991). Work in precast flooring facilities is mainly organised on a 'batches and deliveries' basis. This means that raw material deliveries are based on Just-In-Time (JIT) systems. It also means that precast manufacturers prefer to import such material from local (or at least close enough) suppliers to minimise the possibility of delay and unnecessary time loss, in addition to economic considerations. Many precast manufacturers in the UK import reinforcement steel from overseas suppliers where this is economically advantageous and the necessary quality can be obtained (Brown, 2003).

4.3.2.2 Storing raw materials

The storage facilities for raw materials are usually limited in precast plants, so most of the bulk material (cement and aggregates) is consumed within hours of delivery (on most days). Richardson (1991) stresses the continuous provision of data (between different departments) which can be used in determining adjustments to the batching and casting programmes for the purpose of smoothing demand. A small buffer stock of finished product is kept against delays and defects. There is limited literature on storage requirements other than warning about excessive steel corrosion, careful storage of cementitious material (Cement, pulverised fuel ash, ground granulated blast-furnace slag, etc.) in dry conditions to avoid setting (Levitt, 1982).

4.3.2.3 Concrete batching plants

A typical concrete batching plant has storage areas for aggregates, cement silos, weigh-batching equipment, a mixing unit, and an area for recovering unused fresh concrete. The level of sophistication of controls on moisture content (mainly from aggregates) vary widely. But with the increasing availability of reliable measurement equipment (such as Microwave meters) and batching automation equipment, concrete batching operations are becoming easier to manage. Precast plants may have a series of stationary mixers servicing separate production lines, the concrete being delivered by skip or hopper directly (Concrete Society, 2001). Richardson (1991) stresses that the mixer should be located in a position so the gantry cranes can operate without interference. Systems are established to ensure that where different products are being made in the same factory, the correct mix goes into each type of product.

4.3.2.4 Pre-tensioning

The reinforcement is wire or strand pulled along the beds or through the moulds, stressed and secured before the concrete is cast around it. The tension is maintained until the concrete has attained sufficient strength to be able to transfer pre-stress from the steel via the cement/ steel bond. The tendons are released after the cast concrete is cured and strong enough for handling (Threlfall, 2002; Gani, 1997). The observance of safety precautions and the keeping of records of stressing is an important aspect in the preparation for casting.

4.3.2.5 Concrete casting

Concrete is distributed in skips of various types. These are carried by a crane, or track-mounted, to the casting machines and concrete moulds. The FIP guide for good practice advices that concrete should be at a temperature of around 40 degrees Celsius prior to placement and casting (Richardson, 1991), but pre-heating of concrete (other than using warmed water in the mix) is unusual in the UK. There are three main methods of casting for prestressed products:

1. **Slipform casting (prestressed products):** Slipform casting machines shape concrete by processing it through a forming machine that moves along the entire length of the casting bed to give the concrete the required final product shape. The casting machine (slipform) is provided with wheels, it may be driven or pulled with a winch.
2. **Extrusion casting (prestressed products):** With extrusion casting machines the concrete is forced through the machine by rotating and vibrating augers that form the cores in the concrete flooring (hollowcore). The moving concrete presses the concrete already cast and the reaction to the pressure pushes the casting machine along the bed. It should be noted that extrusion is only used for hollowcore products (prestressed beams are usually slipformed or wet-cast).

Figure 4.4 Casting beds in a hollowcore production shed (Courtesy of BPCF, 2003)

In slipforming and extrusion flat casting beds are used, these are usually in contact with only the bottom face of the slab or beams (Figure 4.4). The sides and edges are formed within the casting and the concrete is stiff enough to stand without support immediately after casting.

3. **Wet casting (prestressed and reinforced products):** As the name would suggest, this method uses a more fluid mix than the previous two. Concrete is cast directly from a mixer (or ready-mix truck) into the casting moulds or troughs. Unlike extrusion and slipforming, the wet-cast process produces very little waste concrete.

4.3.2.6 The curing process

Concrete can be left to cure naturally (at a temperature above freezing) to reach the adequate handling strength. The concrete is covered with impermeable material (usually polythene sheeting) to retain moisture, prevent evaporation, and enable maximum hydration of the cement content within the concrete.

Richardson (1991) points to several accelerated curing techniques that can be used by manufacturers to meet time and delivery requirements. Heating (in the form of water circulated in a closed system within the casting beds or in pipe work under the moulds for wet-cast products) is applied for a period of hours after casting. The temperature may be controlled to a heating cycle or simply limited by a thermostat controlling the temperature of the circulating water. Heat is sometimes applied by running electrical currents through the stressed wires (electrical heating), or by passing steam under the covers. A study in Canada (Ball, 2002) advises that the concrete needs to be kept for a short period (prior to the application of curing heat) to set and reach a compressive strength of 3.5 MPa. However, it was not possible to find any similar applications within UK manufacturers.

The curing process is complete when concrete test cubes (kept under the cover) are showing to have achieved the compressive strength necessary for the transfer of prestress to the product.

4.3.2.7 Internal transport of precast elements

Precast elements are transported from production sheds to stockyards using rail-mounted bogies, fork-lift trucks, or trailers. In some larger factories, gantries and crane systems are used. Precast manufacturers employ advanced circulation systems to ensure that the flow of production is not affected. Richardson (1991) refers to the 'clear shop principle' which requires out-loading of products to be carried out without upsetting the ongoing production in each shift. Crane movements must be arranged to avoid conflicting demands from teams placing concrete whilst bed stripping is in progress. In some factories the products are carried out using proprietary machines which lift one or more beams at a time and travel on rails to set-down points from which products are transported to stockyards by fork-lift trucks, straddle loaders, or cranes.

4.3.2.8 Stockyard control

Elements should be stored in such a way that they are not damaged, distorted or contaminated. Racks, stillages, and stacking battens are provided (as required by the product). Stockyards employ a range of mobile and fixed plant to handle the units. Records of stocks are usually referred to by specific data written on the product itself. Some precast manufacturers have tested the use of Radio Frequency Identification (RFID) systems for stock control (Brown, 2003). Figure 4.5 shows units stored in a stockyard.

Figure 4.5 Precast flooring (hollowcore) stockyards - Courtesy of BPCF (2005).

4.3.2.9 Concrete Waste Handling

Concrete waste is removed from the production shed or prior to or after curing. This is taken to crushers and reused in new products or used as hardcore for road or other construction.

4.3.2.10 Transport to site

Loading is carried out in accordance with the specific delivery vehicle and its plated carrying capacity (all loading vehicles have an official plate specifying the maximum load the vehicle is licensed to carry). Some precast manufacturers include transport to site as part of their operations while others prefer to use a separate transport contractor.

4.3.2.11 Site erection and crane selection

Flooring erection usually involves cranes; in case a site does not have a tower crane, then a mobile crane can be used. Installation of the product is generally carried out by the manufacturer (under supply-and-install contracts).

It should be noted that all these production processes can be designed to fulfil specific production objectives all shaped to achieve maximum profitability, this is explained in the following section 4.4. Each has evolved over time, but slight variations can be seen in different factories.

4.4 Business Objectives of Precast Flooring Manufacturers

As explained in Chapter Three, introducing organisations to new principles such as social responsibility and environmental improvement is a challenging task. To assess the difficulty of this within the precast flooring industry, it is necessary to identify different business objectives and recognise the meaning of business improvement within the precast flooring industry.

4.4.1 Business improvement within precast flooring organisations

Unfortunately, there is no clear literature on the exact meaning or definition of business improvement within a precast organisation. Although most precast concrete literature concentrates on technical and functional aspects (such as concrete strength and workability), it still offers a clear view of the business drivers and objectives that precast manufacturers pursue in order to achieve business improvement. For example, Levitt (1982) summarises the precast manufacturer's workability business case interests in five points (mainly discussing new additions to the mix or production process):

- Does the addition improve the early (0-10 minute old) product handling properties?

- Does the addition improve early (6-18 hours old) strength of the concrete?
- Does the addition give the product better surface appearance and edges?
- How are other relevant properties (segregation, slumping after casting, etc.) affected?
- Does one get less wear and tear on machinery and plant?

The points mentioned by Levitt (1982) target time, quality (appearance), functionality (structural strength), and cost/ overheads (maintenance). The same drivers are also addressed by Richardson (1991) who stresses that capital cost, cost per unit of concrete cured, ease of application in the working environment, and controllability must be the main criteria against which any system is evaluated. The need to achieve these key business drivers (functionality, quality, reduced costs, shortened lead-times) entirely shape the various economic, technical, and managerial solutions employed by manufacturers. Indeed, all production and material based systems mentioned in the preceding sections are based on these four major business objectives. This can be demonstrated through the following examples

- **Mass production systems:** As explained in section 4.3, precast flooring production systems (including accelerated curing, long cast beds, gantry systems, etc.) are designed to achieve the advantages of mass production. One of the main advantages achieved through mass production is economies of scale. Figure 4.6 somehow explains the advantage of mass production – an increase from 'one off' to 'two off' per mould makes a significant difference to the unit cost, in this case for cladding.

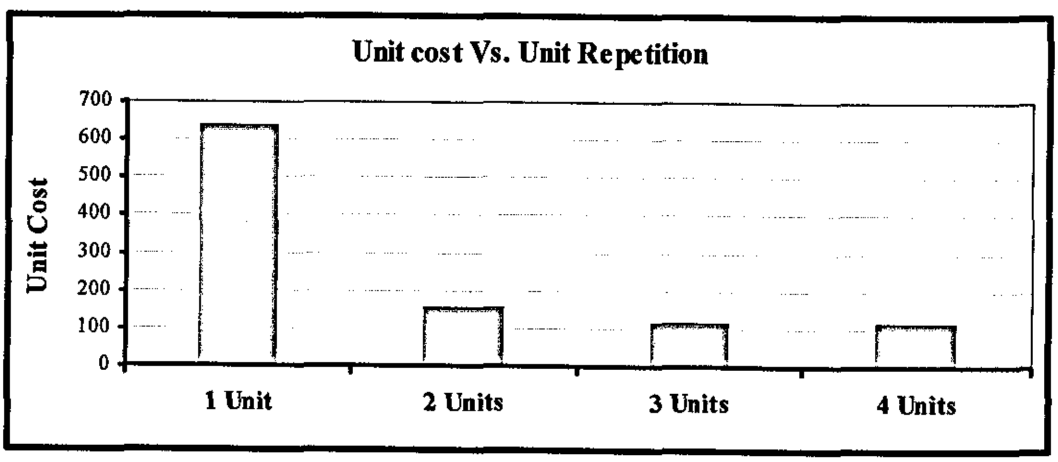


Figure 4.6 Relationship between unit cost and unit repetition for precast concrete (derived from Gibb, 1999).

It should be noted that although Figure 4.6 illustrates economies of scale, it covers a different context (bespoke cladding) that might not apply to all precast flooring products. However, the concept should still apply.

- **Cement content:** Increasing cement content usually helps in accelerating strength and products' early handling, with acceleration of production and better utilisation of the available casting lines and moulds.
- **PFA use:** Pulverised Fuel Ash (PFA) is much cheaper than cement; run-of-station PFA is nearly 10% the price of cement (Quality Ash Association, 2003). The replacement of some cement content with PFA can help in making considerable savings. There is also evidence that low-lime fly ash (combined with silica fume and metakaolin) can be used to improve chloride resistance in concrete and protect reinforcement (Dhir and Jones, 1999). However, PFA could cause some retardation and delay to the strengthening process (Li and Zhao, 2003). Manufacturers prefer to use Ground Granulated Blastfurnace Slag (GGBS) as it offers faster curing. However, GGBS is also expensive. Therefore, PFA is preferred when long curing periods are possible. Li and Zhao (2003) note that a combination of PFA and GGBS (with Portland cement) can be very successful in both short and long term compressive strengths and in resistance to H_2SO_4 attack.
- **Aggregate content:** Where economically available, precast flooring manufacturers prefer to use Limestone with $CaMg(CO_3)_2$ (mineral dolomite) as aggregate to minimise the costs of sawing (limestone is easier to saw). Such type of limestone is mainly found in the Eastern parts of England (National Statistics, 2004). Limestone and carbonate-based aggregates also have fire resistance benefits for the product (Buettner and Becker, 1998)[23].

4.4.2 Business improvement and budgetary performance

The business objectives (mentioned in 4.4.1) can also be detected through the examination of profit and loss account items and other functions available in different financial statements. Figures from the annual reports of Consolis Ltd, Hanson Building Products and Aggregate Industries Plc. were used to identify the following key items,

- **Cost of Sales:** This profit and loss account item is defined by Artill and Mclaney (2001) as the cost of the goods sold during a period. This would mainly include the

[23] Lightweight aggregate blocks can be used as infills in a beam and block construction. There are several benefits in using lightweight blocks (e.g. speed of floor erection, cost savings, improved K-values).

raw materials used in production (in addition to the transaction costs associated with finding, purchasing and transporting the materials) and the transaction costs associated with the sales and the purchasing of goods sold. Table 4.1 shows the impact of the cost of sales on the turnover of three precast organisations (data collected from companies' Annual Reports in 2001).

Company	Turnover	Cost of sales	Contribution to turnover
Consolis Ltd.	£ 329.2	£ (272.8)	82.87%
Hanson Concrete (UK)	£ 243.2	£ (211.6)	87%
Aggregate Industries	£ 1306.9	£ (1076.8)	82.39%

Table 4.1 Impact of cost of sales on a precast manufacturer's turnover[24].

With the significant contribution of Cost of Sales to the entire annual turnover (Table 4.1), manufacturers cannot afford to compromise on the Cost of Sales for the sake of any other principle. This would significantly affect decisions on what products to buy, where to find cheaper suppliers, and what concrete mixes to use.

- **Expenses:** Atrill and Mclaney (2001) define expenses as the outflow of assets (or increase in liabilities) incurred as a result of generating revenues. Figures from Consolis and Aggregate Industries in addition to feedback from members of the PFF show that the proportion of expenses can be very critical, making cost savings a genuine priority for the business. Expenses also include capital costs of renewing or adding to the production system.

Manufacturers also need to look at the expenses associated with the implementation or acquisition of a specific system – this is usually considered as part of the transaction cost. Moreover, the manufacturers can look at priorities in production through exploring their 'opportunity cost', all these are essential measures that financial managers, accountants, and major decision-makers need to consider (Katz and Rosen, 1998). Expenses also have a direct impact on quotations, tender offers, and prices in the business given that the final pricing of an order (within a quotation) will usually compose of the actual cost and the mark-up for the tender bid or quotation (Holland, 1998).

[24] All figures are in millions of pounds Sterling. Figures for Consolis Ltd. (European manufacturer) were originally given in Euro (€). The figures were converted using the H. M. Revenue and Customs Exchange Rate for December 2001 (£1 = €1.613).

4.4.3 Business improvement and the sustainability challenge

As evident in 4.4.1 and 4.4.2, profit is the lifeblood of a precast manufacturer and the means to its growth. Many systems and techniques used (such as accelerated curing or increased cement content to reduce curing cycle times) are selected on the basis that profitability will improve. Moreover, most efficiency measures, competitive advantages, and performance criteria are linked (either directly or indirectly) to profits or overheads. Smart (1992) noted that corporate managers worldwide recognise and respond naturally and efficiently to cost and price signals. Through these they select resources and convert them into useful products. On the face of it, the precast industry's decision-making frameworks do not align with the needs of sustainable development. The employed systems cannot recognise or estimate environmental consequences or social risks of a specific decision. Indeed, introducing a new concept (such as environmental improvement) that challenges the superiority of profits is a difficult if not an impossible task, especially if there is a conflict between conventional business interests and the newly introduced 'environmental' interests.

The potential conflict of interests between environmental and economic aspects is one of the main challenges that face industries worldwide. The fact that environmental and economic interests would occasionally conflict is supported by the literature; indeed, there are already concepts and processes used to balance the various and potentially conflicting components of sustainable construction. These have collectively been termed *Lifetime Engineering* (Nixon *et al*, 2002). According to the '*Better Quality of Life*' report (DETR, 1999) the best option to deal with such conflicts is to compromise. The report makes it clear that the concept of abandoning economic growth is not a sustainable option, the report also refers to some '*environmental limits*' for any economic activity. Such elaboration is vague or unhelpful in making any judgements unless more information on the nature of environmental impacts is collected.

However, different academic interpretations can have an influence on how compromises are looked at. Pearce (2003) refers to the 'shadow price', or social cost, of carbon as an economic quantification for the damage and socioeconomic consequences of environmental impact. He suggests the use of cost-benefit analysis as a means to assess this social cost. However, Pearce (2003) seems to acknowledge the difficulty of calculating an exact cost (and timescale) for the possible damage of long-term environmental impact (such as Climate Change). Such long-term consideration is part of sustainability, but it might be hard for a precast manufacturer to incorporate and account for. Information on the nature of the environmental impacts arising from precast flooring production is explored in the following section.

4.5 The environmental effects of precast concrete flooring production

As noted in different parts of the thesis, current business-centred, profit achieving production and decision-making frameworks for precast flooring do not recognise the needs of sustainable development. This should raise concerns on the nature and magnitude of the undetected environmental impacts generating from precast flooring production. This section examines literature on the environmental impacts associated with precast flooring production.

The literature shows that the manufacture of concrete products is associated with a range of environmental impacts. These usually differ in occurrence and level of effect; Figure 4.7 gives an indication of the typical environmental impacts for concrete production.

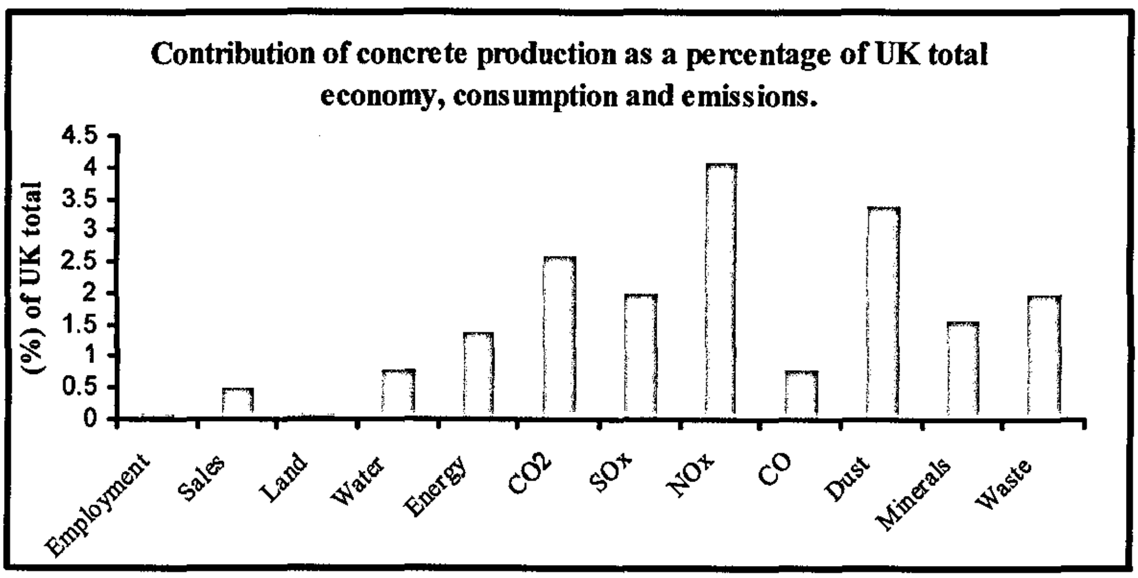


Figure 4.7 The contribution (%) of concrete production as a percentage of the UK total economy, consumption and emissions – including all industry and community sectors (Concrete Society, 2001).

In precast manufacturing a number of specific environmental concerns emerge. Bijen (2002) stresses that the main environmental burdens in precast manufacturing are associated with cement content and transportation. The energy-intensive process of cement manufacture accounts for nearly 65% of total CO_2 emissions and 46% of the embodied energy content of precast hollowcore products (Addtek, 2000). Transportation impacts for precast products can also be significant because of the weight and size of units. In addition, considering the economic aspects of production, Elhag *et al* (2005) notes that two more environmental impacts need to be looked at; these are the relationship of (a) Energy Consumption; and, (b) Waste Generation, to associated economic penalties (i.e. The Climate Change Levy and the Aggregate Levy respectively). These four key issues are considered in depth in this section. Other environmental impacts (see section 3.1.3) are also considered in this thesis; outline information is presented in the following sections.

4.5.1 Cement content and raw materials

The manufacturing of cement has always been a concern for environmentalists as the process involves consumption of significant quantities of fuel. Moreover, the calcination of limestone ($CaCO_3$) during cement production generates a considerable amount of carbon dioxide. Vares and Hakkinen (1999) claim that most of the environmental impacts in a precast product's life-cycle come from raw materials production and transport. Table 4.2 shows the various environmental impacts associated with the production and transport of the ingredients of precast hollowcore units.

	Steel	Cement	Aggregates	Admixtures	Water
Weight	1.4%	13%	80%	0.1%	5.5%
			Environmental Impacts		
CO_2	18.5%	77.5%	1.7%	2.3%	-
NO_x	25.2%	60.2%	10.1%	4.5%	-
SO_2	13.9%	81.8%	2.1%	2.2%	-
Energy	26.1%	67.9%	4.2%	1.8%	-

Table 4.2 Hollowcore flooring: relationships between individual raw materials (by % of weight) and their % contribution to the product's environmental impact – *cradle-to-gate* (Addtek, 2000).

The table clearly shows the substantial contribution of cement to the products' environmental impact; cement is apparently the major raw material contributing to emissions from concrete production (similar results can be found in Table 6.11 in Chapter Six). It was estimated that an approximate one tonne of carbon dioxide is generated by the production of one tonne of cement (Pocklington, 2004). However, more recent figures put emissions at 880 kg of CO_2 per tonne of cement (Gilbert, 2005). This broadly explains how a slight change to the cement content (i.e. changing the mix proportions along the weight row) can have a significant impact on CO_2, SO_2, NO_x emissions, and energy consumption levels. For example, cement commonly represents just 13% of a precast unit by weight, but accounts for most of the four impact categories shown in the table. A small change in cement content can significantly affect the overall environmental impact of a product, but the lion's share of environmental impacts associated with one tonne of product will still arise from cement.

Although aggregate extraction appears to be a low priority ingredient (in terms of environmental impacts) in Table 4.2, crushing and processing of aggregate consumes considerable levels of energy (particularly considering that the UK's annual consumption of aggregates stands at over 250 million tonnes). The use of virgin aggregates and extraction of resources is another concern; the new Aggregate Levy is forcing precast manufacturers to consider the use of recycled aggregates. Impacts from steel are also substantial, however the small amount of steel used due to pre-stressing is an advantage that minimises the upstream impacts. Admixtures also have upstream environmental impacts: a study by Rouwette and Schuurmans (2001) shows that cradle-to-gate admixture-associated climate change emissions reach 0.38 kg of CO_2 per 1 kilogram of admixture. However, these impacts remain marginal considering the relatively small quantities of admixtures used in each batch (Deulshe-bauchemie website: June, 2003; Vares and Hakkinen, 1999).

4.5.2 Machinery energy consumption

The impact of energy consumption is associated with fossil fuel depletion, greenhouse gas, SO_x and NO_x emissions. Precast concrete manufacturing is not as energy intensive as cement or steel production: Asumnaa (1999) estimates the range of energy consumption in precast factories to be around 350 – 790 MJ/m^3 of concrete produced. However, other studies estimate this figure to be much higher ranging between 851 MJ/m^3 (Alexander *et al*, 2003) to 1113.2 MJ/m^3 (Punkki, 2001). Moreover, the amount of CO_2 emissions from precast concrete factories' energy use is estimated to be between 8% (Vares and Hakkinen, 1998) to 10.6% (Alexander *et al*, 2003) of total *cradle-to-site* CO_2 emissions associated with precast flooring. Although there is a lack of literature in this area, there are several reports confirming that precast concrete energy performance is better than that for in-situ concrete (e.g. Alexander *et al*, 2003). However, looking at the manufacturing stages within the process, energy consumption may still be a critical and influential measure.

Most of the manufacturing processes in precast flooring production consume energy. Accelerated curing (using heated beds, electrically heated tendons, steam curing, or hydration chambers) can make considerable savings in time. However, the amount of energy consumed is vast, reaching 70% of the total energy consumption at a precast flooring plant (Lincoln Green, 1999). Richardson (1991) notes that various electrical processes in curing are more efficient and cleaner in use (given the amount of energy consumed and waste saved due to avoidance of creep and shrinkage). However, considering primary energy[25], electrical curing techniques may have a considerable impact on the environment (given the amount of emissions and the energy consumed). Other activities consuming energy include internal transport activities using gantries and mobile plant. These gantry handling systems use electricity; a study of primary energy may show that these systems are less efficient than a system employing mobile handling plant and fork-lift trucks. However in mass production operations, a gantry system, capable of mobilising large amounts of finished products, will consume less energy (Alexander *et al*, 2003).

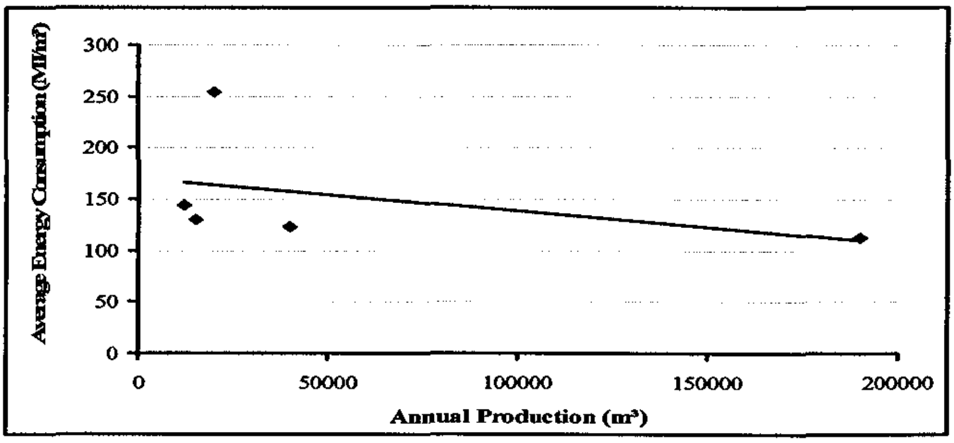


Figure 4.8 Impact of production volume at precast factories' (in m³) on energy consumption levels – Data taken from five different precast factories with different annual production capacities (derived from Kaysser and Kott, 2002)

[25] Amount of energy used to operate energy generation plants and deliver energy to consumer (manufacturer).

One advantage of the machinery currently used in precast flooring plants is the employment of mass production systems (long casting beds, large mixing plants, transport and storage facilities) which enable greater production volumes with fewer resources (see Figure 4.8). In a study by Kaysser and Kott (2002), it was found economies of scale can dramatically reduce the amount of energy consumed, SO_2, NO_X, and CO_2 emitted. The same study notes that savings in waste can also be achieved.

4.5.3 Transportation impacts

Transport affects six of the environmental impact categories usually considered in Life-Cycle and Environmental Impact Assessments (some of these are mentioned in Section 3.2), these include Climate Change, Acid Deposition, Human Toxicity emissions, Eutrophication (depletion of dissolved oxygen) and Fossil Fuel Depletion. There are several transportation stages associated with the manufacture of precast products, both for the raw materials and for the finished product (see Figure 4.3). At least theoretically, the proportion of impacts given over to transport of precast products might seem to be more substantial than that for other building products due to the weight of products, in practice this would depend on the manufactured products' loading efficiency and nature of the supply chains.

For example, it was found that the efficient and time saving Just-In-Time (JIT) transport delivery system may have a negative, undetected environmental impact (DETR, 2003). Rather than having four to five deliveries each of 10 tonnes of production, it would be more efficient (environmentally) to deliver two 20 to 25 tonne deliveries and therefore reduce the total environmental impact from transport. However, there is literature that plays down the environmental impacts associated with transportation. Alexander *et al* (2003) argue that precast product transport holds some environmental advantages; the repetitive routes and standardised operations for precast products and raw material transport are simpler to tackle and improve. Moreover, environmental impacts arising from recurring trips to and from site for formwork, propping, scaffolding, etc. are avoided.

4.5.4 Production Waste

There are several streams of concrete waste in a precast factory, depending on products being manufactured. In hollowcore production, most concrete waste arises from cutting to width to achieve bespoke designs together with removal of concrete portions to provide openings. Waste also comes from discarded elements due to breakdowns, casting, setting-out or curing defects, wastage at each end of bed and concrete waste in mixers and skips.

The amount of concrete waste generated in typical precast plants does not appear to be *significant*; anecdotal accounts suggest <5% of gross production would be typical. Figures from the PRODOMO study estimate hardened concrete wastes to be around 1-3% of gross production (Kaysser and Kott, 2002). Some Nordic studies offer a similar rate: 100kg per 1 m^3 of production, which is around 4% (Alexander *et al*, 2003). However, this percentage will probably increase if all concrete waste streams, including bespoke design waste, were to be considered. Figures from a Dutch study reveal that cradle-to-site solid wastes might reach 13.6% of the total net mass of a hollowcore product where this includes all concrete/ non-concrete general waste including waste from raw materials extraction, general rubbish and packaging in factories and construction sites (Fluitman and De Lange, 1996).

Two surveys, both carried out in Western Europe in 1996, estimate waste from precast structures building sites to be more than one third (35 and 38.2%) less than in-situ concrete waste at construction sites (Alexander *et al*, 2003; Fluitman and De Lange, 1996). Moreover, Consolis Ltd. (formerly known as Addtek) reported a 45% decrease in material consumption (Addtek, 2000). However, none of these studies accounted for the actual amount of concrete waste generated in production due to bespoke design.

4.5.5 Emissions and other environmental impacts

In addition to the environmental impacts identified in sections 4.5.1 to 4.5.4, there are other impacts arising from the production of precast elements, these include the following:

- **Dust emissions:** Dust is one of the major health and hygiene concerns in concrete batching or aggregate crushing and handling. However, this aspect can be tackled effectively by complying with regulations regarding the use of filters and proper materials handling.
- **Chromium VI:** Chromium VI content within cement is a health and safety concern. However, the level of damage is limited to those in direct contact with fresh cement (CSTEE, 2002). An EU regulation was issued on the minimisation of Chromium VI impact within cement through the addition of ferrous sulphate, and restrictions on the 'shelf life' of cement.

- **Water consumption:** There is no specific literature on the exact amount of water used in precast flooring mixes. It is known that water is a major ingredient in hollowcore with around 5.5% of the mix (see Table 4.2). However, the total amount of water used in production exceeds that. Water is used daily in washing equipment (Levitt, 1982). Moreover, Alexander *et al* (2002) note that water is also used in other applications such as sawing. The amount of wastewater in production reaches around 45 Kg per 1 m^3 of production. This adds around 1.8-2% to the 5.5% rate. Results from a Norwegian Environmental Product Declaration (EPD) also show similar results where the water content reached 22.9 kg per 1 m^2 of hollowcore; this is around 4.8% of total raw materials used (Alexander *et al*, 2003).
- **Other emissions:** It should be noted that there is a range of other emissions generated from the different activities associated with energy consumption, these include SO_2, CO, CH_4, NO_x, and other Volatile Organic Compounds (VOC) emissions (Howard *et al*, 1999). These vary from one energy source to another. Moreover, energy sources can also affect the amount of primary energy used and the level of fugitive emissions arising during the energy generation and energy delivery.

It is difficult to account for many of these impacts given that most of these are not covered by any legislation at this stage in the supply chain. However, the use of some decision-support tools such as Life Cycle Assessment (LCA) can considerably help in accounting for some of these impacts. This is looked at in Chapter Five.

4.6 Conclusion

Links between precast flooring environmental and business literature offer significant information on how environmental impacts (or environmental improvement activities) can be affected by, or can affect, economic criteria. Looking again at the business win-objectives and the possibility of conflict between economic objectives or gains and environmental performance, it is possible to identify several advantages and obstacles.

For example, there is a visible conflict between the economic importance of increased cement content and its influence on the environmental profiles of precast flooring. The use of PFA and GGBS can *significantly reduce the amount of* CO_2 emissions *(in addition to* economic savings). However, there are several environmental concerns regarding these two ingredients in precast production as it retards curing (Li and Zhao, 2003) and therefore affects curing energy. This is in spite of the fact that hollowcore has been successfully produced with a 30% PFA replacement level by a Canadian Precast manufacturer (Ball, 2002). There are also claims that PFA minimises the possibility of carbonation (Atis, 2003).

Another example is found in the concept of carbonation itself. Carbonation induces corrosion damage, and several studies have been conducted into methods of reducing it (Jones *et al*, 1997). On the other hand, carbonation is an advantage for the environmental profiles of concrete products. Similar positive and negative links can also be established when looking at other aspects such as transport (influence of cost of sales against raw material transportation impacts), or energy consumption (economic benefits of accelerated curing against its contribution to energy consumption).

These examples clearly show the need to establish a structured approach that addresses business as well as environmental improvement. However, there is a clear lack of literature addressing whether and how a successful compromise between economic gain and environmental improvement measures can be achieved. Literature on different decision-support frameworks capable of integrating these different requirements is reviewed in the following Chapter.

CHAPTER FIVE: LITERATURE REVIEW – ENVIRONMENTAL IMPROVEMENT AND DECISION-MAKING FRAMEWORKS

Chapter Five: Literature Review- Environmental Improvement and Organisational Decision-making Frameworks

In order to achieve the aim and objectives of this research (see section 1.3), it is necessary to look at literature covering different decision-making frameworks and decision-support systems that may be capable of containing and integrating environmental and economic objectives and requirements. As noted by Avadikyan *et al* (2001), very little research has been done in the economics field to analyse the way environmental decisions are made and the influence of these decisions on coordination, hierarchy and delegation within an organisation. This section looks at some of the available literature and a review of different problem-solving tools (capable of incorporating concepts such as environmental improvement) is also included.

5.1 Main characteristics in decision-making

Webster's Dictionary defines Decisions as "*The passing of judgment on an issue under consideration*". This "*issue under consideration*" will typically be a problem or a situation involving a collection of obstacles that can develop and become problematic. Hicks (1991) notes that to understand decisions and the decision-making process within a specific organisation thoroughly, one should look at the nature and types of problems and obstacles affecting an organisation's performance. Different industry practitioners are always faced with situations that require daily decisions. However, decision-making requires the existence and recognition of the problem. A solution should not be a by-product of an irrelevant decision; in other words, the solution for a problem should not arise from another decision targeting a different objective.

This link, between decisions and problems, is evident in all literature handling problem-solving and decision-making. Ackoff (1981) defines a problem as a situation in which "*a decision-making individual or group has alternative courses of action available. The choice made can have a significant effect, and the decision maker has some doubt as to which alternative should be selected*". This might be one of the main reasons why creative problem solving stages usually match those found in decision-making frameworks (Green, 1994). The following two sections (on problem-solving and decision-making) investigate this match and identify the most appropriate types for tools enabling the recognition and integration of environmental and economic requirements.

5.1.1 Decision-making frameworks

Hicks (1991) notes that decision making is often thought of as a relatively simple choice between several courses of action. This might apply to routine business decisions, but may not be possible in real-life complex and dynamic situations. Manufacturers are often faced with problematic situations with more than one objective obstructing each other and several problems affecting the different possible courses of action. Such situations will require the use of a more rational approach to decision making. According to Adair (1985), there are five major steps within the conventional decision making framework (see Figure 5.1):

- **Define Objectives:** Specify the aim or objective, having recognised the need for a decision.
- **Collect information:** Collect and organise data; checking facts and options; identifying possible effects; establishing time constraints and other criteria.
- **Develop options:** List possible courses of action; and generate ideas.
- **Evaluate and decide:** List possible pros and cons; examine the consequences; measuring against criteria; trials; test against objectives; and select the best.
- **Implement:** Act to carry out the decision; monitor and review the decision.

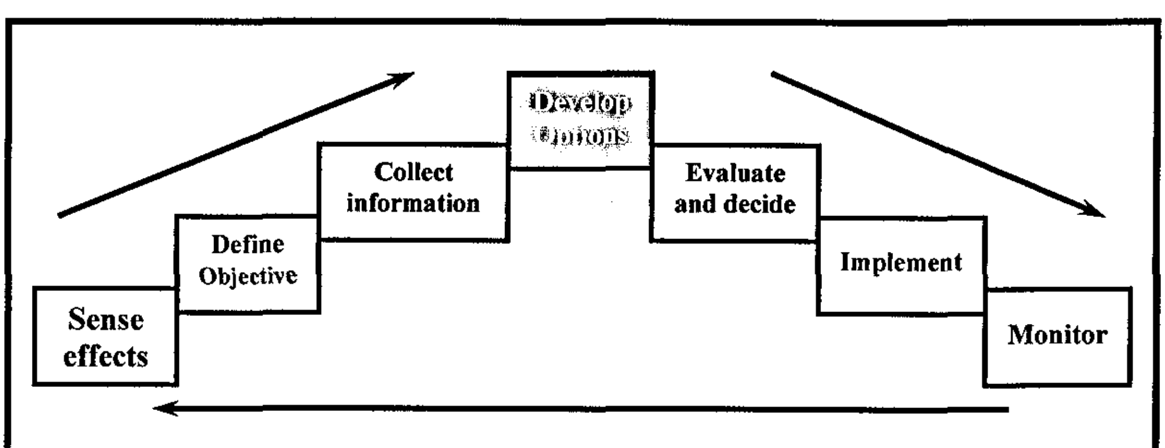


Figure 5.1 A decision-making model (Adair, 1985)

Two other stages are identified by Adair (1985), these are 'Monitor progress' and 'Sense effects' to investigate whether the decision is having its desired effect (see Figure 5.1). This usually helps to obtain feedback and continuously improve the decision/ process.

However, Hicks (1991) also makes reference to studies pointing to the complete lack of evidence that, in reality, these steps exist, or are in fact performed. He notes that no rational and distinctive decision-making framework is usually followed for problems or problematic situations within organisations. Unfortunately, there is no literature on decision-making structures in precast and concrete organisations or factories. Quotations and statements made in precast flooring manufacturers' websites and brochures (Milbank, 2005; Aggregate Industries, 2005) reveal however that some problem-solving tools and packages are employed. Therefore, proving that the applicability of classic decision-making frameworks within precast flooring organisations depends on proving the similarity and match between decision-making and creative problem-solving. This is discussed in section 5.1.2

5.1.2 The process of problem-solving

Creative problem-solving is a framework which employs many different thinking skills and tools to identify, isolate, and solve a specific problem (Lumsdaine and Lumsdaine, 1995). This takes place in four major steps:

- Define and understand the nature of the problem.
- Brainstorm and generate alternative ideas about how the problem can be solved.
- Evaluate the feasibility of the ideas generated. Fully develop and test the ideas that are judged to be the most suitable.
- Decide on and implement the best solution.

The similarity between creative problem-solving steps and decision-making steps (in section 5.1.1) is clearly evident. Not surprisingly, the 'job plan', employed by value engineers, is known to be analogous to key procedures undertaken in creative problem-solving. The same applies to several problem-solving and decision-support techniques (Green, 1994). However, to be clear about the tools used, it should be noted that some of the tools help in achieving the first or second stages in the 'job plan'. On the other hand, some of the methodologies explored are concerned with the entire problem solving framework (using a range of tools and several versions of models and diagrams to achieve end goals and aims). Accordingly, any attempt to identify and exploit the link between economic gains and environmental performance (to achieve business improvement through a structured approach to sustainability) should include the appropriate mechanisms to identify the problems, find the most appropriate solutions, and make the most sensible decisions. Literature on such mechanisms (and techniques) is reviewed in 5.2, 5.3 and 5.4

5.1.3 Classification of organisational decisions

To properly address environmental improvement requirements within organisational decision-making frameworks, it is necessary to identify the different levels of decisions within organisations. This is carried out through a review of literature classifying decisions across different levels within organisations.

Decisions vary considerably from vital, often complex, to daily and routine ones; they also vary in terms of influence, expected outcome, and levels of risk. Ansoff (1968) classified business decisions as strategic, operating, and administrative:

- **Strategic:** These are long-term decisions that resolve the organisation's relation to its environment. Ansoff (1968) included some fundamental aspects to be handled through strategic decisions, these include questions such as what are the organisation's objectives and goals, whether to diversify production and how best to develop and exploit its present position, which products or services it should be offering, and where these should be marketed.
- **Operating (Tactical):** These are the bulk of the decisions an organisation has to make. These are short-term and concerned with maximising the efficiency of resource, allocation, including measures such as production scheduling, quality management, inventory control, pricing, choosing a marketing strategy, budgeting, etc.
- **Administrative:** These decisions ensure harmonious and effective collaboration over the implementation of strategic and operational decisions and are concerned with the organisational structure (chain of command, areas of responsibility, work flows, communication channels, location of facilities and distribution networks) and the acquisition and development of resources.

These are slightly different from the classification used by Jennings and Wattam (1998), who divided decisions into strategic, tactical, and operational (see Table 5.1). Their classification is mostly associated with the impact of the decision (long-term, short-term, etc) and the management level making it (senior management, middle management, shop-floor). More primary data is required to identify how decisions within precast flooring organisations are to be classified in light of the literature reviewed in this section. However, the Jennings and Wattam (1998) classification is relevant and easy to consider, especially because the categories can be tailored to specific departments within precast flooring organisations.

	Timescale	Nature of risk	Structure	Control
Strategic	Long-term	High	Ill-defined	Heuristic
Tactical	Medium-term	Moderate	Variable	Qualitative
Operational	Short-term	Low	Well-defined	Quantitative

Table 5.1 Characteristics of decisions (Jennings and Wattam, 1998)

5.2 Organisational frameworks and environmental impacts

To focus on the most appropriate problem-solving and decision-support tools, it is necessary to review literature exploring the impact of organisational frameworks on environmental performance. It should also be noted that literature tackling environmental impacts in precast production mainly looks at limited shop-floor operations. Therefore, this section concentrates on other general studies tackling the subject.

A study carried out by Budapest University of Economy (Zilahy, 2004) concentrated on the organisational factors hindering energy-related cleaner production measures. The study looked at energy efficiency gaps[26] in many industries and organisations. A number of organisational barriers were identified in the study, including:

- **Lack of information due to gaps in communication:** Prior to each and every investment decision, a concrete and detailed feasibility study is prepared covering economic and technical status and conditions (including possible energy consumption levels). However, a large number of respondents in Zilahy's (2004) study were not aware of the existence of such analysis in their companies. This proves that such

[26] This was identified as the energy efficiency potential not being exploited, in other words; it indicates the difference between the economically optimal and actually implemented levels of energy efficiency measures.

issues (energy consumption, etc.) are not usually considered or accounted for in different levels of company communication.

- **Lack of proper recording of environmental information:** Results from the study also showed that energy consumption calculations made by respondent organisations were based on estimations made from financial statements.
- **Lack of knowledge:** Zilahy (2004) also refers to lack of an organisational knowledge framework as a major cause of employees' lack of knowledge and one of the main obstacles hindering proper implementation of environmental improvement measures.
- **Other barriers:** Zilahy (2004) also identified other barriers including: emphasis on short-term gains, conflicting interests, poor communication, lack of proper recording, bureaucratic obstacles, and unsuitable company structures as main barriers to identify or implement change.

Although Zilahy (2004) has identified many of the root problems hindering the implementation of environmental improvement measures, the recommendations offered were limited. The main recommendation was the elimination of bureaucratic obstacles hindering change and fast-tracking of decisions as a solution. Zilahy (2004) also seemed to be making a link between lack of efficiency improvement criteria and implementation of environmental improvement (notably energy efficiency) solutions. Accordingly, implementation of continuous improvement mechanisms can be considered as another major recommendation. Zilahy (2004) did not offer any suggestions of how change to environmental improvement should take place, and whether using cheaper energy, or generating less environmental impact, is the end goal.

However, another study (conducted by Avadikyan *et al*, 2001) offers a more elaborative approach to organisational incorporation of environmental improvement requirements. Avadikyan *et al* (2001) proposed that development of an effective environmental management capacity based on the adoption of three mechanisms within the organisation. These are based on organisational hierarchy, organisational knowledge, and individual and group action (within the organisation). The proposal is based on a theory known as the 'Firm Theory'.

Avadikyan *et al* (2001) looks at two main organisational models: centralised or decentralised. A reference is made to the atmosphere surrounding the organisational change (whether stable or volatile). The Firm theory dictates that when the environment of change is too stable or volatile, the most appropriate structure would be based on a centralised organisational model. On the other hand, if the atmosphere of change was '*continually, but not too drastically, changing*', then the decentralised model would be preferred. Since environmental policies and technologies do not follow abrupt changes but are modified by incremental adaptations through time, environmental management can profit from decentralisation and delegation at the operational level. This can be carried out through rotation or effort allocation between environmental and production activities, and integration of environmental responsibilities within job descriptions.

The study also looks at possible means used to incorporate environmental requirements into the conventional decision-making framework. A reference is made to the integration of ISO 9000 measures to the industry using 'organisational routines'[27], it is suggested that the same may apply to the ISO 14000 measures. Moreover, any development of new environmentally friendly systems and initiatives should also be driven by the organisational daily routines. Furthermore, Avadikyan *et al* (2001) recommends a cross-functional team approach to tackle the challenges associated with organisational environmental change. Such teams can help in rapidly accelerating the organisational learning process and develop a 'group technology'. The study suggests the establishment of environmental units (cited from Groenewegen and Vergragt, 1991) as a means to implement a team-based approach.

Furthermore, Avadikyan *et al* (2001) identify stages for the implementation of organisational change:

- The first stage involves the senior and middle-management levels, experts and specialised project groups being appointed to champion the introduction of the environmental management issues. The cross-functional team approach is introduced at this stage.
- In the second stage, firms gain more knowledge on the issue and form a stable structure which evolves through time towards decentralization. This structure should be based on the conventional procedural framework already existing in the organisation.

[27] 'Organisational routines' are regular procedures carried out at different levels of management, notably in the operational and middle-management levels.

5.3 LCA as a decision-support and problem identification tool

Prior to the implementation of any organisational change, it is necessary to define and explore the environmental problem. Given the extent of environmental information covered by LCA (refer Chapter Three), it would be appropriate to employ LCA as a problem identification (decision-support) tool.

5.3.1 Life Cycle Assessment (LCA): Definition[28]

Awareness of the importance of environmental protection (and possible impacts associated with products manufactured and consumed) has increased interest in the development of methods to better comprehend and reduce these impacts. One of the techniques developed for this purpose is Life Cycle Assessment (LCA). LCA is a decision- support tool/ method used to environmentally map manufacturing processes and assess the environmental performance and the potential environmental value of a product. ISO 14041 defines LCA as "*Compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life-cycle*" (BSI, 1998). LCA offers a detailed account of nearly every long to mid term environmental impact. LCA has four main stages, these are: definition of the study's goal and scope, Life Cycle Inventory Analysis, Life Cycle Impact Assessment, and Life Cycle Interpretation (as shown in Figure 5.2).

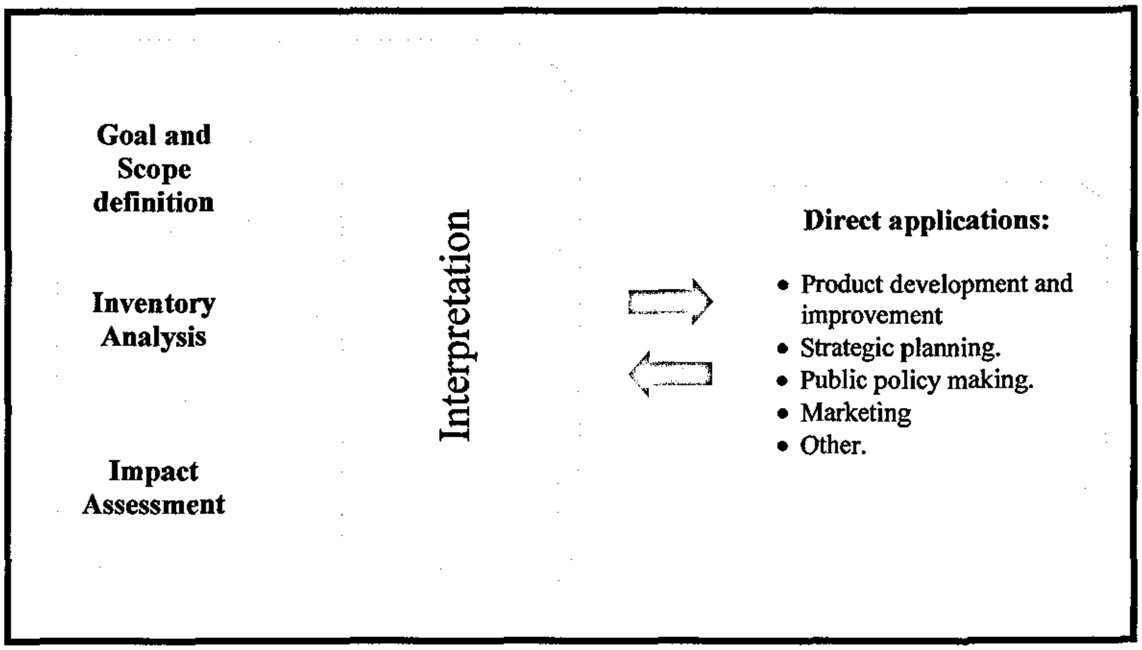


Figure 5.2 Phases of a Life Cycle Assessment (BSI, 1997).

[28] More information on LCA can be found in Appendix C

The aims of LCA need to be consistent and scientifically robust to ensure that burdens and impacts are being completely accounted for without any double or under-counting. There are several LCA methodologies used worldwide; these include the CML – Institute of Environmental Sciences at Leiden University – Methodology (Guinée, 2002), the Pré Consultants' Eco-Indicator 99 methodology (Pré Consultants, 2005), and ATHENA (Athena SMI, 2005). However, the one used in the UK is the Building Research Establishment (BRE) methodology for environmental profiling (Howard *et al*, 1999).

LCA can be shaped and used to serve different purposes. It is usually used for competitive or product benchmarking purposes (e.g. comparing product alternatives), public regulation (e.g. product approval based on results of comparison with a standard or Eco-label), product or process innovation (e.g. identifying dominant processes in the environmental profile to obtain information about the potential effect of an innovation), or as a tool for strategic studies based on policy scenarios (BSI, 1998). It is therefore necessary to define what should be incorporated within the parameters and boundaries of the study. LCA accounts for a collection of environmental impact categories, the first LCA study was carried out in 1992 in which 22 different environmental impact categories were considered (Heijungs *et al*, 1992). However, the BRE methodology for Environmental Profiles accounts mainly for 12 major environmental impact categories. Most of these categories can be found in Section 3.1.3, and Appendix C (Section 2.6).

LCA studies usually consider a number of rules on organisational goals and scopes, functional units, data collection, allocation and correlation of environmental interventions, and characterisation and normalisation of information (BSI, 1998). The level of detail within LCA studies is one of the main advantages, producing strong interpretations and links between various environmental impacts and different production activities throughout product life-cycles. The level of detail provided by the LCA will also be important in understanding the relationship between environmental and business objectives.

5.3.2 LCA as a tool in a decision-support framework

LCA studies handling concrete products can use functional units based on area or volume to satisfy construction and customer needs. However, precast manufacturers might wish to use different functional units that respond to their business objectives (time oriented: per working shift, quality oriented: weight of 'good product' and waste, or cost oriented: per production cost).

On the other hand, precast manufacturers might use different measures in Life-Cycle Interpretation, such as employing the interpretation as part of a wider decision-support framework. This was carried out in previous studies. For example, Guinée (2002) points to how some studies attempted to use LCA as part of a larger production-function framework and Tukker (2000) set some measures that can help in using LCA as part of a larger environmental impact assessment framework. Moreover, in BS-ISO 14043 it is noted that the interpretation stage can be used to link LCA findings to other environmental management systems to reach more balanced decisions (BSI, 2000).

The availability of weighting tools (such as Eco-points, LEEDS, ATHENA, etc.) can help considerably in setting the various environmental impacts in a single scale that can be linked and integrated easily to different managerial and environmental assessment frameworks.

5.3.3 Inclusion of LCA within conventional decision-making frameworks

There are several sources explaining how LCA can be employed as part of a conventional organisational decision-making framework. Guinée (2002) refers to specific examples where LCA results were linked to conventional technical models (such as Technology Assessment or Substance Flow Analysis) used regularly by some businesses. However, one of the most complex, and well constructed, examples in the precast concrete industry can be found in Marley Eternit[29] at their precast roof tiles and slates production operations.

Marley Eternit was one of the first companies to produce a Building Research Establishment (BRE) certified Environmental Profile in 2001 (Carter and White, 2005). Following the establishment of a robust database on environmental impact information based on LCA, these were linked to specific business objectives and measures used in the industry to improve production, reduce time and costs. The LCA results helped in identifying the main crucial areas associated with increased environmental impacts. These were tackled through the introduction of a range of environmental improvement initiatives at the company, as follows:

[29] This case-study was a prize winning entry in the British Precast Sustainability Best Practice Awards in 2005 at http://www.britishprecast.org/sustainableprecast/downloads/documents/MorefromLessNewsletter3.pdf

- **Substitution of non-renewable materials:** Marley Eternit increased the proportion of recyclable materials and ingredients within their production processes. Several recycling schemes were introduced within the manufacturing process of several of their products (mainly roof tiles).
- **Minimisation of packaging:** Packaging was recognised as a source of significant waste and environmental impact. A packaging reduction and recycling scheme was introduced.
- **Reduction of waste to landfill:** This includes concrete waste (which is being recycled under new parallel initiatives) and a reduction in the amount of processing materials sent to landfills.
- **Energy efficiency initiatives:** These were introduced to a number of production and management activities across the production process.
- **Water use reduction:** This was achieved through the introduction of guidelines on water use and the installation of water recycling systems in a number of factories.
- **Supply chain initiatives:** Marley Eternit influences suppliers to improve performance to help them tackle environmental impacts associated with transportation and improve their environmental profiles.
- **Application of standards on environmental management systems (ISO 14001):** a continuous improvement mechanism was introduced to manage the initiatives employed and manage the environmental management system incorporated.

Moreover, the company is looking at future initiatives; these includes plans to introduce a better process control, more advanced maintenance frameworks, and improved product design (through promoting thinner sections with increased durability). Marley Eternit even developed a 'Green Guide to Roofing' consolidating different operational solutions targeting the minimisation of environmental impacts associated with products. However, Carter and White (2005) admit that marketing and positive publicity have been two of the main objectives behind their efforts.

Although the example does not offer exact information on how and why these initiatives were assessed and approved by the conventional decision-making framework, the example clearly demonstrates how proper problem definition (through the use of LCA) can play a major role in rationalising the integration of environmental improvement measures and conventional organisational frameworks.

5.4 Using creative managerial tools to identify routes to problem-solving

As noted by Zilahy (2004) in section 5.2, managerial and technical continuous improvement tools and techniques can be used to promote and incorporate many of the main environmental improvement measures into organisational frameworks. This section identifies routes to environmental problem-solving by examining literature on known efficiency tools, such as Lean Production, Total Quality Management (TQM), or Quality Function Deployment (QFD). Some information from the precast concrete industry is also used to demonstrate the importance and applicability of the tools examined.

5.4.1 Lean production and environmental problem-solving

Lean thinking is the principle of providing a way to do more with less (less human effort, less equipment, less time, and less space) while coming to provide customers with exactly what they want. Lean production is a concept containing a considerable number of tools and techniques used to reach the end goal of an organisation, many of which have proved to be successful for different industries. Womack and Jones (1997) offer a framework for lean transformation:

- Precisely specify value by specifying products
- Identify the value stream of each product.
- Make value flow without interruptions.
- Let the customer pull value from the producer.
- Pursue perfection (Continuous improvement) through *Kaizen* and *Soikufu*[30].

The steps might seem simple and easy to fulfil. However, to accomplish the requirements of each step effectively, the appropriate monitoring, processing, and problem solving tools need to be employed in each phase (Monden, 1998).

Huovila and Koskela (2000) make a link between a main sustainability principle, which is resource efficiency, and the crucial lean principle of waste (*Muda*[31]) elimination. This dictates that many of the tools and techniques used as part of lean production frameworks

[30] See Glossary.
[31] This Japanese term meaning waste, this term is repeatedly used by different lean production academics and practitioners.

should enable savings in materials and energy. This link was also made by Weizsaker *et al* (1997) in case studies demonstrating the efficiency of lean supply chains in minimising environmental impacts arising from transportation. Moreover, the lean concept of value streaming can substantially help in the elimination of unnecessary and repetitive steps and therefore save costs. This principle, if implemented successfully, can considerably help in removing many of the operational activities consuming energy and generating harmful emissions (CO_2, SO_2, NO_x, VOC, etc.) in precast flooring production.

However, due to the different sets of end-goals for the two principles (sustainable development and lean production), there are several contradictions that can be detected. The concept of lean production implies the elimination of any excess resources, which may include employees. This principally conflicts with the concept of sustainable development and its objectives. One example from the precast concrete industry is found in the use of Just-In-Time (JIT) delivery systems. JIT is a lean-logistics concept that proved to be useful to different supply chain partners in coordination, avoidance of delays in time, elimination of inconsistencies in products' delivery, and communication between upstream and downstream organisations. The principle helps to avoid any disruptions or space problems associated with storage and transportation.

Moreover, JIT has a significant strategic benefit to the concrete industry, the 2001 Movement for Innovation (M4I) report "*Rethinking construction: Concrete Thinking*" (2001) noted that the market loss of concrete to other competitors was due to inconsistencies and under achievement within concrete supply chains (as shown in Figure 5.3). This, in spite of the fact that concrete supply chains are relatively easier to manage, compared to other construction supply chains known to be experiencing significant levels of fragmentation and increased number of partners (Briscoe and Dainty, 2005). This highlights that JIT is vitally important to manufacturers.

Despite the cost and efficiency benefits of JIT, the number and size of site JIT deliveries could be more harmful in terms of environmental impact. As noted in Chapter Four, environmental impacts arising from raw materials transportation are significant.

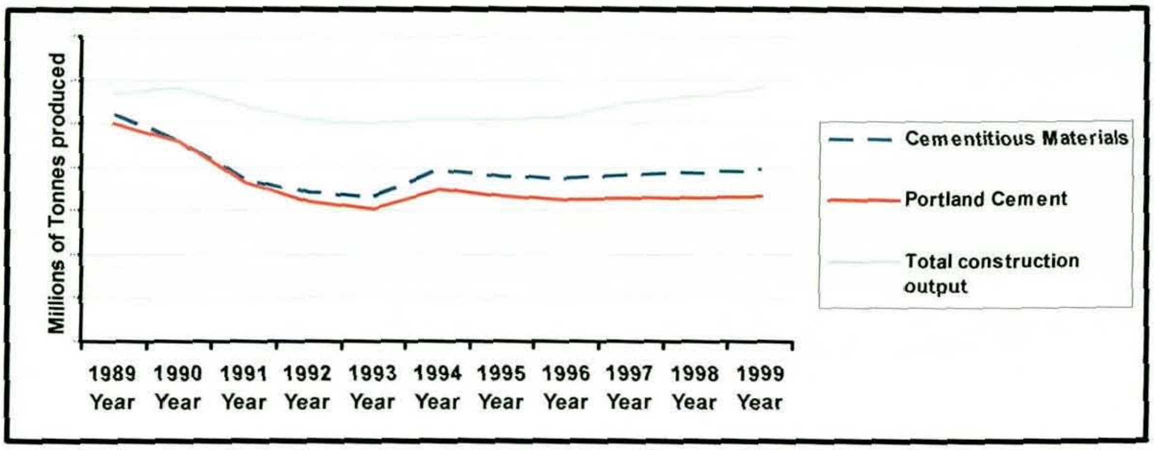


Figure 5.3 Cementitious materials and Portland cement volume trends for Great Britain compared with construction output (M4I, 2001)

5.4.2 Value engineering and environmental problem-solving

Many value engineering and management tools can be employed successfully in addressing and incorporating the concept of environmental improvement within conventional decision-making frameworks in organisations. There are two main examples that can demonstrate this, which are presented below.

The first example uses the LCA methodology within an "Environmental Value Engineering" context. Roudebush (1998) defines Environmental Value Engineering as 'an environmental life cycle assessment methodology that can also be used to assess and compare built environment alternatives'. A measurement unit was developed to assess different products' environmental impact and cost scenarios, this was identified as "EMERGY". EMERGY, as defined by Odum (1996), is all the available energy that was used in the work of making a product and expressed in units of one type of energy. EMERGY is calculated by multiplying input quantities (grams, Joules, or US dollars) by their corresponding transformations. However, it should be noted that there is no evidence that this suggested system is being widely used. Moreover, the tool requires continuous updating of EMERGY values. Nevertheless, other conventional value engineering tools can still account for environmental requirements successfully.

Another value engineering example is found in the use of Quality Function Deployment (QFD). The concept of Green QFD (or GQFD) has become popular in the USA. QFD is a value management methodology that accounts for product quality requirements, environmental impacts, and costs at the product design stage. The methodology requires the development of complex matrices and value hierarchy trees (Bovea and Wang, 2002). The methodology also works successfully with LCA (as a source of environmental impact information). Moreover, the sequence of steps considered in GQFD (these include concept product planning stage, matrix design stage, and decision-making stage) are compatible with conventional decision-making and problem-solving frameworks.

It should be noted that the implementation of any of the problem-solving tools (identified in this section), or sustainability incorporation tools (identified in section 3.3), depends on the manufacturer's organisation. Some of the tools suggested, such as QFD, are used mainly for complex product systems with a substantial level of technical, managerial, and information requirements. The use of such tools in a medium delivery, low technology industry (such as precast production) might not be feasible.

The following table (Table 5.2) summarises the characteristics of these tools.

	Lean Production Tools	**Environmental Engineering Tool**	**Green Quality Function Deployment**
Purpose	Elimination of waste in process (and associated cost and waste)	Compare built environment alternatives. Elimination of impacts and costs.	Compare and detail built environment alternatives. Elimination of impacts and costs.
Expected level of organisational change	Substantial change in processes and capacities in organisations.	Change in products – possible effect on processes and capacities.	Change in products – possible effect on processes and capacities.
Compatibility with problem-solving	Compatible	Compatible	Compatible
Use in industry	Popular concept	Very limited applicability	Popular concept – limited applicability
Compatibility with sustainability	Compatible with a few contradictions.	Compatible	Compatible
Level of sophistication	Simple concept	Sophisticated, but complicated.	Sophisticated, requires a wealth of information.

Table 5.2 Problem-solving tools considered for incorporation of sustainability.

It should be noted that these tools should not necessarily be used individually; these tools can be used as part of a problem-solving framework that may incorporate other useful systems and tools (such as EMS and Environmental Accounting). It is very difficult to depend only on secondary information to make clear preferences between these tools. The primary data collected from the industry should help in identifying the characteristics of the most appropriate tool.

5.5 Conclusion

As explained in Chapter Five, the literature handling environmental improvement application on organisational decision-making frameworks is limited. However, by combining studies from different disciplines tackling the influence of environmental considerations on organisational factors and decision-support, it was possible to build up an understanding of how environmental objectives and requirements may relate to the business's conventional economic and managerial decision-making framework in a business. It should be noted that the issue is more complex given the social impact of introducing such principle. Other social sciences problem-solving tools such as Soft Systems Methodology (SSM) might also prove to be useful and successful in understanding the obstacles and the complexity of the problem.

To understand the chances of improving the precast flooring production business through a structured approach to sustainability, it is necessary to collect primary information on the main environmental impacts. The information collected should help in understanding the depth of the problem and identify the most appropriate solutions and tools available and assess the final influence of environmental improvement criteria (and sustainability criteria) on the business case of precast flooring manufacturers.

CHAPTER SIX: RESULTS, ANALYSIS, FINDINGS, AND FEEDBACK FROM THE LCA STUDY

Chapter Six: Results, analysis, findings, and feedback from LCA Study

This chapter sets out and analyses the major results of the Environmental Profile study carried out for five members of the Precast Flooring Federation (PFF) where primary data, covering the period from January to December 2002[31], on precast hollowcore and precast prestressed beams was collected. The Chapter presents the nine calculated environmental profiles (five environmental profiles for hollowcore and four for prestressed beams, as detailed in Appendix F) along with a generic environmental profile for each of the flooring products. Each of the environmental impact categories considered in the study (totalling 12 categories) was analysed. The study uses the Life Cycle Assessment (LCA) technique in collecting and presenting the information; it also offers an explanation for the results of the environmental profile and links these to specific elements and aspects in production. Specific decision-areas are identified as critical in terms of environmental impact.

References and findings from similar studies in the UK, Europe and North America are used, where appropriate, to explore findings and demonstrate the significance of the results. The chapter also offers findings and feedback for use in the subsequent stages of the study. This feedback comprises the main decision-areas where major environmental impacts occur, and quantified environmental options that can be employed for environmental problem solving.

Companies' names have been anonymised in all sections relating results, analysis and findings; companies are thus referred to as PFF1, PFF2, PFF3, PFF4, and PFF5. The individual factories participating in the study are shown in Table 2.1

[31] Information for PFF3 was collected for the period between April 2003 to March 2004.

6.1 LCA results: Generic Environmental Profiles

The Environmental Profile results for hollowcore and concrete prestressed beams production at the five factories show a significant variation in results (see Appendix F). However, the gate-to-gate environmental profiles were combined to produce the following average generic environmental profiles for hollowcore and precast prestressed beam flooring (Table 6.1). The functional unit used for the generic profiles (below) is one tonne of production.

Impact categories (per 1 tonne of net production)	**Hollowcore**	**Prestressed beams**
Climate Change (kg CO_2 eq.)	23.09	20.82
Acid Deposition (kg SO_2 eq.)	0.255	0.206
Ozone Depletion (kg CFC_{11} eq.)[32]	-	-
Human Air Toxicity (kg TOX)	0.304	0.244
POCP (kg ethene eq.)	0.0118	0.0111
Human water Toxicity (kg TOX)	1.75×10^{-5}	1.91×10^{-5}
Eco-toxicity (m^3 tox)	410.6	361
Eutrophication (kg. PO_4 eq.)	0.0123	0.0117
Fossil Fuel Depletion (TOE)	0.0064	0.0057
Mineral Extraction (tonnes)	1.041	1.03
Water Extraction (litres)	136.6	121.4
Waste Disposal (tonnes)	0.0659	0.0562
Transport (tonne.km)	2.87	3.016
Primary Energy (GJ)	**0.352**	**0.327**

Table 6.1 Generic environmental profiles of hollowcore and prestressed beams

Looking at the generic profiles, it can be seen that there are no significant differences between hollowcore and prestressed beams in many of the impact categories. Indeed the differences between the five environmental profiles of PFF factories (compared with each other) are larger than differences between the hollowcore and prestressed beams generic environmental profiles *per se*.

[32] Due to the almost negligible impacts associated with this category, and due to the abolition of CFC_{11} use in the industry in 2000, it was not possible to include this category. Indeed, most of the recent LCA studies carried out by the BRE do not account for this category.

However, when comparing carbon dioxide emissions (Climate Change impact) for two of the prestressed beams environmental profiles (PFF3 and PFF1), PFF3's CO_2 emissions were nearly 52.3% of those from PFF1 (see Appendix F). The same applies to other impact categories within the PFF3 and PFF1 environmental profiles. It is possible that use of secondary information and standardised conversion factors played a major role in these differences. However, it is clear that these differences are more consistent with factory-specific manufacturing conditions rather than other general product-based criteria.

It should be noted that the environmental profiles were developed using delivered energy information. These criteria would be quite different if primary energy CO_2 emissions information was considered. By including the impact from primary energy generation, some values (notably those associated with electricity) would be around 2.6 times greater, and the difference in the CO_2 emission scores between PFF1 and PFF3 will therefore reduce to about 34%, this is due to the different systems (and types of energy) employed in both factories. The following sections consider each of the LCA categories in turn.

6.2 Detailed LCA results and analysis: Environmental impact categories

Each of the 13 environmental impact categories included in the BRE accredited environmental profiles methodology refers to a specific environmental intervention (burden) with a specific impact on the environment. However, not all these impacts share the same level of effect on earth's eco-system (Dickie and Howard, 2000). It is necessary to thoroughly explore the results associated with these impact categories and identify the main factors that might be associated with these results, therefore some tests were also employed in this section to measure the real impact of LCA results.

6.2.1 Climate Change (CO_2 equivalent emissions)

The calculated averages are 23 kg CO_2 eq. per tonne of Hollowcore and around 21 kg CO_2 eq. per one tonne of prestressed beams. The total CO_2 emission from the five PFF production sites is 8,057 tonnes of CO_2[33]. This is still an insignificant figure in the construction industry; it represents less than 1.4% of the total emissions produced annually

[33] 13,319.2 tonnes of CO_2 if primary energy is considered (office energy is excluded).

by just one major concrete, aggregate, and cement supplier such as CEMEX/ RMC[34]. However, considering that CEMEX/ RMC produces only 47 kg of CO_2 per tonne of production (aggregate, cement, concrete production, and office use energy included), this CO_2 emission score could turn out to be a serious challenge for a major company with a large number of similar production sites. Therefore, more detailed results should be obtained.

6.2.1.1 Differences in carbon dioxide emissions

One of the main issues in the environmental profile results is the broad range in CO_2 emissions between the various manufacturers (Figure 6.1). The highest level of emissions was from PFF1 hollowcore production; recording 29 kg of CO_2 eq. to produce one tonne of hollowcore. The lowest was PFF3 wet-cast prestressed beams (15 kg of CO_2 eq). These differences in factory emission estimations were consistent with variation in type of energy used, casting systems employed, transport systems utilised, and several other measures. In other words, the differences in CO_2 emission values can be explained (at least partly) by the diversity of production technical, managerial, and strategic solutions affecting energy consumption, manufacturing methods, and external/ internal transporting criteria, i.e.:

- **Energy consumption levels:** Most CO_2 emissions in precast production arise directly from energy consumption. There are several factors that affect energy consumption in factories: these are explained in detail at Section 6.5
- **Nature of operations/ unit processes employed:** It should be noted that some manufacturers (such as PFF4) have totally different manufacturing processes where the process takes place at two sites and ready mixed concrete is used in production. Such differences can positively, or negatively, affect the environmental profile.

[34] RMC is a major cement, aggregate, and concrete supplier in the UK. RMC emissions are 581,650 tonnes CO_2 eq taken from 2001 RMC report: http://www.rmc.co.uk/downloads/RMCUKSustainableDevelopmentReport2001.pdf

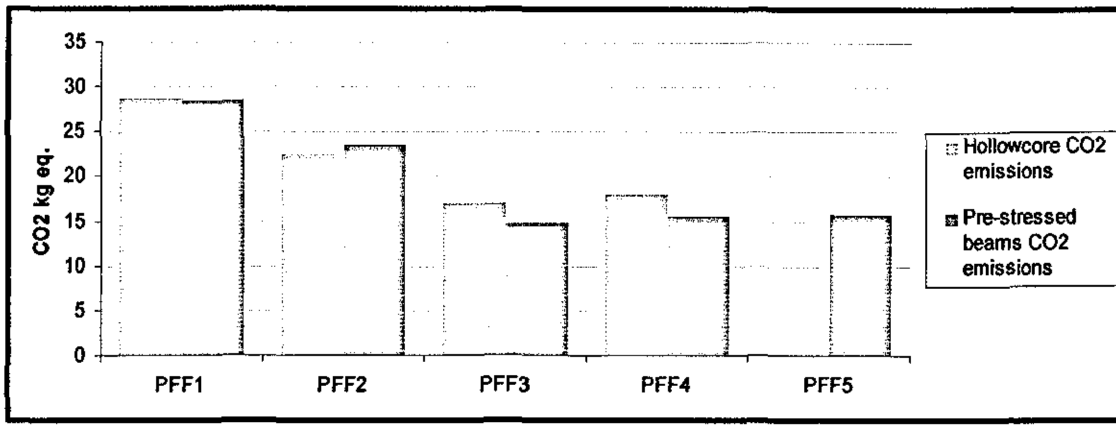


Figure 6.1 CO_2 emissions for prestressed beam and hollowcore (per tonne of production).

6.2.1.2 Climate change impacts breakdown

It is crucial to identify and account for major activities and processes causing CO_2 emissions. Identifying the exact reasons behind climate change impacts is the first step in building an effective strategy to tackle CO_2 emissions. Table 6.2 shows the breakdown for Climate Change emissions (in CO_2 eq.)

	Electricity	Gas oil	Kerosene	Heavy Fuel Oil	Light Fuel Oil	External transport	Total CO_2
Average-Hollowcore	6.63	3.73	1.1	4.66	2.88	4.08	**23.1**
Average-Prestressed beams	6.83	5.08	0.51	2.72	1.68	4.01	**20.8**

Table 6.2 Breakdown of CO_2 emissions (in kg) within generic Environmental Profiles.

These emissions can be classified into three main groups:

- **Emissions associated with electricity consumption:** Electricity is used to operate mixers, extruders and casting machines, hopper/ bullet gantry systems, cranes, offices and laboratories attached to production halls, general lighting, and (for some factories such as PFF2 and PFF3) accelerated curing. If primary energy is considered in the generic profiles, the CO_2 emissions generated by electricity consumption would reach 30% of hollowcore's (33% of prestressed beams') emissions.
- **Emissions associated with fossil fuel oils consumption:** Fossil fuel oils are used to operate mobile plant, lifter stackers and fork lifts, extruders, and boilers heating the

accelerated curing beds. The generic profiles show that 49% of hollowcore and 45% of prestressed beams CO_2 emissions come from consumption of fuel oils.

- **Emissions associated with external transport:** CO_2 emissions from external transport vary significantly from one manufacturer to another (from 1.76 kg CO_2 per tonne of prestressed beams at one factory to 6.19 kg CO_2 per tonne of hollowcore at another). The generic profiles show that 20% of hollowcore (and 21% of prestressed beams) CO_2 emissions are generated by transport of raw materials to factory sites.

It should be noted that this breakdown would be proportionately different if primary energy was incorporated, because greater CO_2 emissions arise from electricity generation (nearly 50% of total CO_2 emissions for the five factories combined). Figure 6.2 provides hollowcore production energy type breakdowns for the PFF manufacturers included.

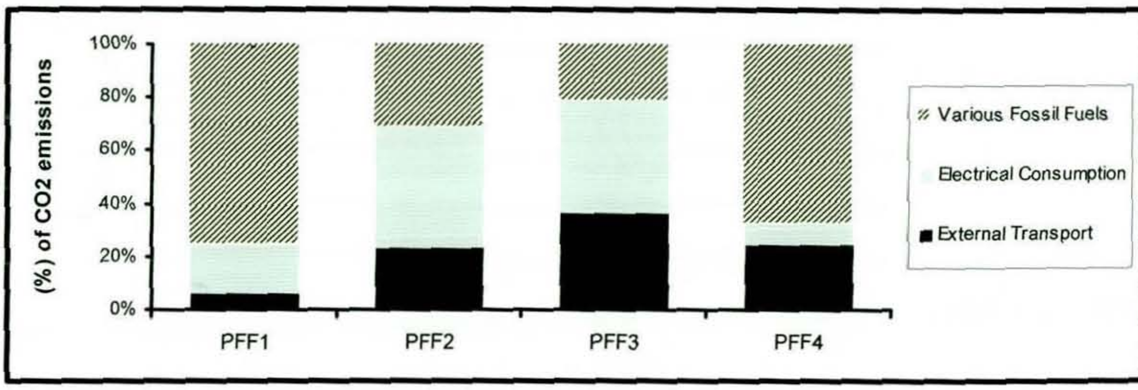


Figure 6.2 CO_2 emissions breakdown (per Energy type) for hollowcore producers.

6.2.2 Other energy-associated impact categories

In addition to climate change, impact categories affected by energy consumption levels include Acid Deposition, Human Air Toxicity, Eutrophication, POCP, and Fossil Fuel Depletion. Table 6.3 presents the profile impacts from hollowcore PFF manufacturers. These impacts are consistent not only with the amount of energy consumed per tonne of production or the type of energy used, but also with transportation measures and impacts.

Impact Category (per 1 tonne)	**PFF1**	**PFF2**	**PFF3**	**PFF4**
Acid Deposition (kg SO_2 eq.)	0.376	0.189	0.147	0.235
Human Air Toxicity (kg TOX)	0.447	0.225	0.174	0.282
POCP (kg Ethene eq.)	0.012	0.013	0.011	0.01
Eutrophication (kg PO_4 eq.)	0.012	0.014	0.013	0.0088
Fossil Fuel Depletion (TOE)	0.00821	0.00587	0.00443	0.00571

Table 6.3 Breakdown of energy-associated impact categories (hollowcore only).

6.2.2.1 Fossil Fuel Depletion (Tonnes of Oil Equivalent – TOE)

This category accounts for the amount of energy consumed (in TOE). It should be noted that the amount of primary energy consumed for electricity is much higher than that for other types of fossil fuel. Indeed, the Climate Change Levy ignores primary energy from different types of fuel oil. Sections 6.4 and 6.5 offer detailed analysis on this category.

6.2.2.2 Acid Deposition (SO_2 equivalent emissions)

Acid deposition values in Table 6.3 are dominated by the amounts of energy consumed. This is evident in PFF1 factory figures. PFF1 consumed the highest level of energy per tonne of production and highest score in Acid Deposition emissions (for both hollowcore and prestressed beams). Figure 6.3 shows how Acid Deposition values seem to be dominated mainly by the overall amount of energy consumed (rather than transportation criteria or type of energy used in the factories).

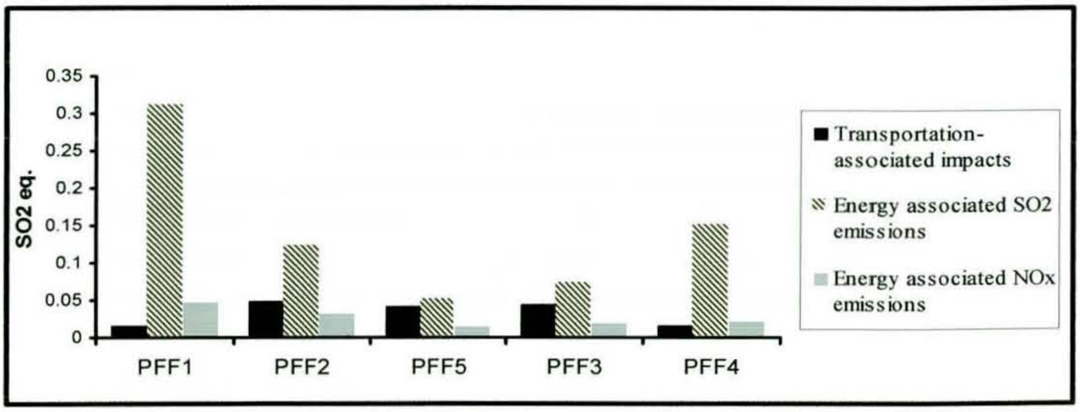


Figure 6.3 Breakdown of Acid Deposition emissions per tonne of prestressed beams production[35].

Figure 6.3 demonstrates how SO_2 emission, caused by the amount of energy consumed, mainly dominates the Acid Deposition impact category. Even if primary energy is considered, the PFF1 score remains the highest. The figure, to some extent, also demonstrates the impact of choice of energy used, in spite of the substantial difference in SO_2 emissions between PFF3 and PFF4, their NO_x emissions are similar. This is due to the higher proportion of NO_x emissions content arising from electricity use at PFF3. This is found again when comparing PFF1 and PFF2 emissions as electricity consumption at PFF2 is proportionally higher than that at PFF1.

[35] The same principle applies for hollowcore production.

6.2.2.3 Human Air Toxicity (TOX. Equivalent emissions)

Human Air Toxicity is also dominated by the amount of energy consumed. This category is largely associated with SO_2 and NO_x emissions (in addition to CO and NMVOC[36]), therefore, levels of Human Air Toxicity will always match that of Acid Deposition.

6.2.2.4 Photochemical Ozone Creation Potential (POCP) – Ethene eq. emissions

This category's impacts are associated mainly with VOC and Methane emissions. Unlike other impact categories mentioned above, POCP impact is not always consistent with energy consumption levels as some types of fuel oils generate nearly four times more VOC compared with that from electricity. Rather, it appears that the major factor determining POCP impacts is transportation. Figure 6.4 demonstrates the proportion of these major impacts per tonne of prestressed beams production.

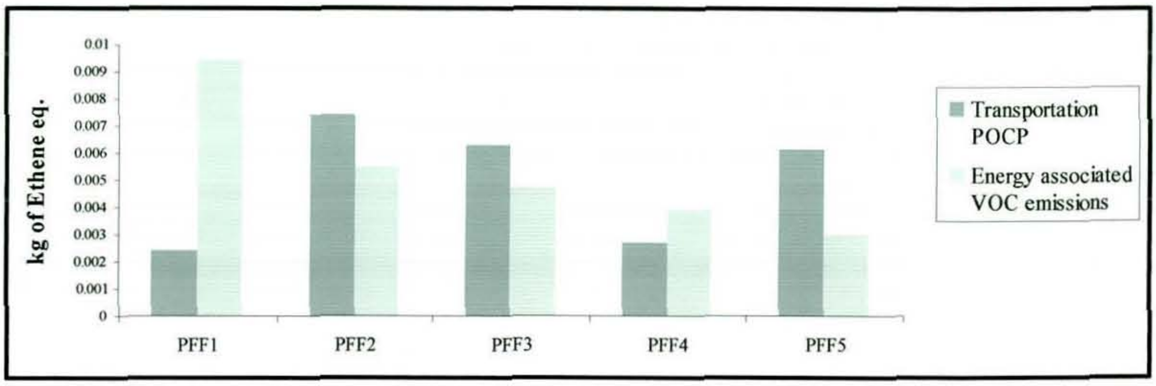


Figure 6.4 Breakdown of POCP emissions per tonne of prestressed beams production (in kilograms of ethene equivalent).

Average energy consumption at PFF1 is significantly higher than that at PFF2, whereas the figures above show that POCP impacts for PFF2 are slightly higher than that at PFF1. This shows how transportation impacts (especially for factories located at a distance from raw material suppliers) can have a substantial influence considering that sourcing distances for PFF2 are slightly longer than that for PFF1.

6.2.2.5 Eutrophication (PO_4 equivalent emissions)

Eutrophication is considered as a water-associated emission category, however, as seen in Figure 6.5, transportation seems to have the dominant impact on Eutrophication. Fossil fuel emissions (especially NO_x and N_2O) also have a major impact on the category.

[36] NMVOC: Non-Methane Volatile Organic Compounds

However, if raw material sourcing distances are short, then the amount and types of energy used will become the most influential factors. It should be noted that if primary energy is considered, most of the impacts will come from factory energy consumption.

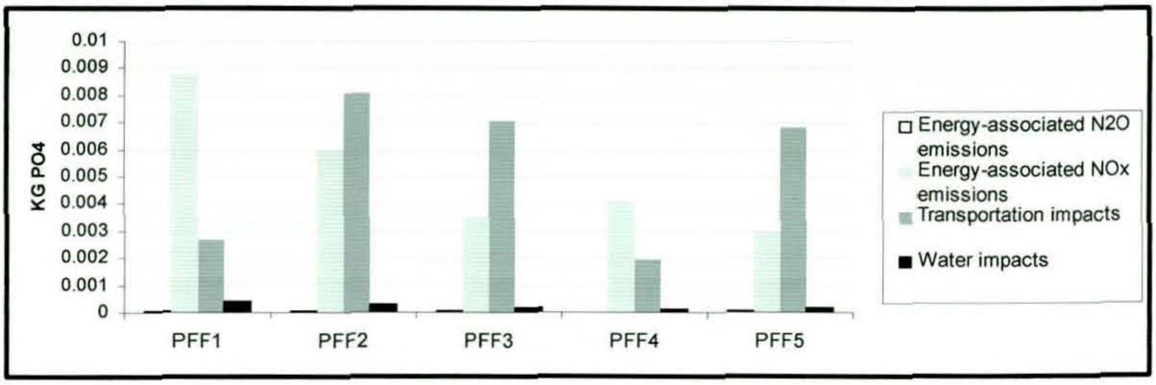


Figure 6.5 Eutrophication emissions (per tonne of prestressed beams production)

6.2.3 Water associated impact categories

The Quality of Life report (DETR, 2000) notes that there are no urgent water affordability concerns. However, water consumption should still be considered as a crucial aspect for a precast organisation aiming to improve its environmental performance.

6.2.3.1 Water Use

Water is an important ingredient in concrete production. In a precast concrete factory, there are several activities that require the use of water. These include the following

- **Concrete Mix:** In addition to aggregates, cement, and admixtures, concrete mixes need water. The amount of water added to the mix depends on several factors such as the required water/cement ratio and concrete consistence (workability). Compared with concrete used for other purposes (in situ or wet-cast products), an extruded precast product mix considers only a small proportion of water, The PFF1 factory consumes around 190 litres of water per 1 tonne of hollowcore produced, yet, information on the concrete mix employed for most PFF1 products indicates that only around 36 litres (per tonne of production) added to the mix (the mix should also contain water held within the sourced aggregates).
- **Industrial activities:** Even if the main product is extruded or slip-formed, water is always used in several other industrial activities, such as customising products.

- **Washing and Cleaning:** Precast production halls require constant cleaning to maintain safe conditions for good quality production. This process consumes a considerable amount of water every day.
- **Individual workers' use of water:** Employees working on production processes, or in other tiers of production management, will usually consume water in drinking, washing and WC facilities. In some of the factories included in the study, operatives take showers following the end of their shifts.

However, these are not the only factors affecting water consumption levels in PFF members' factories (see Figure 6.6). Other reasons, such as levels of customisation or the amount of concrete cast and wasted, can have a major effect on variations in average water consumption patterns in a precast factory.

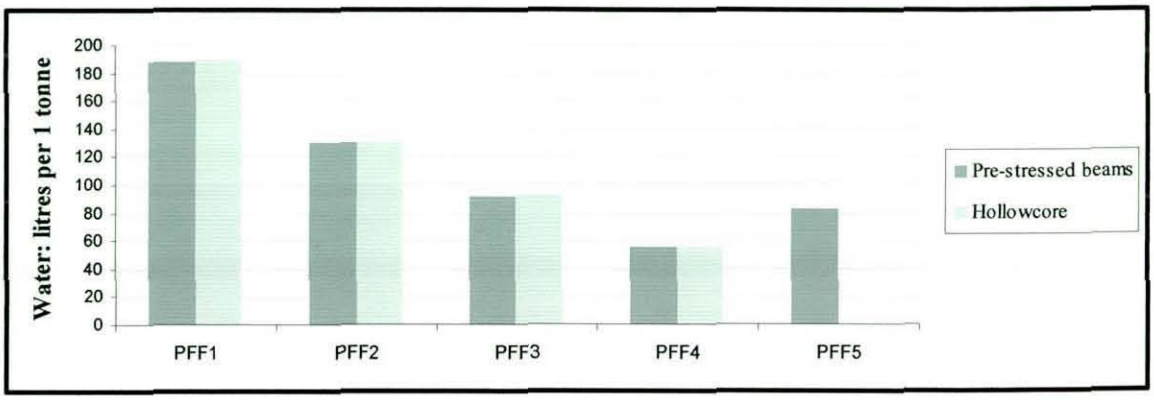


Figure 6.6 Water consumption levels for PFF manufacturers per tonne of production.

The figures reveal substantial differences in water consumption between PFF1 and PFF3/ PFF4, one main reason for this is the water recycling facility installed at the PFF3 factory; the water consumption rate at PFF3 fell considerably during the last two months in 2002 (by 40-43%). Otherwise, the water consumption at PFF3 would have surpassed 100 litres per tonne of production.

Another reason is that the concrete production processes at the factories included in the study differ from one manufacturer to another. Unfortunately, the water consumption figures provided by some manufacturers may not have included the actual amount of water used directly in the mix. This amount was in some instances estimated by some of the manufacturers (based on mix standards) and verified by their management. Some important elements, such as the moisture content in aggregates used in each batch, were not considered.

The water consumption patterns (Figure 6.6) are very similar to CO_2 emission levels (see Figure 6.1); there are several possible reasons for such consistency. If a manufacturer carries out a great deal of product customisation operations, the amount of water used in sawing, patching, and re-casting activities will obviously increase. Customisation of production can also lead to more concrete waste (See section 6.2.5), which will escalate CO_2 emission levels considerably. Moreover, errors in production tonnage figures provided by manufacturers may result in a consistency being found where in fact one does not exist.

6.2.3.2 Other water associated impacts

These include impacts which are classified as causing a direct environmental effect on water released by the factory. These include Water Extraction, Human Air Toxicity, Eco-toxicity, and Eutrophication. Unfortunately, it was not possible to collect primary information from each production site for the amount (or qualitative analysis) of water discharged. The method employed to estimate the amount of discharged water was based on primary information from one site (PFF3). Information from the hazardous Substances tables provided at the Environment Agency website[37] were used to estimate the content of released water.

However, as long as precast companies are complying with regulations on water toxicity and water discharge, water-associated impact categories (mentioned above) should not be considered as high-priority categories[38]. Unlike the chemical industries or steel and cement manufacturing, precast concrete production is a low-technology industry sector with a relatively low amount of hazardous material used or produced, thus, it represents less of an environmental threat.

6.2.4 Mineral extraction

This category is directly associated with raw materials use and consumption. Indeed, it is also associated with the conventional business and productivity factors considered by the organisation, including measures such as efficiency, logistics, and supply chain issues. Understanding the environmental impacts associated with such measures is important.

[37] Refer The Dangerous Substances Directive: http://www.environment-agency.gov.uk/yourenv/eff/water/213902/290690/290939/?version=1&lang=_e

[38] This principle was established during LCA calculations through contacts with BRE experts.

The Mineral Extraction Category, also known as Biotic Depletion, accounts for the amount of mineral material (mostly raw) extracted from the ground. It should be noted that the extraction of minerals for construction in the UK is a politically high profile topic, however minerals (including aggregates) are not considered to be scarce.

The average Mineral Extraction (per tonne of production) in the Generic Profile is 1.04 tonnes for hollowcore and 1.03 tonnes for prestressed beams. However, it should be noted that some specific streams of concrete waste, such as waste-by-design, were not considered in the analysis (see section 2.3.5). Waste by depth also has an effect on this category (especially for hollowcore). The levels of mineral extraction are explored and analysed further in Section 6.3.

6.2.5 Industrial waste (waste disposal)

The Waste Disposal category usually accounts for all different types of waste being removed (either to landfill, incineration, recycling facilities, etc.). Even excluding the concrete waste-by-design category, concrete waste still represents most of the industrial waste for all manufacturers (see Figure 6.7). It was possible, through a waste survey, to develop a better understanding of the various concrete waste streams within prestressed beams and hollowcore production (refer section 2.3.5).

Information from the PFF manufacturers identifies several streams and types of waste, including general rubbish, hazardous waste, steel, and concrete waste.

General rubbish usually includes a variety of consumables such as packages, stacking timber, work gloves, spilled aggregate, paper, etc. This waste is usually taken to landfill. Another waste category is hazardous waste; waste is hazardous when it contains substances or has properties that might make it harmful to human health or the environment (Environment Agency, 2004). These include items such as waste oil, contaminated aggregates, etc. During the data collection for this research no records of disposed contaminated aggregates were found in 2002. However, two manufacturers did provide records on waste oil. Another stream of waste is waste steel, the amount of which would usually vary in accordance with the amount of concrete damaged and levels of customisation (affecting steel cut-offs). Steel waste is usually sent for recycling.

Most of the waste reported was concrete waste (63% total waste)[39]. The waste survey results meant that the information on concrete waste can be considered as more reliable than that for other streams. This waste is usually sent for recycling. However, it should be noted that concrete recycling does not take concrete back to its original status; waste concrete is usually crushed and then procured by haulage contractors to be used as hardcore in roads (and in similar applications). Recycled concrete reuse is being explored by manufacturers, however there are several difficulties (see Chapter Nine).

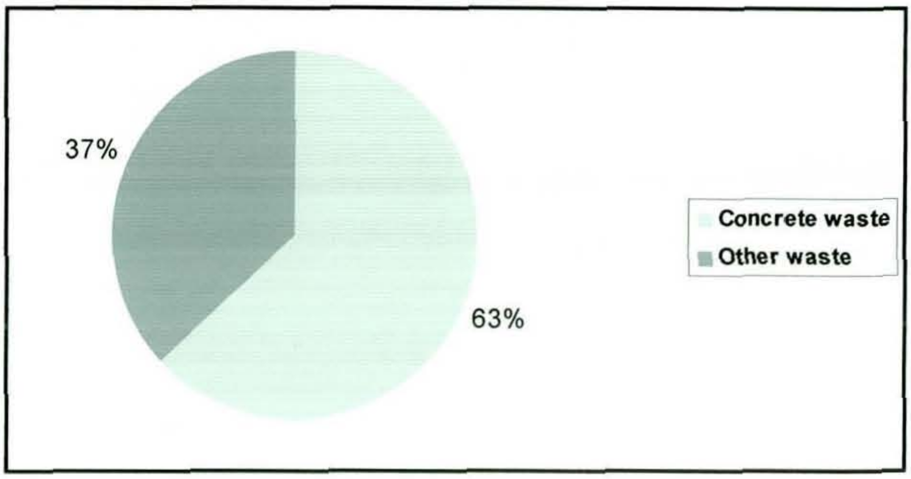


Figure 6.7 Dominance of concrete waste at PFF factories (Hollowcore only).

To explain the major factors affecting concrete waste generation, it is important to understand and account for the different concrete streams in precast prestressed flooring manufacture. These include the following (see Figure 6.8):

- **Waste-by-design:** The survey revealed that most concrete waste is generated from hollowcore concrete portions cut and removed to achieve specific bespoke product designs (e.g. box-outs, splayed, shaped ends, etc.). Results from PFF1 show this clearly, while estimations by the PFF2 Quality Manager prove that most of the concrete waste comes from customisation. Unfortunately, this stream of waste was exempt from the environmental profiles shown in Appendix F. It should be noted that the waste-by-design from prestressed beams is not as significant as it is in hollowcore production, this is due to the size and nature of beams (as standardised products).
- **Concrete remaining in hoppers and casting machines:** These amounts are not usually substantial. Through experience, manufacturers have been able to reduce these amounts to a minimum. Estimations from PFF1 and PFF2 reveal that this

[39] It should be noted that concrete waste-by-design was excluded in LCA profile calculations.

amount is between 0.29 to 0.3 tonnes per bed (30 to 75 tonnes) of production, other manufacturers estimate the amount to be zero or simply '*very small*'. There are several factors affecting this waste; other than judgements and capabilities of manufacturers to minimise it, this amount is affected by job and cast arrangements, capacity of extruder hoppers and bullets holding the wet concrete, and the differences between various casts and concrete mixes prepared at the same time. Some manufacturers, such as PFF3, employ a similar mix for most hollowcore and prestressed beam casts, which reduces the waste in the hopper.

- **Discarded cast portions:** There are several factors that cause damage and waste during and after the casting process (see Appendix G). It should be noted that levels of prestressed beams and hollowcore wastes in this category are extremely variable. Factors affecting this category are level of customisation, efficiency of the extruders, quality of the casting bed, production staff issues, etc.
- **Units scrapped at the stockyards:** These are the elements failing to meet specifications and elements damaged during transportation within the factory area. The reasons for such waste include damage during handling, accidents, etc.
- **Site Rejects:** The amount of site rejects is not usually high, figures from PFF1 and PFF2 estimate this amount to be zero to 1% (hollowcore and prestressed beams).

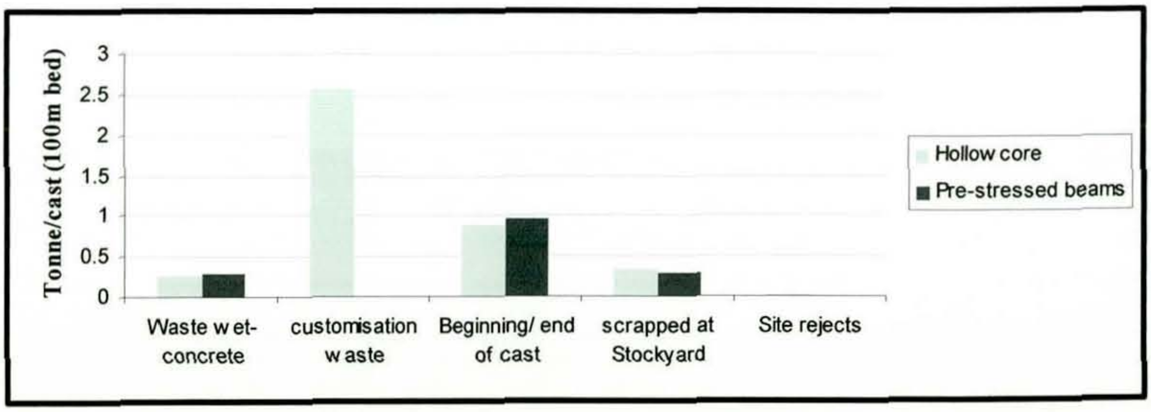


Figure 6.8 Graph demonstrating average concrete wastes at PFF1 (2004).

6.2.6 Transportation-associated impacts

Transportation affects six main impact categories; these include Climate Change, Acid Deposition, POCP, Eutrophication, Human Air Toxicity, and Fossil Fuel Depletion (Howard *et al*, 1999). In addition to these, there is a separate Transportation impact (measured in tonne.km) that indicatively reflects local transport pollution, congestion, noise, dust and discomfort to people affected. Transportation impacts have a considerable effect on the total environmental profile calculated. The influence of transportation was as follows:

- Transportation impacts represent around 20% of CO_2 emissions for Hollowcore and 21% for Prestressed beams.
- Transportation impacts represent around 19% of Acid Deposition impacts for Hollowcore and 23% for Prestressed beams.
- Transportation impacts represent around 46% of Eutrophication impacts for hollowcore and 51% for prestressed beams.
- Transportation impacts represent around 18% of Human Air Toxicity impact for hollowcore and 23% for prestressed beams.
- Transportation impacts represent around 23% of Fossil Fuel Depletion impacts for hollowcore and 24% for prestressed beams.
- Transportation impacts represent around 46% of POCP impacts for hollowcore impacts and 50% for prestressed beams.

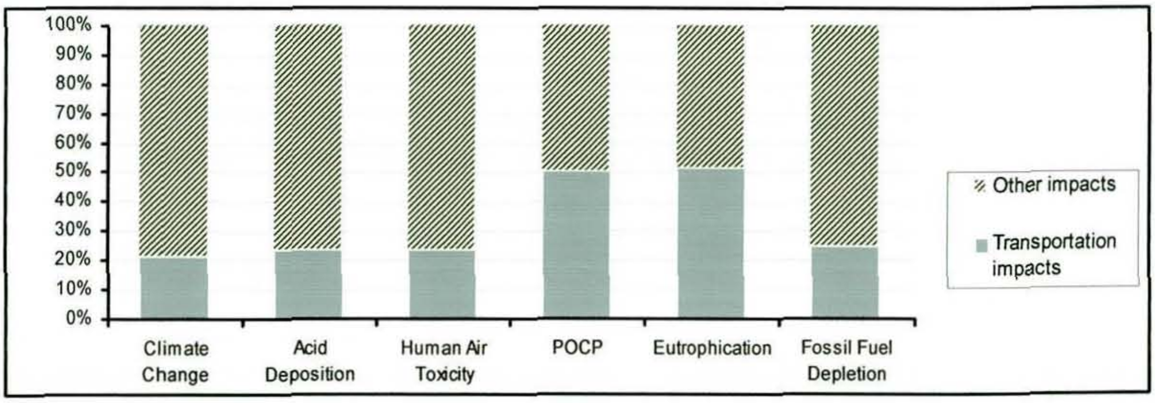


Figure 6.9 Transportation contributions to the generic environmental profile (Prestressed beams).

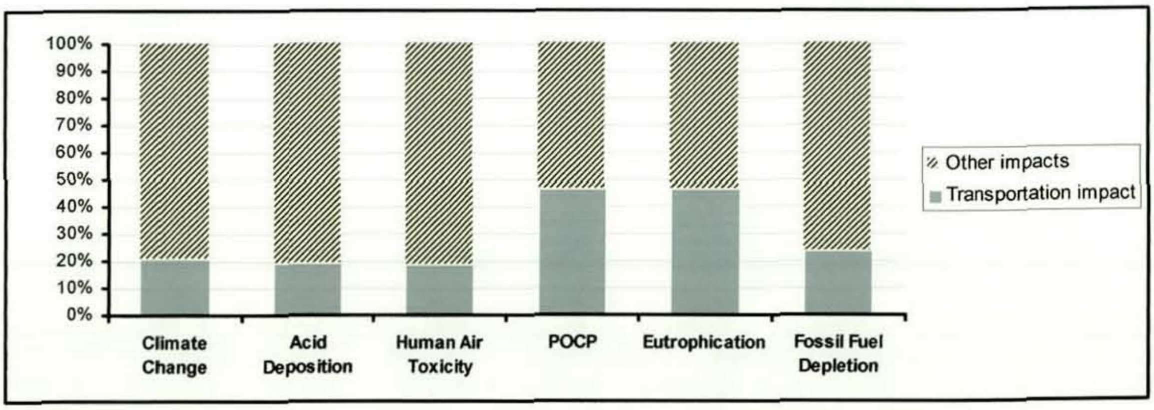


Figure 6.10 Transportation contributions to the generic environmental profile (Hollowcore).

Figures 6.9 and 6.10 reveal the importance of transportation and logistic measures in shaping the environmental profiles of hollowcore and prestressed beams. The influence of transportation on various impact categories is significant. However, this impact varies from one manufacturer to another. Tables 6.4 and 6.5 summarise the transportation impacts as percentages of the total impact categories for prestressed beams and hollowcore.

Company	Climate change	Acid Deposition	Human Air Toxicity	POCP	Eutrophication	Fossil Fuel Depletion
PFF1	6.13	4.34	4.25	20.25	22.5	5.51
PFF2	22.13	23.83	24.13	57.46	56.02	16.94
PFF3	30.67	31.88	31.5	66.95	64.18	23.95
PFF4	20.4	8.56	8.98	34	31.6	19.33
PFF5	28.16	37.37	38	61.61	68.5	23.62
weighted Average	21%	23%	23%	50%	51%	24%

Table 6.4 Transportation impacts as percentages (%) of total environmental impact categories (prestressed beams).

Company	Climate change	Acid Deposition	Human Air Toxicity	POCP	Eutrophication	Fossil Fuel Depletion
PFF1	6.25	4.41	4.33	20.75	23.04	6.73
PFF2	23.42	25.82	25.87	57.77	58.64	27.77
PFF3	36.45	35.65	34.77	71.82	68.8	42.89
PFF4	24.35	11.67	12.17	45.5	44.63	24.94
weighted Average	20%	19%	18%	46%	46%	23%

Table 6.5 Transportation impacts as percentages (%) of total environmental impact categories (hollowcore).

The figures in Tables 6.4 and 6.5 appear to vary widely. However, given that these are percentages of the total emissions at each of the five factories, and given the different supply chain arrangements for each of these factories, these substantial variations seem to be reasonable.

6.2.6.1 Aggregate transportation impacts

Aggregate is the main ingredient (in terms of mass) in concrete, comprising around 70 to 85% of a concrete mix (see Figure 6.11). Therefore, one can presume that most of the raw material transportation impacts come from aggregate supplies. The PFF information reveals that coarse and fine aggregate in total represented 83% of materials sourced and used for hollowcore production (80% for prestressed beams). However, Tables 6.6 and 6.7 show that impacts arising from aggregate transport do not represent 83% of the total transportation impacts. At PFF1, hollowcore transport-associated impacts for aggregate are about 59% of total transportation impacts, at PFF3 it is less than 43%[40], while at PFF2 it is 62%. This is due to the influence of travel distances between specific aggregate suppliers and PFF manufacturers' factories.

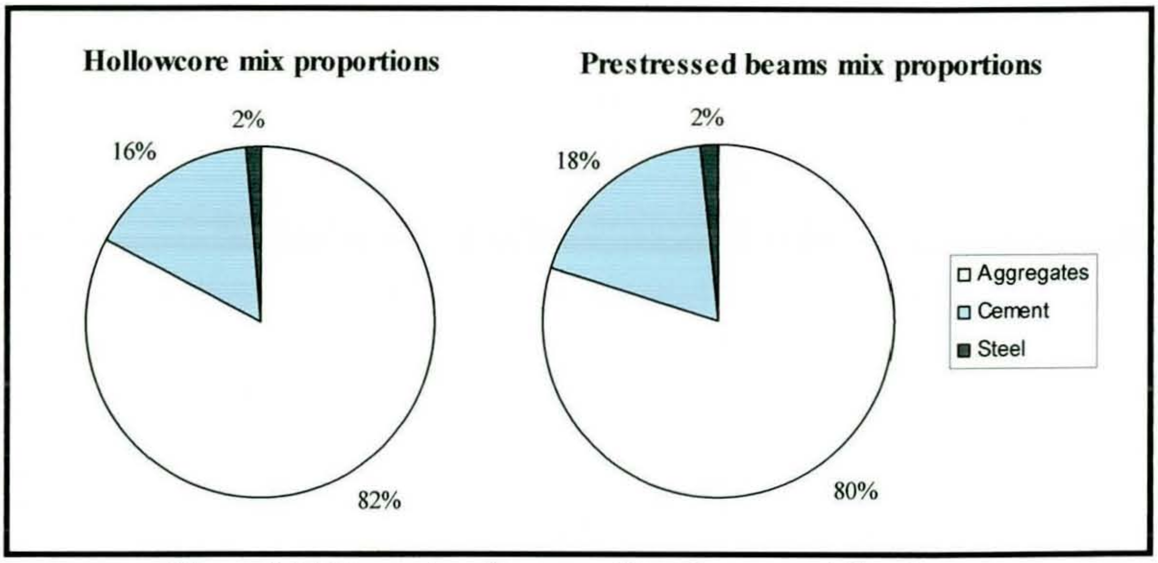


Figure 6.11 Concrete mix proportions for precast flooring.

6.2.6.2 Cement transportation impacts

Cement is the second main ingredient in a concrete mix (see Figure 6.11). The amount of cement used by the five factories included in the study was around 16% of the total raw materials sourced for hollowcore[41] (around 18% for prestressed beam). Tables 6.6 and 6.7 show that the proportion of transportation impacts from cement is relatively higher than that for aggregates in the generic profile. This is mainly because the average distance for cement supplied is 48 to 57 km further than the average distance travelled by aggregate supplies (considering that numerous aggregate journey distances are taken as 0 to 0.5 km due to quarries being on the same manufacturing sites). This has raised cement-associated impacts considerably. Another reason is the amount (tonnes) of cement and aggregate that can be supplied to factories in one delivery load, the maximum amount of cement that can be supplied in one delivery is slightly less than that of aggregate. These factors can disproportionately increase the influence of cement on transportation impacts to levels as much as 47% of the total transportation impacts (PFF3 Hollowcore). This makes cement-

[40] Considering road impacts only.
[41] Water is not included.

associated road transportation impacts at PFF3 higher than aggregate-associated road transport impacts. The percentages for PFF1 and PFF2 are also high (22% and 28% respectively).

6.2.6.3 Steel transportation impacts

The amount of steel used by PFF manufacturers in 2002 represented less than 1.5% of the total raw materials' weight. Despite this, Tables 6.6 and 6.7 show that the transportation impact arising from the procurement and transport of pre-stressing strands can be significant. Wire transport usually requires relatively greater space and different handling. The amount of aggregate (in mass) that can be supplied in one delivery is 1.2 times greater than that for pre-stressing wire. Moreover, the distances for steel transport are usually very lengthy. Some PFF manufacturers import steel from overseas, notably Spain and Italy. Due to an increase in UK steel and pre-stressing wire prices in 2004, it is expected that precast manufacturers will seek cheaper wire from within and outside the UK.

However, it should be noted that for most manufacturers, this will not have any considerable impact on the environmental profile. This is mainly due to its small proportion in the concrete mix (See Figure 6.11). Steel transport-associated CO_2 impacts represent no more than 17% of total transportation CO_2 impacts at PFF1 (11% at PFF2 and PFF3, and 16% at PFF5). Impacts from cement and aggregate transport are far more significant.

	Proportion by mass	Sourcing distance by road (km)	Trucks load capacity (tonnes)	Contribution to total transportation impacts
Aggregates	82.7%	20.3	23.8	52.3%
Cement	15.8%	68	23.6	29.1%
Steel	1.5%	284	19.4	18.6%

Table 6.6 Details on materials sourced for the manufacture of hollowcore.

	Proportion by mass	Sourcing distance by road (km)	Trucks load capacity (tonnes)	Contribution to total transportation impacts
Aggregates	79.8%	23	23.8	48%
Cement	18.4%	80	23.6	34.5%
Steel	1.8%	243	19.4	17.5%

Table 6.7 Details on materials sourced for the manufacture of prestressed beam.

6.3 LCA Analysis: Assessing environmental impacts data through comparisons with other studies and results

Prior to the identification of the most influential environmental impact categories in the profiles, the environmental profile results obtained are assessed and tested against results from previous studies. In addition to the identification of significance in environmental impact results received, the comparisons can help considerably in detecting abnormalities in the results received and established the applicability of study findings to other factories in the UK and elsewhere.

6.3.1 Comparison with other environmental profiles from similar studies

The generic environmental profile figures (given in table 6.1) cannot be compared directly to similar studies carried out abroad because none of these were based on complete gate-to-gate environmental profiles accounting for all 13 environmental impact categories considered in the BRE methodology. However, it was possible to identify two studies offering results that can be used to conduct a comparison, the first uses figures from an Environmental Product Declaration (EPD), and the other includes CO_2 emissions and energy fossil fuel depletion scores derived from two European studies on hollowcore. On a positive note, the profiles in these studies were also based on *delivered energy*, which does enhance their value for comparison.

Table 6.8 provides figures taken from an EPD for hollowcore manufactured in Sweden, the factory belongs to the European precast concrete manufacturer Consolis Ltd (Alexander *et al*, 2003).

Impact Categories (Gate-to-gate) Consolis- Sweden (1 tonne of Hollowcore)		**Generic Profiles for PFF members** (1 tonne of Hollowcore)
Climate Change (CO_2 eq.)	24.21	23.09
Acid Deposition (SO_2 eq.)	0.121	0.255
Human Air Toxicity (kg TOX)	0.146	0.304
Fossil Fuel Depletion (TOE)	0.00954	0.0064

Table 6.8 Environmental profile categories developed from an EPD (Alexander *et al*, 2003), compared to PFF generic profile from Table 6.1 (Hollowcore).

Using the PFF generic profile for comparison, it appears that the Consolis CO_2 emission score closely matches the PFF CO_2 generic emissions level (with less than a 5% difference).

Differences in the figures for Acid Deposition and Human Air Toxicity may at first seem alarming: the PFF generic profile levels are more than double that of the Consolis EPD. However, when comparing the Consolis study profile to the profile of one of the manufacturers (PFF2)[42], it was found that differences in Acid Deposition and Human Air Toxicity scores between Consolis and PFF2 (see Appendix F) are about 1.6 and 1.5 times respectively. This is due to the fact that PFF2 relies more on electricity (electricity generates more SO_2 and NO_x emissions than fossil fuel oil) than the Consolis factory.

When checking Fossil Fuel Depletion (energy consumption) levels for Consolis against the generic PFF profiles, it was found that the Consolis energy consumption levels exceed the PFF generic profile level by nearly 1.2 times. It was not possible to explain this, however, it is possible that the Consolis figure includes adjacent offices' and halls' energy consumption, which as far as possible have been excluded from the PFF study. The colder climate in Sweden can also have an impact.

Other factors that might affect CO_2, Acid deposition, and Fossil Fuel Depletion comparisons are the study boundaries and upstream /downstream environmental gains and losses identified by the different studies. It should be noted that the literature reveals some reservations about comparisons between studies with different backgrounds. Milne and Reardon (2004) note that different studies will have various interpretations for a product's embodied energy. Moreover, Edwards (2004) referred to the difficulty (and sometimes unreliability) of comparing figures from different parts of the world.

[42] PFF2 was chosen for comparison with Consolis due to similarity in CO2 emissions (See Appendix F).

The other example for comparison is derived from two studies, both covering hollowcore production. The first is a LCA cradle-to-grave study carried out by a Dutch environmental institute -CREM (Fluitman and DeLange, 1996). The profile was developed for 1 m^2 of hollowcore (mass 266.94 kg/m^2). See Table 6.9.

Impact Categories (Cradle-to-grave) (Fluitman and DeLange, 1996)	
Climate Change (CO_2 eq.)	55.2
Acid Deposition (SO_2 eq.)	0.252
Human Toxicity (kg TOX)	0.318
Fossil Fuel Depletion (MJ)	461
Eutrophication (PO_4 Kg)	0.0356

Table 6.9 Environmental profile for 1m^2 of hollowcore (Fluitman and DeLange, 1996).

The figures (above) were converted to represent a profile for 1 tonne of hollowcore production, as below (See Table 6.10).

Impact Categories (Cradle-to-grave) (Fluitman and DeLange, 1996)	
Climate Change (CO_2 eq.)	206.79
Acid Deposition (SO_2 eq.)	0.944
Human Toxicity (kg TOX)	1.19
Fossil Fuel Depletion (TOE)	0.04127
Eutrophication (PO_4 Kg)	0.1333

Table 6.10 Environmental profile for 1 tonne of hollowcore (derived from Table 6.9).

The second study is a breakdown (in percentages) for CO_2 emissions and energy consumption through the various life cycle stages of hollowcore. The breakdown was presented in a paper by Vares & Hakkinen (1999) – as shown in Table 6.11.

CO_2 emissions breakdown through hollowcore Life Cycle (Vares and Hakkinen, 1998)		
Production stages	**(%) of total CO_2 emission**	**(%) of total Fossil fuels**
Cement Manufacture	79	63
Transport of ingredients	3	4
Hollowcore production	8	15
Other activities	10	18

Table 6.11 Impacts breakdown for hollowcore life cycle (Vares and Hakkinen, 1998).

Taking the results of the first study and the details from the second study (Figure 6.12), it is possible to make estimations for emissions associated with hollowcore production and raw material transport (11% of 206.79 kg of CO_2 eq.). The estimated CO_2 gate-to-gate emission rate is 22.75 kg of CO_2 eq. per 1 tonne of hollowcore produced. Likewise, the estimated gate-to-gate Fossil Fuel Depletion is 0.00784 TOE.

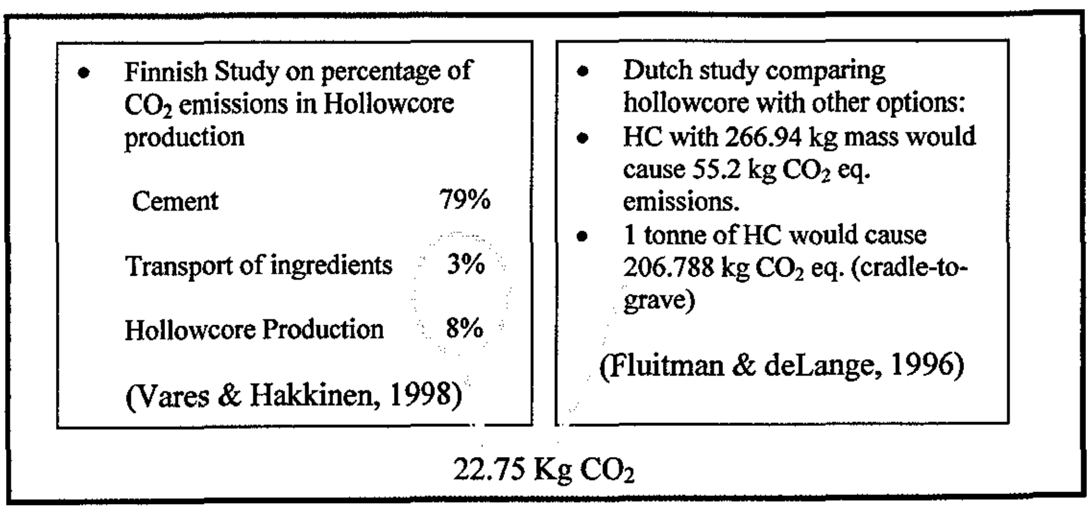


Figure 6.12 Deriving gate-to-gate CO_2 emissions from two hollowcore studies.

When comparing these two figures to the PFF generic profile scores (delivered energy), it appears that the CO_2 emission at the PFF generic environmental profile (23.09 Kg CO_2 eq) is very similar to the derived CO_2 emission (22.75 Kg CO_2 eq). On the other hand, the generic profile fossil fuel depletion score in this study (0.0064 TOE) is 18% lower than the derived fossil fuel consumption figure in the Dutch study (0.0078 TOE).

These two comparisons show clearly that emission levels for hollowcore (and possibly for prestressed beams) are similar in most precast flooring production factories. This obviously implies that many of the findings established in the PFF study can be applied to other manufacturers in Europe. However, additional data were required for comparison with the PFF generic energy consumption average and these are presented below.

6.3.2 Energy consumption – compared to European studies

Considering that most emissions arise from energy use, it is necessary to look specifically at energy consumption patterns in the study and compare them with other results from earlier studies. Unfortunately, it was not possible to obtain studies with sufficient detail to carry out a comprehensive comparison. Figures were collected from a number of Nordic studies exploring precast manufacture energy consumption: these are compared with figures from PFF1, PFF2, and PFF3 (see Table 6.12). The figures for PFF1, PFF2, and PFF3 appear to fall within the range given by the different studies, but there remains some concern regarding the relatively high consumption levels at PFF1. The range in energy consumption averages from the European studies is wide; contacts with some of the authors reveal that this is due to the nature, mass and density of products manufactured, climate, and the research data collection methodology. This also demonstrates the challenge of obtaining accurate international results in this field.

Type of product	Averages, ranges (MJ/m^3)	Type of curing energy	Study/ Source
Precast elements	790 (400-1700)	Electric/ fuel oils	Asumnaa, 1998
Mixed Plants	580 (300-1500)	Electric/ fuel oils	Asumnaa, 1998
Precast plant (General)	743	Unknown	RTT- Finland, 1998
Hollowcore	1113	Unknown	Punkki, 2001
Hollowcore	851	Fuel Oil (delivered energy)	Consolis EPD: Addtek, 2000
Hollowcore	968	Fuel Oil	PFF1 Profile, 2002
Hollowcore	469	Electric	PFF3 Profile, 2002
Hollowcore	800	Electric	PFF2 Profile, 2002

Table 6.12 'Delivered Energy' consumption averages for factories[43]

NB: Contacts with practitioners responsible for the first study (Asumnaa, 1998) reveal that the site office energy was not included in their figures.

[43] Products' density for the 3rd, 4th, and 5th averages was estimated to be 2.3 tonnes/m^3

6.3.3 Mineral Extraction levels – compared with other studies

The average Mineral Extraction amount in the generic profile is 1.04 tonnes for hollowcore and 1.03 tonnes for prestressed beams (considering aggregates only). Unfortunately, it was not possible to compare this amount (of mineral extraction and waste potential) with any of the established BRE profiles (due to the lack of published BRE gate-to-gate profiles). However, figures were obtained from some European studies for precast hollowcore manufacturers; these will be used for comparison purposes.

Raw materials (kg)	Bogeskar *et al*, 2002. (Norway)	Addtek, 2000. (Sweden)	CREM 1996. (Netherlands)[44]	PFF Hollowcore profile
Coarse Aggregate	344.34	210	455.32	470
Fine Aggregate	443.374	560	502.12	391
Steel	18.07	63[45]	12.06	15.6
Other materials (PFA, or limestone from other upstream activities	350.6	260	168.15	164
Total material & Mineral Extraction	1,156.4	1,093	1,137.65	1,040.6
Net Production	1000	1000	1000	1000
Solid Waste/ loss	156.4	93	137.65	40.6

Table 6.13 Mineral Extraction (per 1 tonne of hollowcore produced) for PFF manufacturers versus European manufacturers (derived from: Bogeskar et al, 2002; Addtek, 2000; Fluitman and deLange, 1996)[46].

Table 6.13 above should not be taken as robust evidence that the PFF manufacturers' Mineral Extraction rate is lower than that found in European studies. There are some specific limitations in the PFF study that did not allow for a complete mineral extraction/ industrial waste calculation, as below:

- Some specific streams of concrete waste, such as waste-by-design, were not considered. This can have a considerable impact on Mineral Extraction per tonne of

[44] Fluitman and DeLange (1996), raw material information was derived from hollowcore concrete mix with a similar density.
[45] Steel values include scrap steel, iron ore, and other waste in iron ore mines and steel production (upsteam).
[46] It was not possible to find studies accounting for prestressed beams profiles.

production as waste-by-design is considerable in Hollowcore production (See Figure 6.8).

- The European figures were taken from EPDs and cradle-to-gate studies. On the other hand, the PFF figures are based on a gate-to-gate study. Some upstream industrial wastes groups, mainly from aggregate and cement production, are not included in PFF data.
- The amount of aggregates recorded in PFF manufacturers' accounts is affected by the amount of water (and moisture) contained within the material as delivered to the manufacturer. It was not possible to verify whether the European studies above were subject to the same issue.

The hollowcore mineral extraction figure (1.041 tonnes) was compared with results from another cradle-to-site LCA study on effects of Pulverised Fly Ash (PFA) on concrete environmental profiles using *SimaPro* (Higgins *et al,* 2000). The estimated Mineral Extraction value (for concrete with no PFA content) was 1.048 tonnes, matching the amount provided in the PFF generic profile.

6.4 Analysis and discussion of LCA results: Major environmental impact categories

In order to identify the major environmental impacts and measure all the impact categories on one scale, the BRE's Eco-point system – designed specifically to work with the BRE LCA methodology – was used (section 6.4.1). As explained earlier in Section 5.3.2, this scaling system offers quantified measures for each of the environmental profile categories based on its significance and impact on the environment (Dickie and Howard, 2000).

6.4.1 Use of the Eco-point Score

The Eco-points score is one of several available tools to help manufacturers focus on specific elements, rather than targeting all the categories and aspects contained in an Environmental Profile. The Eco-point score was employed in this study to identify the major environmental impacts associated with hollowcore and prestressed beams production (See Appendix C – section 6.1 for more information on Eco-points).

To give an indication to the value of an Eco-point, the results at Table 6.14 can be compared with the impacts caused by 1 UK citizen per annum (which is 100 Eco-points). It should be noted that the scores below are per 1 tonne of net production.

Impact categories (per 1 tonne of production)	**Hollowcore**	**Prestressed beams**
Climate Change	0.0669	0.0604
Acid Deposition	0.0217	0.0175
Ozone Depletion	-	-
Human Air Toxicity	0.0234	0.0188
POCP	0.0014	0.0013
Human water Toxicity	0.0035	0.0038
Eco-toxicity	0.0082	0.0072
Eutrophication	0.0062	0.0059
Fossil Fuel Depletion	0.0172	0.0153
Mineral Extraction	0.625	0.618
Water Extraction	0.00137	0.00121
Waste Disposal	0.0547	0.0466
Transport	0.0266	0.0178
Total Eco-point Score/ tonne	**0.856**	**0.814**

Table 6.14 Hollowcore and prestressed beams Generic Eco-points score.

The Eco-point scoring methodology (Table 6.14, Figures 6.13 and 6.14) highlights the greater relative importance of the following three environmental impact categories:

- **Waste Disposal and Mineral Extraction:** These are by far the most influential impact categories, contributing 79% to the total Eco-point score for hollowcore manufacture (roughly 76% for prestressed beams). It should be noted that this would decrease if the study was carried out on a cradle-to-grave basis and concrete recycling reductions were applied to the profiles. However, these do not feature in a gate-to-gate study, in which only gate-to-gate impacts are included. This indicates that measures such as concrete recycling and minimisation of industrial waste are important to environmental improvement of PFF's products even if not within the scope of this research.
- **Carbon Dioxide Emission:** This is known to be the main impact associated with global warming and climate change (refer Chapter Three). The score shows that

climate change effects contribute nearly 8% of the total impacts occurring at this stage of a hollowcore product's life-cycle (7% for prestressed beams).

- **Acid Deposition and Human Toxicity:** These two impacts categories are associated with emissions (mainly SO_2 and NO_x) generated by energy consumption.

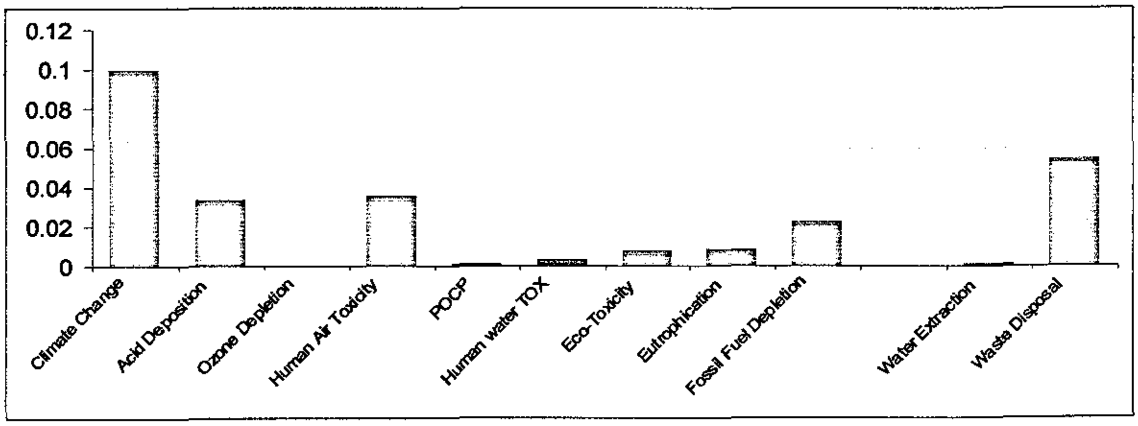


Figure 6.13 PFF Generic Environmental Profile in Eco-points (Hollowcore) excluding Mineral Extraction.

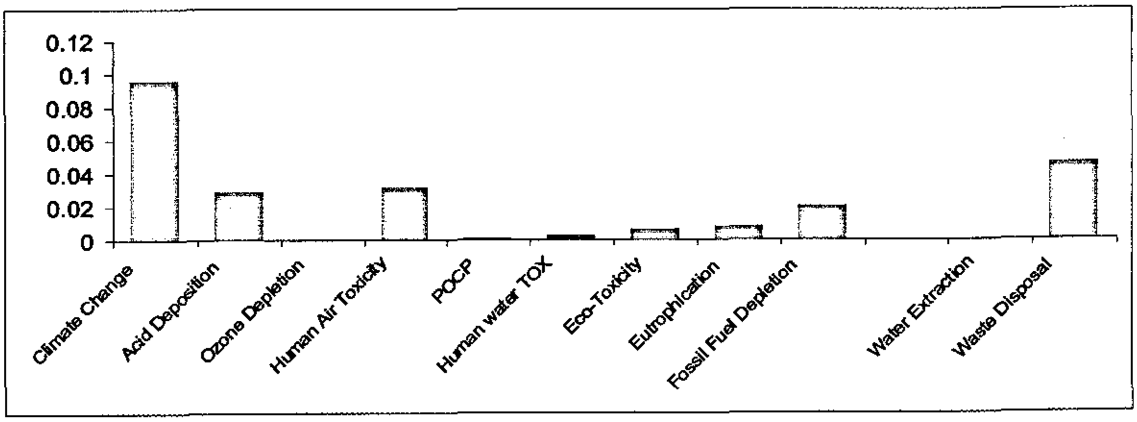


Figure 6.14 PFF Generic Environmental Profile in Eco-points (Prestressed beams) excluding Mineral Extraction.

In addition to the above, there are further aspects that need to be added at this stage of analysis; these include the following:

1. **Transportation (as a separate category):** In addition to the impacts directly associated with transportation, this category also affects the choice of suppliers and amount of upstream impact.
2. **Cement content and the upstream environmental impacts arising from the production of cement:** As explained in Chapter Four, most of the impacts associated with concrete arise from emissions and impacts associated with cement

The categories mentioned above are dominated by energy and material consumption patterns at the factories. The following sections carry out further analysis for the major environmental impact aspects affecting the profiles, these are raw materials and concrete waste, energy consumption, transportation-associated impacts (as a separate category), and upstream impacts (mainly from cement). All of these need to be considered by manufacturers to explore the business case for improvements to the environmental profiles of hollowcore and prestressed beam production.

6.4.2 Energy consumption in PFF factories

As noted in Section 6.2, most gaseous emissions from precast manufacturing are associated with energy consumption. Energy use directly affects Climate Change impacts, Acid Deposition, Human Air Toxicity, POCP, Eutrophication, and Fossil Fuel Depletion. To understand the major technical and managerial solutions triggering such impacts, a robust and detailed energy breakdown was carried out (for two of the PFF manufacturers) to reveal the particular processes and operations consuming most energy (see Appendix H for a brief on energy breakdown).

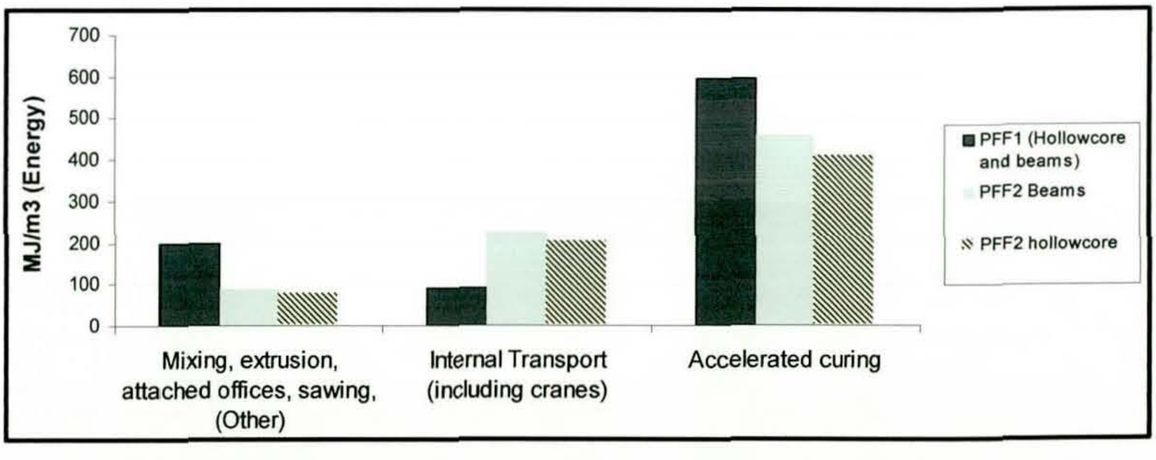


Figure 6.15 Energy consumption breakdowns for PFF1 and PFF2 (2002).

Figure 6.15 offers an improved understanding of the main processes and operations mostly associated with energy consumption, which are described as follows:

- **Accelerated Curing:** Most of the energy consumed in the factories included in the study is consumed in Accelerated Curing. This represents around 62% of PFF1 production energy emissions in 2002 (and 56% of PFF2 energy consumption in the same year).

- **Internal Transport measures:** Energy consumed in transporting products and elements in the factory using either mobile plant, such as lift-stackers or fork lifts, or cranes represented more than 15% of PFF1 energy production emissions (and 36% of PFF2 energy production emissions). The difference between the two figures is not necessarily significant: energy consumption at PFF1 is generally much higher than that at PFF2, and the factories' arrangements of stockyards to shop-floors are substantially different (see section 6.5.2.3).
- **Mixing, casting, etc.:** This category includes energy consumed on mixing, casting, and other electrically-powered operations directly associated with production. This category is the most challenging as the possibility of errors or miscalculation occurring in such a broad category is very high. However, comparing this with the energy consumed in accelerated curing, the amount of energy consumption in this category is actually rather lower, at just 40% to 30% of the total.

This energy breakdown helps to explain where energy is being consumed (and therefore emissions arising) in PFF factories. However, several factors require further discussion.

6.4.2.1 Accelerated curing associated factors

Linking energy consumption levels to accelerated curing is a major step towards identifying how business decisions relate to energy consumption. In addition to economies of scale, several factors control energy consumption patterns in the accelerated curing process, some of which are discussed in a broader context in Section 6.5

Impact Category	Electricity	Electricity (Primary energy)	Fuel Oil	Gas Oil
Climate Change (CO_2 eq.)	106.65	276.45	81.82	70.29
Acid Deposition (SO_2 eq.)	1.254	3.26	1.316	0.189
Human Air Toxicity (kg TOX)	1.487	3.87	1.568	0.2232
POCP (kg Ethene eq.)	0.0267	0.069	0.033	0.0326
Eutrophication (kg PO_4 eq.)	0.456	0.1185	0.0278	0.1322
Fossil Fuel Depletion (TOE)	0.0196	0.0196	0.0239	0.239

Table 6.15 Impacts on profile coming from fossil fuel choice (1 GJ)[47].

[47] Conversion factors derived from multiple sources. See LCA report in Appendix C for details.

Table 6.15 shows the impacts generated due to the consumption of one Giga Joule (GJ) of fossil fuel. The choice of type of fuel used can have a substantial effect on energy consumption levels in curing. The manufacturers involved in the study use a number of methods (and fossil fuels) to heat and cure the products. Two manufacturers use electricity to heat the product's strands. The other three use boilers (Fuel oil, Kerosene, Gas oil, etc.) to heat water under the production beds. While Richardson (1991) praises the use of electricity as an energy and cost saving measure, its upstream impacts on emissions, due to primary energy consumption, is substantial.

The heating cycles employed, generally between 8 to 12 hours, can also have a considerable impact on the amount of curing energy consumed per 1 m² of production. Figure 6.16 shows a heating cycle from PFF2 in 1999. From then until 2002, PFF2 managed to gradually reduce its heating cycle. This resulted in a considerable energy saving for the factory (as shown in Figure 6.17).

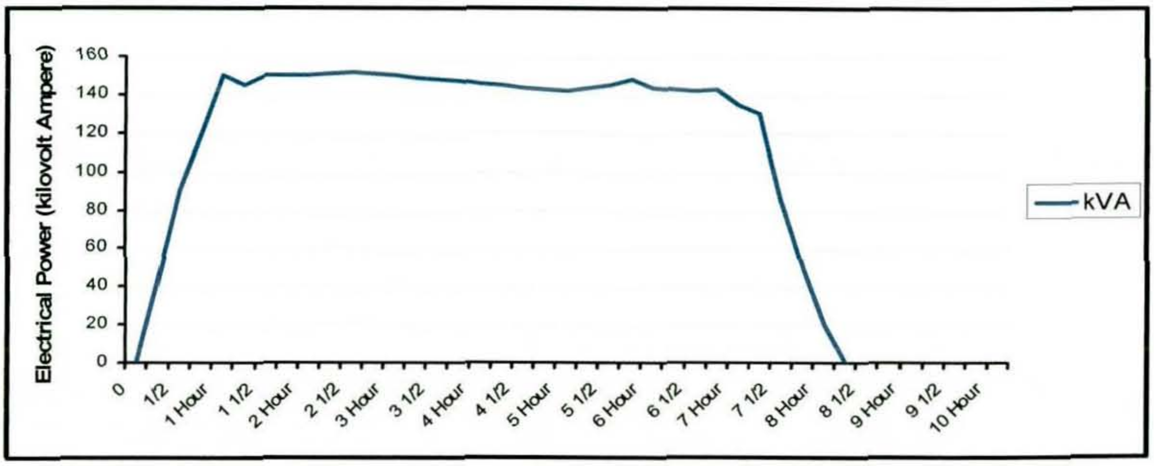


Figure 6.16 The heating cycle employed at PFF2 (Lincoln Green Ltd, 1999)

Figure 6.17 PFF2 energy annual consumption 1999- 2002[48].

[48] Derived from manufacturer's entry from BPCF Waste minimisation Awards - 2004.

Another factor is the length of the curing beds used, which can affect environmental impact and energy averages in several ways. Other than concrete waste streams impact (discussed in Section 6.3.4 and 6.4), the length of the heating beds affects levels of economies of scale. Dedicating the required machinery (extruders, energy, hoppers, gantry systems, etc) to a bed with 180 m^2 of production will save potentially more energy, per 1 m^2, than dedicating the same machinery and measures to 120 m^2 of production in a shorter bed.

The curing energy consumption average is also affected by depth and mass of products cured. Discussions with manufacturers on the shop-floor at PFF1 and PFF2 reveal that the range of heating cycles employed for hollowcore increases from approximately 8 hours for relatively shallow (150mm to 200mm depth) to up to approximately 12 hours for deep (up to 450mm depth) hollowcore. The mass difference between products with the extremes of these depths (150mm and 450mm) is nearly 1:2.5 (this is discussed in more detail in Section 6.5).

6.4.2.2 Energy and economies of scale

The economy of scale advantage is one of the major factors affecting energy consumption levels at a precast flooring factory. One of the findings made during the energy breakdown research was associated with the vital role played by economies of scale solutions in shaping the energy consumption average. In one Finnish study, it was stated that energy consumption efficiency can be improved by running a factory at maximum capacity. This will lower the energy consumption rate in production by 25%, lower the energy content by up to 8%, and emissions to air by 5% to 12% (Asumnaa, 1999). Given the mass production nature of prestressed flooring production, all these energy savings will be due to economies of scale, which is the most influential element in mass production efficiency.

Data collection from PFF1 confirms that such an advantage can be achieved and could have a decisive effect on the entire Climate Change impact category. Casts, and cast organisation, depend mainly on area rather than mass information. Using monthly m^2 and linear-metre production information[49], the annual energy consumption average was found

[49] Total PFF1 production in 2002 was 268,228 m^2 for hollowcore, and 1,180,735 linear-metres for prestressed beams

to be 84.719 MJ/m² for hollowcore and 7.194 MJ/ linear-metre for prestressed beams[50]. The average monthly production is 22,352.3 m² for Hollowcore and 98,394.6 linear-metres for prestressed beams. However, when exploring the monthly production information in conjunction with details for energy consumption, a possible relationship was revealed.

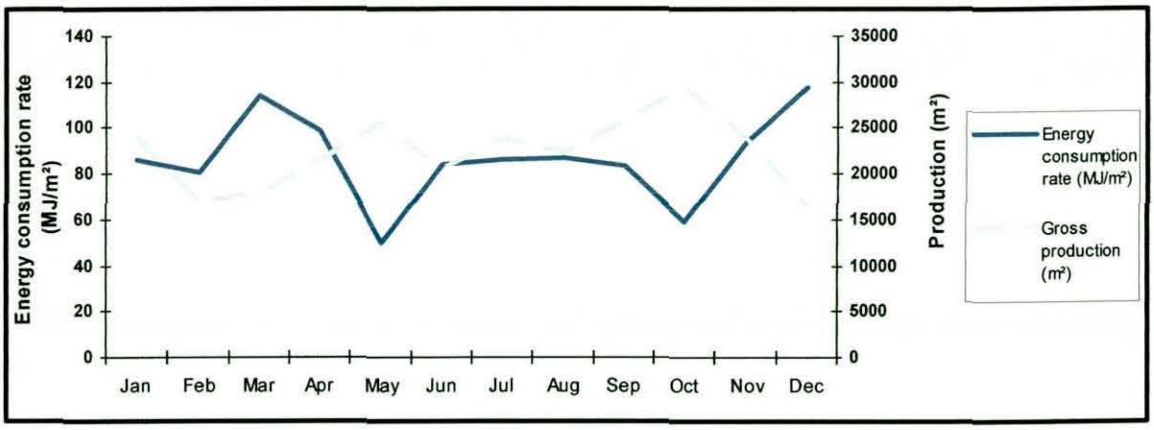


Figure 6.18 Relationship between fuel oil energy consumption and production output in 2002 for PFF1 (Hollowcore only).

Figure 6.18 suggests that a relationship exists between production amounts and energy consumption (per m^2). Through the twelve months of 2002, results from March, May, October, and December reveal a pattern that strongly supports a hypothesis based on economies of scale:

In March, PFF1 hollowcore monthly production was 18,003 m^2, which is 19% lower than the 2002 monthly average (the third lowest in the year). On the other hand, energy consumption level was high at 114.4 MJ/m^2; 35% higher than the 2002 monthly fuel oil energy consumption rate (the second highest in the year).

In May, PFF1 hollowcore monthly production was 25,588 m^2, which is 15% higher than the 2002 monthly average (the second highest in the year). On the other hand, energy consumption rate was the lowest in 2002 at 50.2 MJ/m^2 (which is 41% lower than 2002 average).

In October, PFF1 hollowcore monthly production was 29,453 m^2, which is 32% higher than the monthly average (the highest in 2002). On the other hand, energy consumption

[50] The massive difference between m² and linear metre averages is normal as the nominal weight of 1 m² of hollowcore (regardless to depth) can reach ten times the nominal weight of one linear metre of a prestressed beam holding a similar depth.

rate was 59.4 MJ/m^2; 30% lower than the 2002 monthly fuel oil energy consumption rate (the second lowest in 2002).

In December, PFF1 hollowcore monthly production was 16,607 m^2, which is 26% lower than the 2002 monthly average (the lowest in 2002). On the other hand, fossil fuel energy consumption rate was 117.46 MJ/m^2; 39% higher than the 2002 monthly average (the highest in 2002).

The findings, therefore, support the notion that the impact of economies of scale is significant when considering fuel oil consumption in accelerated curing. Another explanation is the possibility that the unused empty beds are also being heated (discussed below) and due to lack of thermal covering for these empty beds, the heat consumed in these beds is higher in average than in employed beds. This explanation would give the effect shown in Figure 6.18. However it cannot explain the similar effects found in Figure 6.19; the same effect can be found in other types of energy such as electricity (see Figure 6.19). Due to a lack of production (tonnage) information at PFF1 for 2002, the 2001 figures, along with 2001 electricity information, have been used. Contacts with PFF1 reveal that no major changes were carried out to the factory during the period between 2001 and 2002. So the figures are valid for this exercise.

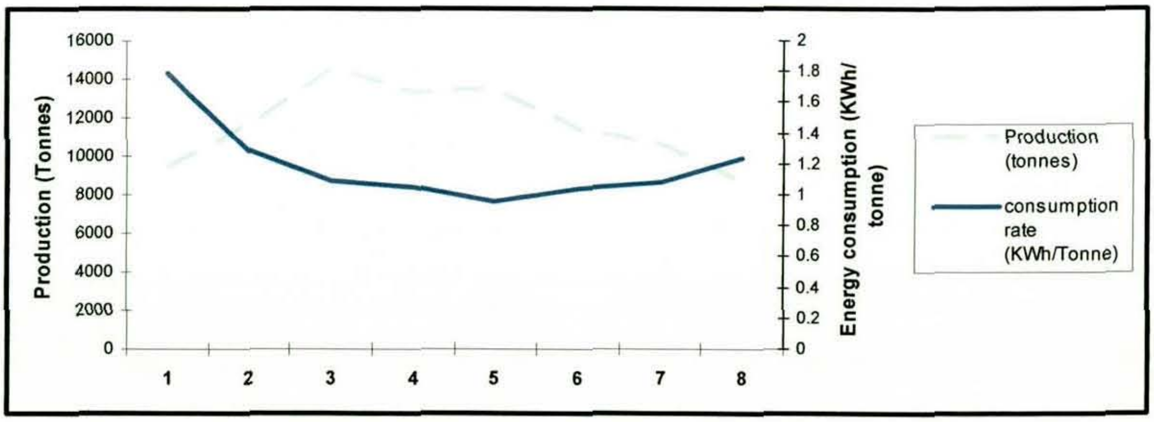


Figure 6.19 Relationship between electrical energy consumption and production capacity for PFF1 in 2001 (Hollowcore and prestressed beams).

6.4.2.3 Usability of beds in the production shop-floor

Contacts with the Technical Manager at PFF1 revealed that an increase in Fuel Oil consumption (this does not include electricity) is influenced largely by the operational manager's decision to maintain heat in the curing beds between the casts. This was investigated further through a quantification study carried out following the LCA study (Appendix J).

The study quantified the numbers of castings made monthly, which has helped in identifying the number of times that beds were left unused during shifts (numbers of empty beds). A broad consistency was found between the employability of beds and curing energy consumption levels (Figure 6.20). This has proved that, in many cases, the beds may be left still operating and heating even when left empty in production. Following updates from managers at PFF1, this possibility was later confirmed.

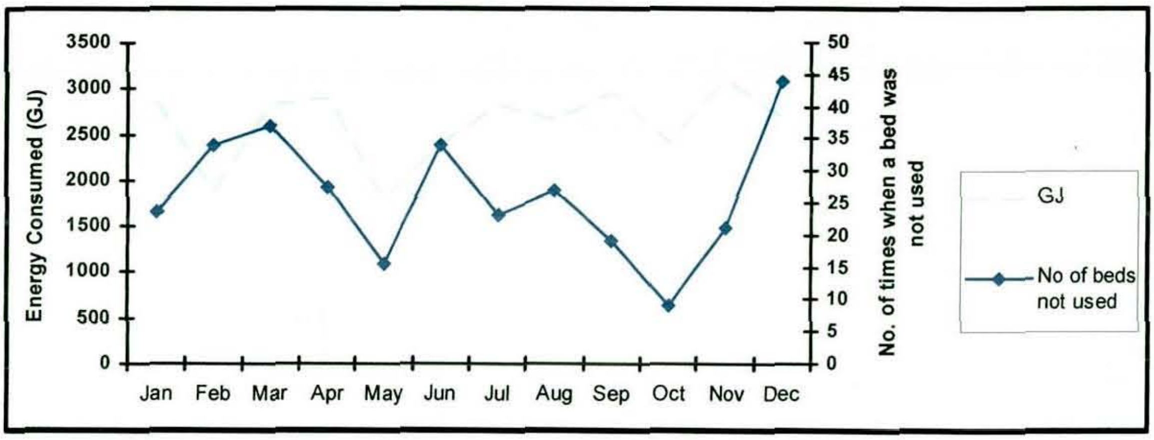


Figure 6.20 Number of times when heated beds were not utilised compared to curing energy patterns at PFF1 (2002).

Although this can partly be considered as an economies-of-scale associated element, it offers a demonstration of how the methods by which orders and jobs are organised on a daily basis (shop-floor decisions) can have a substantial effect.

6.4.2.4 Other factors affecting energy consumption

There are other factors that affect energy consumption patterns at a precast concrete factory, including:

- **External ambient temperature:** This is known to have an impact on curing energy consumption levels. There is evidence from a study carried out in Finland that temperature can have a significant influence on energy consumption. 40% of the energy consumed in a Finnish precast factory during winter is due to buildings' heating (Alexander *et al*, 2003).

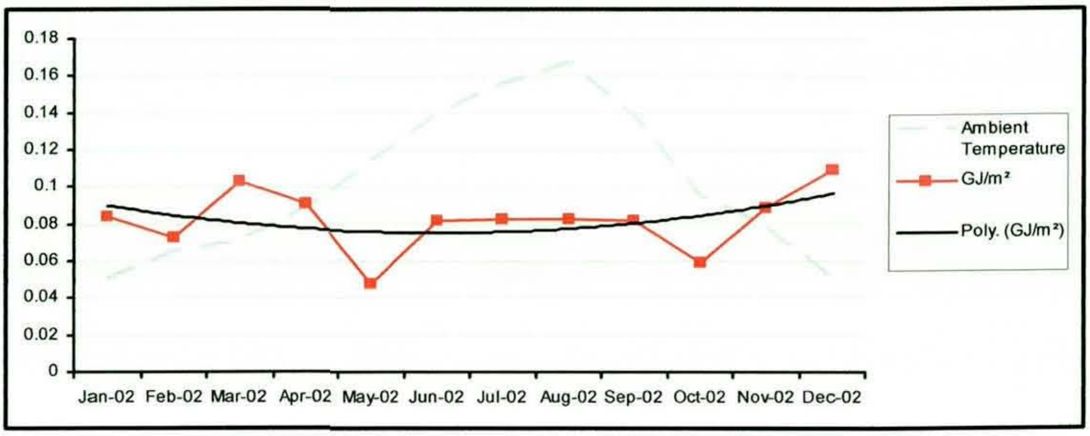


Figure 6.21 Comparing curing energy consumption averages with monthly temperature levels.

Unfortunately, primary data on temperature does not show a convincing consistency. Figure 6.21, which was based on PFF1 information, compares between monthly average temperatures and energy consumption averages per production level in 2002, using a trend-line (resembling energy average) it is possible to identify a slight consistency or relationship in their pattern.

- **The possible influence of maintenance and age of machinery and plant:** This was established through contacts with Arto Suikka[51]. The PFF1 factory is the oldest of the five factories included, this had an evident effect on all the environmental impacts associated with energy in the environmental profiles for PFF1 (see Appendix F).
- **The impact of concrete waste levels:** This can have influence on the entire environmental profile (more waste means more work, effort, and impacts). Concrete waste-by-design was exempted from this study due to difficulty of estimation and lack of sufficient documentation systems available for research, however, concrete waste can increase the average energy consumption level in precast plants.

6.4.2.5 Energy consumption and corporate decisions

As noted above, energy consumption is influenced by several factors. However, the differences in climate change, and other energy-associated impacts, between factories show that the choices made by manufacturers, either on a daily regular, structural, or strategic basis, will have a considerable impact on energy patterns and associated emissions.

[51] Arto Suikka is a well known concrete expert and division manager at the Confederation of Finnish Construction industries.

6.4.3 Concrete waste impacts

This section explores some of the factors that seem to affect waste generation levels. Many of these factors can be linked to decisions undertaken in different levels of management. From the information provided in 6.2.5, it appears that there are several aspects affecting the type and amount of waste generated. These include the following:

- **Customisation:** This is the main element contributing to concrete waste (at least for hollowcore). The amount of concrete waste-by-design varies from one job to another, and is determined by the customer's own requirements on product dimensions. Manufacturers are flexible in meeting such needs, but a knock-on effect may develop due to the lack of consistency in product sizes and shapes.
- **Level of flexibility within the production system employed (hollowcore):** the hollowcore production systems employed by most PFF manufacturers do not allow for the customisation of products without generation of waste[52]. Any job conflicting with the fixed width of the casting bed will generate concrete and steel waste. Although casting bed planning routines aim to minimise waste at the ends of beds, there is often a mismatch between the length cast and the total lengths of the required units. This is a typical problem in mass production systems (Womack and Jones, 1997).
- **Level of work organisation:** There is no clear evidence how work, job and cast organisation affects waste generation. The only evidence (or hypothesis) that can be developed is from units damaged in the stockyard due to mishandling. Another possibility is the amount of waste concrete remaining in extruders, hoppers, bullets or skips (explained in 6.2.5.1). There is always a suspicion that inexperience or disorganisation might lead to waste. Indeed, a study in Ireland links 70% of a manufacturer's concrete waste to inefficiencies in the marking and checking process for concrete being sawn (Sutcliff and Murphy, 2003). However, it was not possible to establish such a link from the information available from PFF manufacturers.
- **Length of the casting bed:** The length of the casting bed has a direct effect on one specific concrete waste stream: A fixed length of concrete waste at the beginning and end of the cast bed. The longer the casting bed, the less (smaller in proportion) concrete waste. It could also have an impact on steel scrap/ waste if concrete is not cast on the total length of the bed.

[52] Excluding the production system employed at PFF4,

- **Other operational/ structural arrangements:** Some operational arrangements could have an impact on waste. These include aspects such as the use of polyethylene to separate prestressed beams wet castings (given that the polyethylene is disposed as waste), or the use of slurry recycling system (such as PFF3).
- **Other factors (associated with aggregate contamination):** While there are several factors that may account for possible aggregate contamination (mostly associated with SHE measures and frameworks), the other possible source of hazardous waste comes from waste oil (lubricant oil, fossil fuel oil, etc.). All these will depend on the type and quality of machines used, types of energy employed, and, most importantly, the nature of measures employed.

6.4.3.1 Waste Generation and corporate decisions

There are several potential links that can be established and investigated between concrete waste generation and some corporate decisions. The information collected indicates that excessive waste (especially concrete waste by-design) is mainly associated with measures and decisions undertaken (or influenced) by departments such as the design department, marketing department, operational production departments, and the strategic/ senior management within the organisation.

6.4.4 Impacts associated with raw materials use

Raw materials use can affect many environmental impact categories either directly or indirectly, the direct impact of raw materials arises from Mineral Extraction (which was covered in Sections 6.2.4 and 6.3.3). However, there are other and more serious effects which are associated with upstream environmental impacts generated by cement and aggregate production.

6.4.4.1 Upstream cement impacts

Cement, which accounted for around 16% of the total raw materials used by manufacturers in 2002, is a major source of environmental impact. Cement manufacturing is an energy intensive process and hence produces a substantial amount of carbon dioxide, sulphur dioxide, and nitrogen oxides. The most recent figures from the British Cement Association (BCA) put CO_2 emissions associated with cement production at 880 kg of CO_2 eq. per tonne of cement produced, 525 kg of CO_2 eq. of which is due to the chemical breakdown of Calcium Carbonates (Gilbert, 2005).

Although cement represents around one sixth of the total mix, it still accounts for the majority of total cradle-to-gate impacts. The following figure (Figure 6.22) shows the emissions and impacts associated with the hollowcore cradle-to-gate impacts. The data is based on an EPD developed for Swedish precast manufacturer Consolis.

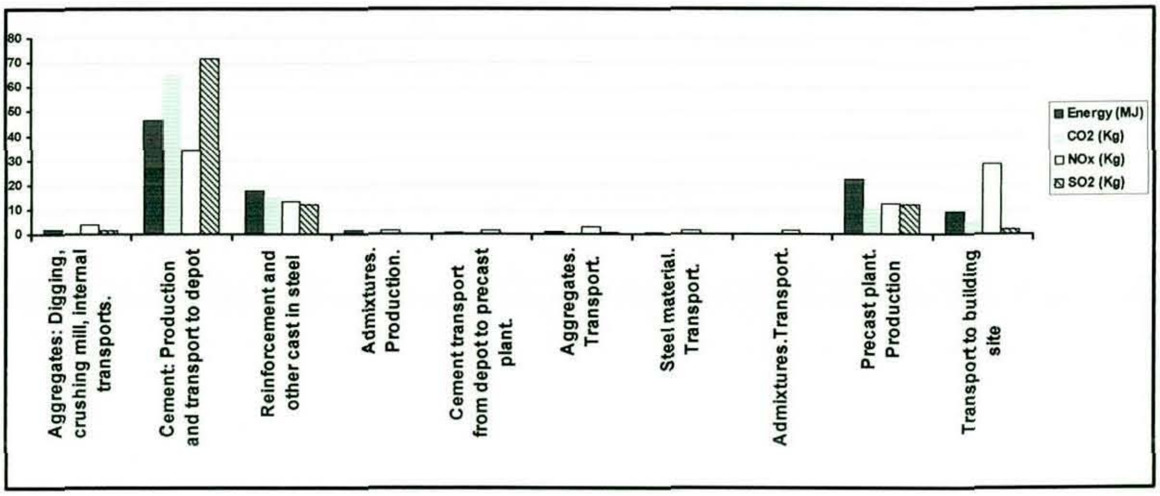


Figure 6.22 Environmental impacts associated with hollowcore production (%)

Figure (6.23) shows environmental impacts as developed from a Finnish Study (Vares and Hakkinen, 1999).

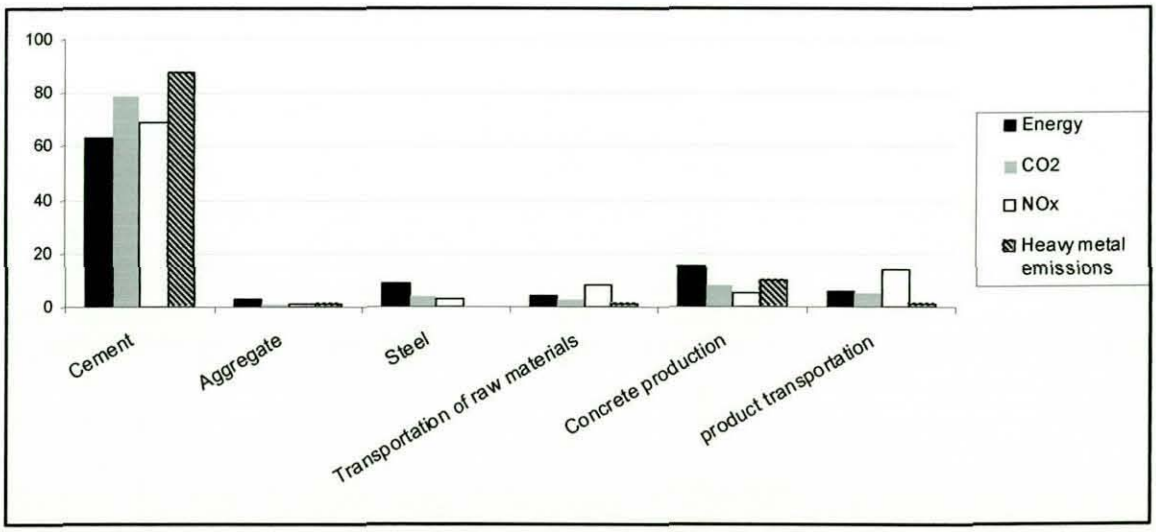


Figure 6.23 Environmental impacts associated with hollowcore production (%)

Figure 6.24 is derived from another Finnish study also referred to by Vares and Hakkinen (1999); it shows how an increase in cement content affects the cradle-to-grave environmental burdens of concrete considerably.

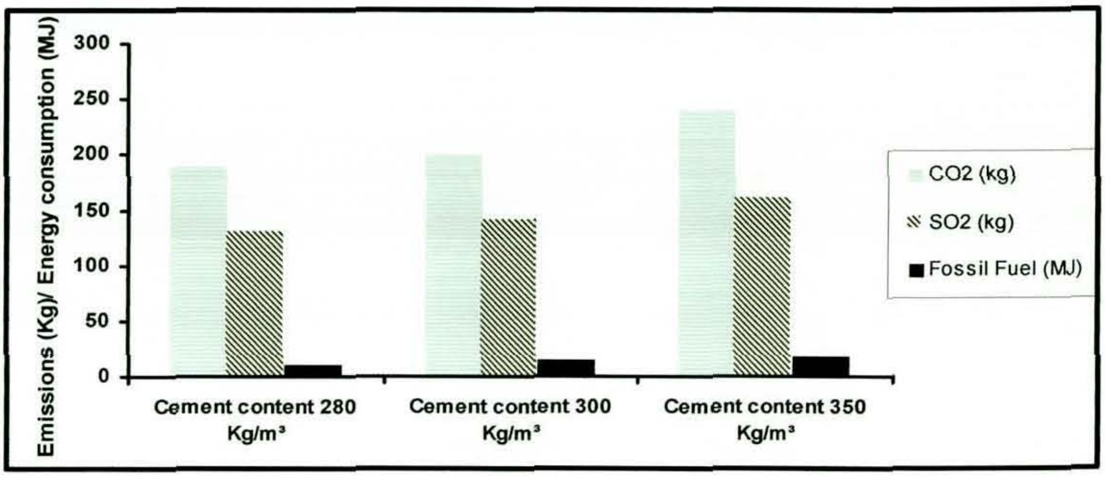


Figure 6.24 the impact of different cement contents within a precast product (derived from Vares & Hakkinen, 1998)

6.4.4.2 Upstream aggregate impacts

Being the most dominant precast concrete ingredient by mass, aggregates should clearly be considered by manufacturers wishing to improve their environmental performance.

Apart from Mineral Extraction and possible depletion of biotic resources, the extraction of aggregate does not have a significant impact on the environmental profile *per se*; a study by the Asphalt Institute (USA) reveals that energy consumption from aggregate extraction and processing is between 65 and 47 MJ/tonne (The Asphalt Institute, 1979). This figure is similar to the one provided by another older American study by Epps (1977) which was 47 MJ/ tonne. Consolis's EPD developed for its hollowcore products manufactured in Sweden reveals a relatively similar number (55.33 MJ/tonne).

These figures may seem small compared to energy consumption figures at a cement production plant (±4000 MJ/tonne). However, when considering the economic value and sheer amount of aggregate used, it would be appropriate to explore the possible upstream impacts coming from aggregate and how that would affect the total environmental performance and possible EPD for a precast element.

6.4.4.3 Raw materials and corporate decisions

Decisions regarding the type of aggregates and cement used and suppliers for these materials are often based on informed, technical opinion (such as the need for a specific type of aggregate or cement due to strength or workability potential). However, it is a strategic, financial decision that in fact plays the vital role, such decisions (especially decisions concerned with purchasing raw materials) are associated with the cost of sales. The cost of sale[53] of a precast concrete company can easily reach more than 80-83% of its entire turnover[54].

6.4.5 Transportation impacts

One item that Eco-point scores do not show is transportation as a separate impact category. In the Eco-point system transportation is included across six different impact categories. The significance of transportation has been highlighted in several studies: for example, Bijen (2002) classifies raw materials' transportation as a dominant factor, second only to cement content in the cradle-to-grave life cycle of a precast element (see section 4.5).

The environmental profile impacts generated through transportation for hollowcore manufacture have a 0.0266 Eco-point score (Table 6.12). Excluding Mineral Extraction, this would be 12% of the total profile eco-point score. The environmental profile impacts generated through transportation for prestressed beams have a 0.0178 Eco-point score (excluding Mineral Extraction, this would be nearly 8% of the total profile eco-point score). Table 6.4 (repeated below) offers a picture of the effect of transportation on different impact categories considered in the study. It should be noted that the differences between manufacturers appear to be consistent with differences in sourcing distances, amount of raw material compared with net production, concrete mixes employed, and the way in which logistics are organised (choice of suppliers and targeted markets, type of transport trucks, etc.). The impact of a factory's location is also influential (see Section 6.5.1.3).

Company	Climate change	Acid Deposition	Human Air Toxicity	POCP	Eutrophication	Fossil Fuel Depletion
PFF1	6.13	4.34	4.25	20.25	22.5	5.51
PFF2	22.13	23.83	24.13	57.46	56.02	16.94
PFF3	30.67	31.88	31.5	66.95	64.18	23.95
PFF4	20.4	8.56	8.98	34	31.6	19.33
PFF5	28.16	37.37	38	61.61	68.5	23.62
weighted Average	**21%**	**23%**	**23%**	**50%**	**51%**	**24%**

Table 6.4 Transportation impacts as percentages (%) of total environmental impact categories for prestressed beams – Repeated.

[53] A Profit and Loss account function largely dominated by costs of raw material bought from suppliers.
[54] See Consolis Ltd. Profit and Loss accounts 2003 to 1999: http://www.addtek.com/eng/finance/key_figures.htm

6.4.5.1 Considering other stages of transportation

Transportation criteria are limited not only to the impacts quantified earlier; the impacts of transportation can extend far more widely.

In terms of primary energy, transportation might remain as the third or fourth highest impact (because Mineral Extraction and Fossil Fuel impacts score more Eco-points). However, considering that other transportation stages are not included in this study (such as finished product transportation to a building site), transportation could easily emerge as being of even greater importance. This is supported by other LCA studies on hollowcore. One Finnish study estimates that if the product transportation stage were to be included, the fossil fuel consumption (in transportation stages) would be 2.5 times higher, i.e. 10% of the total cradle-to-grave energy consumption (Punkki, 2001). Others suggest that CO_2 emissions in product transportation would be nearly 2.7 times higher, and NO_x emissions would be 2.75 times higher (Vares & Hakkinen, 1998). However, this will depend on the geographical range of a manufacturer's product deliveries.

6.4.5.2 Transportation and corporate decisions

Transportation is also essential in the business case and the supply chain of a precast manufacturer. Decisions associated with selection of suppliers are main aspects in the determination of transportation criteria. Several manufacturers look at transportation when they make decisions, looking at aspects such as sourcing distances and factory locations. However, there are also several other economic aspects that need to be considered when such decisions are made (see literature review on importance of Cost of Sales in section 4.4.2).

6.5 Discussion of LCA results: Factors affecting environmental profiles

As seen in Sections 6.1, 6.2, 6.3, and 6.4 production processes, characteristics of products manufactured, and the nature of the manufacturing sites differ from one manufacturer to another. These production criteria appear to have a considerable effect on the environmental impacts that are considered in LCA. In this section, these criteria are linked to the environmental profiles of products to help in developing a more established business approach to the relationship between economic considerations and decisions and environmental impacts.

6.5.1 Nature and size of precast flooring factories

The nature, size, layout, and equipment of a factory are usually considered through structural and strategic measures planned and implemented by the senior management of a company. This section links the effects of these variables to possible variations in the scores for the environmental impact categories.

6.5.1.1 Production capacity of a precast factory

Evidence from the PRODOMO study (Kaysser and Kott, 2002) reveals that the mass production advantages in precast factories are not limited to savings in resources and reduction in costs and production time: increasing the capacity can also dramatically reduce average energy consumption, and SO_2, NO_x, and CO_2 emitted. Due to difficulties in distinguishing between various activities and unit processes in each PFF factory, and the variety in production systems used by manufacturers, it was not possible to explore this in depth. However, monthly information collected from PFF1 (see section 6.4.2.2) shows how an increase in production capacity has an inverse relationship to energy consumption levels.

6.5.1.2 Availability of recycling systems

This is not typically accounted for in a gate-to-gate study, however, (as with cement content), in considering the total impact, recycling can have a considerable influence on the cradle-to-grave environmental profile in the BRE Environmental Profile methodology. The availability of recycling can cut cradle-to-grave waste impacts considerably.

6.5.1.3 Location of a precast factory

Impacts arising from transportation proved to be significant. Section 6.4.5 addresses the main factors affecting transportation. However, one major factor not considered in detail in that section seems to have had a considerable influence on transportation impacts. By adjusting the figures in Table 6.4 to account for manufacturers' locations, it was possible to establish an understanding of how a precast manufacturer's location affects the raw materials transportation impacts. For example, it was found that the transportation impact from aggregate transport is relatively lower in factories located in the Midlands (because many aggregate quarries are located in the East Midlands region) and in those adjacent to quarries. Figure 6.25 shows a breakdown of aggregate production across the UK. It should be noted that precast manufacturers using long-line methods (e.g. extrusion) prefer to use hard limestones (Section 4.4.1). This is found mainly in the East Midlands and some areas in Yorkshire.

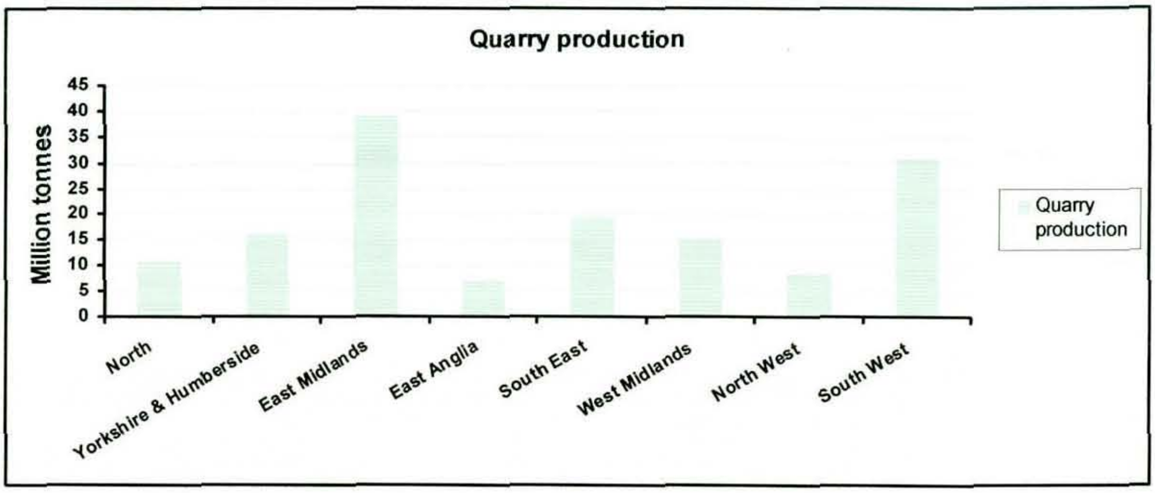


Figure 6.25 Aggregate production in England by region (QPA, 2002).

Figure 6.26 shows a comparison of transportation associated with CO_2 emissions (as a percentage of total CO_2 emissions). Those factories located in the Midlands and those adjacent to quarries have a lower proportion of transportation-related CO_2 emissions than others outside the Midlands area or with no quarries attached. Location can also have an impact on manufacturers' decisions on type of materials supplied. Hollowcore manufacturers prefer to use limestone aggregate for ease of sawing and shaping of final products (Richardson, 1991). However, due to a lack of suitable limestone quarries in some regions in the UK, manufacturers are faced with two options: either to use flint or gravel aggregate and accept the additional sawing costs in production, or to target limestone aggregate suppliers regardless of their distance from the precast factory (Richardson, 1991).

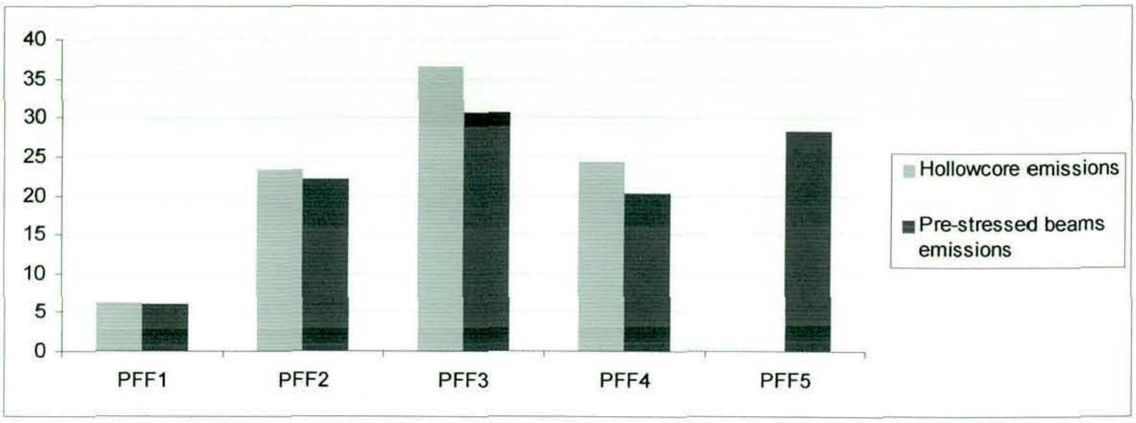


Figure 6.26 Transportation CO_2 emissions as percentages (%) of total emissions from PFF manufacturers.

It should be noted that this should not necessarily imply that PFF3 (Figure 6.26) is the least efficient in terms of transportation-related CO_2 emissions. Manufacturers might be located away from their suppliers but closer to their '*client hot spots*'. However, this study does not account for the environmental impacts of 'site deliveries' because of the spread of factory locations in the study and their different distances from their customers. This transportation phase (transportation to site) cannot be included in a generic profile as it changes on a daily basis and affect each manufacturer differently.

6.5.2 Production processes employed in precast production factories

The manufacturers involved in the study use a range of casting techniques, internal transportation, extrusion, curing criteria, and shift organisation measures. These in combination have a substantial effect on environmental profiles. With such an intricate combination of production variables, it is very difficult to link specific, quantified environmental impacts to any of the specific measures employed. However, there are several indicators that can help manufacturers to understand the potential environmental impact of their production decisions.

6.5.2.1 Product Casting

One of the main differences between the various factories considered in this study is in the methods and technologies used in casting the products. The casting technique affects the product mix and therefore the composition of a manufacturer's upstream supply chain.

Most manufacturers employ extrusion, wet-casting or slip-forming in casting their prestressed products. To accelerate the curing process, manufacturers use higher cement contents than in typical ready mixed concrete; the water content in extruded concrete is also usually much lower than that used in ready mixed concrete. Both of these factors result in a higher, earlier compressive strength allowing for faster curing within a specific production period. As noted in section 6.4.4.1, the upstream impacts coming from cement are significant and any decision to adjust or adapt a casting system to one which uses more cement would have a major effect on the environmental profile. Wet casting techniques use moulds: the concrete mix in these casts has a higher water content but it produces less waste (due to moulding), and therefore requires a higher cement content than extrusion or slipforming.

There are no clear figures on the energy used in either wet or extruded casting techniques (in terms of mixing or casting). However, it is known that waste levels in extruded casting are relatively high compared with wet cast, on the other hand wet cast employs more cement (with substantial upstream impacts). This in itself would have a considerable effect on the total environmental profile of a concrete product.

6.5.2.2 Accelerated Curing

The contribution of accelerated curing (consuming 56 to 62% of a plant's total energy) was discussed in detail in section 6.4. The factors affecting accelerated curing (including the heating cycles, types of energy used, and measures of economies of scale) were discussed in 6.4.2.

6.5.2.3 Internal Transport Measures

As explained in section 6.4, various means of internal transport in a precast flooring factory consume a considerable amount of energy and produce substantial CO_2 emissions. Using a gantry system or mobile plants to transport and distribute concrete from mixer to casting beds, or from beds to stockyards, will have a considerable impact on the energy consumption average. Cranes and gantry systems might be safer in terms of fumes and might have the economies of scale advantage (saving more energy per mass). However, mobile plants do not have a substantial primary energy effect (given that it uses fuel oils), moreover mobile plants have more flexibility in transporting and moving different loads to different locations in the factory.

Figure 6.27 shows internal transport energy consumption in hollowcore production in 2002 (transport energy consumed per 1 tonne of hollowcore production). The differences in transportation energy consumption are considerable. However, by exploring the variables, it is possible to offer an explanation for this situation.

PFF1 employs a number of different mobile plant and cranes to move cast products. This combination seems to have a positive effect (compared to PFF2). The PFF1 stockyards are not far from the main production hall, however, the average journey taken by its mobile plant or cranes is two to three times further than that taken by fork lift trucks at PFF3.

PFF2 employs only mobile plant in transporting products. The journey distances in PFF2's stockyard are considerably longer than these in PFF1 and PFF3 (possibly 1.5 times that in PFF1 and three to four times that in PFF3). Furthermore, the PFF2 factory produces other products, including precast staircases, lintels and precast blocks, so it is possible that impacts from transporting these products are partially included[55].

The site layout of PFF3 must be one of the main factors why its internal transport energy consumption is so low. The main production hall gate directly overlooks the stockyard, and fork lift trucks travel only very short distances (possibly not exceeding 10-100 metres) to transport products.

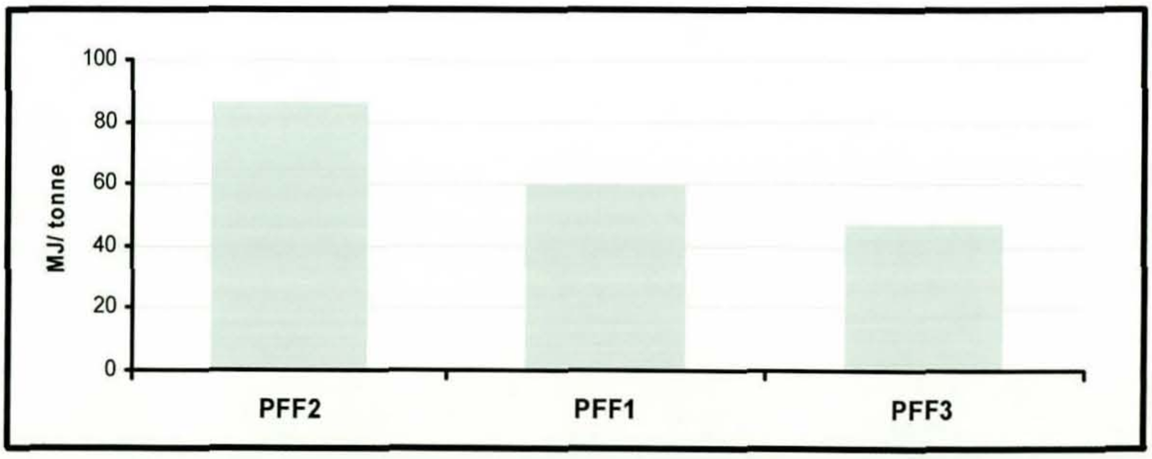


Figure 6.27 Average energy consumed in internally transporting hollowcore (2002 figures).

[55] It should be noted that, in many instances, it was difficult to segregate and allocate impacts associated with specific products. Many of the PFF factories produce a collection of products and sharing site energy bills is a common theme.

Apart from the layout and transport machinery used in the factories, the type of product made might have an effect on internal transport criteria. One manager at PFF2 noted that wet-cast prestressed beams require frequent re-handling, which affects their internal transport energy levels and costs.

6.5.2.4 Recycling Activities

Due to this being a gate-to-gate study, it is not possible to account for the positive impacts of concrete recycling, so this has distorted the Eco-point score somewhat at factories where concrete is recycled. In a cradle-to-grave LCA, accommodating concrete recycling activity on site could reduce cradle-to-site impacts significantly. The environmental profile can be reduced by the ratio of the price of recycled concrete waste (as by-products) on one hand, and prices of final products on the other;

Final Environmental profile (per 1 tonne of production) =

Calculated Environmental profile for 1 tonne of production X [1 – (price of 1 tonne of crushed concrete waste sold x amount of recycled waste concrete sold / price of 1 tonne of production x total production)]

6.5.2.5 Other industrial measures affecting environmental impacts

There are several other factors affecting the total environmental profile of precast products, levels of customisation in production is one of these factors. In addition to customisation's impact on waste, the energy breakdown at PFF1 reveals the significance of some processes such as sawing (Appendix H). With increased levels of customisation, the levels of energy consumption due to sawing will rise.

The environmental profile can also be affected by the organisation of casts and working shifts, the number of daily beds to be cast, and the capacity of the concrete mixers (often causing delays)[56]. Careful arrangement of the work shift should result in more jobs being completed within the given period. Furthermore, deciding on the number and length of casts to meet specific work orders has a substantial effect on energy and material consumption.

[56] Such delays were already reported at PFF3 by one shift manager.

Moreover, the different industrial measures associated with economies of scale (including length of casting beds, size of mixers, extruders and gantry systems) have a direct effect on energy consumption. However, it should be noted that their existence in a production system will not necessarily rule out the need for better work organisation and management to achieve more economies of scale and reduce energy consumption.

6.5.3 Nature of products manufactured

Hollowcore and prestressed beams can be used in a number of building types; the two products can be shaped to meet varied requirements and can therefore fulfil a range of functions. However, the products covered in this study have particular physical characteristics, differences in levels of customisation, and contain a range of raw materials.

6.5.3.1 Physical Characteristics of products manufactured

Precast manufacturers usually produce hollowcore and prestressed beam product-ranges with several depths (thicknesses). A change in size and nominal weight of precast products will certainly affect several impact categories at the environmental profile.

The following example (from PFF1) illustrates the impact of a product's physical characteristics on the environmental profile: PFF1 produces 10 different sizes and versions of hollowcore, the nominal weight of these product versions (per m^2) ranges from 238 to 576 kg/m^2. This results in a cast (batch) of around 29.5 tonnes/cast (for a 150mm depth hollowcore element) to 74 tonnes/cast (for a 450mm depth hollowcore element), which is a difference of 2.5 times. However, this does not appear to result in a similar change in environmental impact values.

Shop-floor managers reveal that it is unlikely that the rate of difference in standard energy consumption and depreciation rate of these extruders is consistent with the rate given above (1:2.5). This means that casting a 250mm hollowcore element will always require more energy (per tonne of production) than the deeper 450mm element.

Another inconsistency is associated with the curing/ heating cycles employed. Information from employees on the shop-floor at PFF3 and PFF1 revealed that heating cycles employed for products range from 8 to 10 hours[57]. Discussions also revealed that the

[57] Unfortunately, it was not possible to calculate the exact range of energy consumption for these heating cycles.

differences in the amount of heat required to cure a relatively shallow hollowcore product (150mm to 200mm depth) and a deep hollowcore product (up to 450mm depth) would not be 2.5 times greater. The same principle applies to internal transportation energy criteria. Information collected on environmental and energy impacts associated with internal transport, fork lifts, and crane movements reveal that fossil fuel consumption patterns are more closely associated with the number, rather than mass, of elements being handled and mobilised.

The points and reasons raised above show that it is erroneous to assume that energy consumption should be discussed without reference to depth or product-specific characteristics.

6.5.3.2 Levels of customisation

Results from the waste survey (see Figure 6.8) revealed that concrete waste-by-design is the main waste category that needs to be addressed by hollowcore manufacturers. Unfortunately, this waste stream could not be included robustly in the research due to some manufacturers refusing to estimate this amount, even approximately. However, information received from PFF1, in addition to estimates made earlier by two managers at PFF2, put this waste stream at around 8% of the total gross hollowcore production. The impact of customisation on prestressed beams is however minimal.

6.5.3.3 Nature of raw materials used

The combination of raw materials used in the concrete mix affects the environmental profiles in a number of ways. These are mentioned in several parts of the Literature Review chapters and in this Chapter (mainly in sections 6.2.6 and 6.4.4). Impacts coming from upstream processes for aggregates and ancillary materials are not as severe as those arising from cement manufacture.

The impact of raw materials continues into the curing process. The use of more cement might negatively affect the cradle-to-grave environmental profile, but it improves the site-to-site environmental profiles by effectively reducing product curing time and energy required for curing and processing. Such inconsistencies between gate-to-gate impacts and upstream impacts are common. The use of Pulverised Fuel Ash (PFA), as a cement replacement by one manufacturer had more transportation gate-to-gate impacts than the use of cement because the PFA supplier was located further away from the precast factory than the cement manufacturer (see Appendix C).

6.6 Feedback from LCA: Most influential decision-areas

The LCA study helped to establish findings which were fundamental to the following stages of the research. The findings suggest clearly that the major factors affecting hollowcore and prestressed beams environmental profiles are mostly associated with factory-specific production conditions because the differences in environmental impact between the various factories have been analysed and linked to specific measures and solutions employed by individual manufacturers or in individual factories.

6.6.1 Major environmental impacts for prestressed flooring products.

The use of the BRE Eco-point system reveals that Mineral Extraction, Waste disposal, and Climate Change are the most significant impact categories representing 75%, 6%, 7.5% (respectively) of the total Eco-point score. However, when devoting a separate Eco-point score for transportation (from its contribution to six of the impact categories considered), it was found that that raw material transportation alone contributes 3% of the total hollowcore Eco-point score. The Eco-point score was thus found to be directly affected by three major factors: material use, energy consumption, and transportation criteria. Another factor which was explored and needs to be considered is the cement content within the concrete mix, considering that cement contributes most of the cradle-to-grave CO_2, NO_x, and SO_2 emissions for precast flooring products.

Analysis of these factors shows how they are linked directly to measures employed and decisions taken by the different tiers of factory management:

- Energy is determined mainly by aspects affecting accelerated curing (such as the techniques used, product physical characteristics, benefits gained from economies of scale, decisions undertaken by the operational management to organise jobs and operate the curing beds), and internal transport (type of internal transport, site layout).

- Transportation seems to be influenced mainly by the factory's location, choice of suppliers, and nature of product mix.
- Industrial waste and Mineral extraction are affected by product mixes used, possible levels of recycling, types of casting employed, levels of customisation, and failure of some factories to recognise waste-by-design as industrial waste.
- The cement content in concrete is mainly affected by the product mixes employed, measures such as accelerated curing, use of admixture and the use of replacement materials. Concrete physical and technical requirements can also influence decisions on cement content.

The findings made in the LCA study can be used to identify specific decision-areas where these four major environmental impact factors influence products' profiles. The study shows that the environmental impacts generated by the production of precast flooring are not substantial. But there is scope for manufacturers to improve their businesses by taking account of the LCA results. Indeed, the findings of the LCA study should be employed properly to investigate the possibility of implementing environmental improvements and broader sustainability-based objectives within an enhanced and thus more successful precast flooring business.

6.6.2 Identifying decisions affecting the environmental profiles

Manufacturer's departments communicate with each other to produce flooring elements with maximum value. However, these institutionalised communication channels seem to fail to recognise environmental impacts as priorities. In fact, there is sufficient evidence that corporate decisions in precast organisations ignore possible environmental damage in pursuit of maximum profitability. The following are some of the key decision-areas identified via the Life Cycle Assessment (LCA) study:

6.6.2.1 Corporate Senior Decisions

Decisions taken by the senior management at organisations can have a significant effect on a precast flooring product's environmental profile, e.g.:

- **Location decisions:** A strategic decision to locate a factory or choose suppliers can have significant effects. The LCA analysis shows that those located in the East Midlands or adjacent to quarries have the least transportation impacts.

- **Fundamental production system decisions:** Major decisions on the type of curing method to be used, the type of casting to be employed, and the means of internal and external transport utilised; all these will have a decisive impact on products' environmental profiles.
- **Customisation decisions:** Such fundamental decisions can have consequences in terms of an increase in concrete waste in the cut-out portions of cast concrete (to meet design specifications). Customisation can also have other environmental impacts such as increased energy consumption due to extra sawing, processing, and internal transport.

6.6.2.2 Technical Decisions

Technical managers have control over the product's concrete mix and the type and quantity of additives used in the mix. The decisions and solutions employed by technical managers can have significant positive or negative impacts on the life-cycle environmental impacts of products. These include the following:

- **Cement content decisions:** Manufacturers tend to increase the amount of cement within the concrete mix as a means of minimising the curing times of products, achieve maximum productivity, and therefore maximise profit. Cement manufacture is the most energy intensive and environmentally significant stage in a concrete product's life cycle. An increase in concrete cement content will considerably raise the environmental impacts associated with flooring products.
- **Additives use:** Additives and admixtures use can have positive and negative impacts. Air entraining admixtures provide some workability for the concrete, enabling some manufacturers to cast products successfully. All manufacturers included in this research only use plasticizers. On the other hand, although many additives are known to be non-volatile compounds, their use can still cause some environmental effects (Vares and Hakkinen, 1998).
- **Use of by-products and cement replacement materials:** Use of materials replacing cement has a positive effect on the environmental performance of flooring products. Even though some of these by-products cause some technical problems, the replacement of the cement content with a small amount of pulverised fuel ash (PFA) or ground granulated blast-furnace slag (GGBS) can effectively save several tonnes of CO_2 emissions per cast.

- **Use of recycled materials:** Recycling is one of the main issues considered by environmentalists and governmental organisations. The ability to include recycled content to a precast flooring product (replacing aggregates or cement content) significantly reduces the environmental impact and eco-point score of a precast flooring element.

6.6.2.3 Marketing and Financial decisions

The impact of marketing decisions is mainly on project specific issues such as the amount of customisation (affecting levels of concrete waste) in the project. However, the impact of financial management and cost estimation in general can extend to include other strategic level aspects. For example, buyers' decisions to prefer specific suppliers over others can have an impact on transportation. Purchasing decisions can also affect the production systems used and the general environmental performance in factories.

6.6.2.4 Design decisions

These are also associated with the level of product customisation. However, designers can always reduce the negative impacts of their designs through development of systems to account for and reuse their discarded elements. Such systems are already used by some of the precast manufacturers in the UK. At PFF1, a colour coding system was introduced in the stockyard to identify parts to be reused, recycled, or disposed. A solution used in PFF2 is mainly based on dividing the cast bed into two portions. The smaller pieces can then be used in a range of projects and jobs where one-offs are required. Other industrial solutions included the use of vacuum suction (a system that cuts unset concrete using a water jet and sucks the waste concrete from the bed for recycling).

6.6.2.5 Operational Shop-floor Decisions

Although most of the product-specific decisions undertaken by other departments in a precast organisation shape most of the environmental impacts generated, the daily decisions undertaken by managers and workers on the shop-floor can have a substantial impact on the environmental performance of precast manufacturers.

- Operational managers need time to deal with multiple orders to be made on just a handful of casting beds. The ways in which orders and jobs are organised and divided have a considerable impact on energy consumption and waste generation (concrete and other waste streams).

- Decisions directly associated with the operation of casting beds, concrete mixers, and skips can considerably affect environmental performance. In one case, it was found that the operational decision to maintain the curing beds' temperature between casting sessions had a substantial impact on energy consumption levels.
- Decisions taking advantage of the economies of scale mechanism at a factory can effectively reduce levels of energy and material consumption. The LCA analysis (above) reveals that such principle could affect up to 40% of energy consumed in precast flooring factories.

To add to the complexity of the problem, it is very difficult to link individual decisions to a specific amount of environmental impact. One environmental impact (such as increased curing energy consumption) may be due to a number of decisions, and may differ from one manufacturer to another. On the other hand, one decision can trigger more than a single impact. This is a problem that cannot be presented, addressed, and tackled using conventional methods of creative problem solving.

6.6.3 Major environmentally problematic decision-areas

In order to tackle and address these different problems properly, it was decided to identify 10 main problematic decision-areas where the four major environmental impacts usually occur; these include the following:

- **Supply chain structure and suppliers' choice for manufacturer (D1):** Decision makers responsible for this decision-area include financial, purchasing and strategic managers.
- **Depth of Products manufactured by the factory (D2):** Decision-makers responsible for this decision-area include marketing and strategic managers.
- **Levels of customisation of products (D3):** Decision-makers responsible for this decision-area include marketing managers, operational managers, and strategic managers.
- ***Size and flow of jobs or orders taken to the shop-floor* (D4):** Decision-makers responsible for this decision-area include marketing, operational, and technical managers.
- **Cement content within the concrete mix (D5):** Decision-makers responsible for this decision-area mainly include technical managers.

- **Accelerating curing through changes to concrete mix design (D6):** Decision-makers responsible for this decision-area mainly include technical managers.
- **Reuse and recycling of materials and products (D7):** Decision-makers responsible for this decision-area mainly include technical and financial managers.
- **Type of production systems employed (D8):** Decision-makers responsible for this decision-area include operational and strategic managers.
- **Operation of curing beds, concrete bullets, gantry systems, and internal transport plants (D9):** Decision-makers responsible for this decision-area include operational managers.
- **The layout of the factory (D10):** Decision-makers responsible for this decision-area include strategic managers.

To tackle these environmental problems, specific solutions can to be identified for each of these decision-areas (mainly from the LCA result).

6.7 Feedback from LCA: quantified environmental solutions

Up to 29 environmental solutions (associated with the 10 decision-areas) were identified and quantified using the LCA study information in addition to information found in academic literature or available in the public domain. These environmental solutions are investigated in the semi-structured interviews stage of the study (Chapter Eight) to explore the possibility of improving the performance of the industry through the employment of more environmental approaches. These are detailed in the following sections (see Appendix K):

6.7.1 Supply chain structure and suppliers choice for manufacturer (D1)

Four solution options were identified for this decision-area:

D1 – Option I. Maintain impacts associated with the supply chain and concentrate on means of transport (more efficient vehicles, use of rail, etc.):

- **Benefits:** Energy savings can be made in changing to rail use. These savings are around 0.426 - 0.533 MJ/tonne for every 1 km saved in the sourcing distance (for electric and diesel trains respectively); this offers a 74-79% reduction in transport energy and fossil fuel consumption. There are also benefits in using energy efficient trucks; these include substantial cuts in sulphur emissions. If LPG fuel is used, savings in CO_2 emissions can reach 35-44%.

- **Drawbacks:** There are some obstacles; lack of availability of rail services in the area might compromise this solution. Moreover, there could be increased overheads in replacing trucks or transport contractors. Moreover, LPG trucks are not usually used in such kind of activities – and for such type of loads.

D1 – Option II. Consider sourcing distance as a factor in choosing suppliers and jobs to be taken:

- **Benefits:** Savings in transport energy, of between 0.576 and 0.7 MJ/tonne per kilometre, can be made for different materials' sourcing distances (depending on transported goods). Less impacts from 'site deliveries'.
- **Drawbacks:** The main drawbacks are associated with the limitations on choice of suppliers due to sourcing distances requirements. This can have an impact on quality (considering the quality of cement, aggregates, and steel nearby); it might also have an impact on costs (considering prices of raw materials nearby).

D1 – Option III. Use more energy efficient raw material trucks:

- **Benefits:** Benefits include substantial cuts in sulfur emissions. If LPG fuel is used, savings in CO_2 emissions can reach 35-44%.
- **Drawbacks:** Increased costs and overheads of replacing trucks and the sourcing contractors.

D1 – Option IV. Ignore impacts from transportation:

- **Benefits:** The most obvious benefit is that there would not be any economic or financial pressure in change and supply chain choice.
- **Drawbacks:** There will be no change in transportation impacts, these will stay around 0.0266 eco-points/tonne for hollowcore, and 0.0178 eco-points/tonne for prestressed beams (see Table 6.14).

6.7.2 Product depths manufactured by the factory (D2) and Levels of customisation of products (D3)

Solutions for the D2 and D3 decision-areas were combined together (considering that both affect the final shape and physical characteristics). Four solution options were identified for these two decision-areas.

D2/ D3 – Option I. Replace the concrete casting system employed:

- **Benefits**: Basic savings in energy consumption averages would vary between 3 – 11.4% (depending on types of casting and waste generation). Savings in waste can reach an average of 2.5 tonnes for every cast carried out.
- **Drawbacks:** If a cast system was replaced to reduce concrete waste (notably waste-by-design), the used casting system will have to be a new or a wet casting system. In addition to the problem of increased costs of replacing casting systems, wet-casting systems will require more cement (to adjust the w/c ratio and maintain strength), which causes an increase in environmental impact. Wet-cast production might also affect internal transportation energy due to increased handling.

D2/ D3 – Option II. Tackle customisation impacts through reuse and recycling of sawn and discarded portions:

- **Benefits**: There will be savings in concrete waste due to reuse and recycling. Moreover, recycling usually improves the environmental profiles substantially (Depending on the prices of recycled by-product and of waste compared with the primary product).
- **Drawbacks:** There could be extra operational and managerial workload due to extra tasks. Moreover, greater financial uncertainty will be caused by recycled waste as there will be possible profits, breakevens or even losses coming from recycled concrete sales and overheads.

D2/ D3 – Option III. Maintain customised waste. Instead work on increasing production per unit of energy consumed:

- **Benefits**: Through improving curing energy consumed per production, savings in curing energy can range from 0.3% to 31.3% (depending on energy factors targeted). Moreover, reductions can be carried out for different concrete waste streams (other than concrete waste-by-design); savings can reach 0.025% to 0.03% of gross production for every linear-metre utilised in the bed,
- **Drawbacks:** There are organisational difficulties due to the many people involved in decision making. Moreover, savings in energy (a maximum of 0.261 eco-points per 100 metre casting) may not offset customisation impacts (reaching up to 2.14 eco-points per 100 metre casting).

D2/ D3 – Option IV. Ignore the problem and invest in other energy saving activities:

- **Benefits**: The most obvious benefit is that there would not be any economic or financial pressure in change and waste minimisation measures.
- **Drawbacks:** Savings in energy (a maximum of 0.261 eco-points per 100 metre casting) may not offset customisation impacts (reaching up to 2.14 eco-points per 100 metre casting).

6.7.3 Size and flow of jobs/ orders coming to the shop-floor (D4)

Five solution options were identified for this decision-area.

D4 – Option I. Consider production for stock to maintain stable flow in production:

- **Benefits:** Savings in main curing energy levels; these are not specifically identified (depending on the quality of the executed solution). However, these could reach up to 34.54 MJ/ m^2 of hollowcore produced (see Section 6.4.2.2).
- **Drawbacks:** There are several obstacles including the need to redesign some shop-floor activities to account for production for stock. Other obstacles include storage requirements, problems of over and under-production, and hindrance to activities targeting customised products market.

D4 – Option II. Modify the way jobs are set and organised (such as never casting products using less than the full length of the bed):

- **Benefits:** Savings in curing energy amounting to 0.66% to 1% for every metre in the casting bed missed in production (depending on the length of the curing bed).
- **Drawbacks:** This action might require redesign of some shop-floor processes and tasks. Operational managers would unacceptably long periods for bed planning, mixing and matching orders to fill beds.

D4 – Option III. Additional tasks for managers to work with shop-floor in reorganising orders to enable productive flow:

- **Benefits:** Savings in main curing energy levels; these are not specifically identified (depending on the quality of the executed solution). However, these could reach up to 34.54 MJ/ m^2 of production (hollowcore). Success chances are fairly high considering that the option is supported by substantial literature on production flow (notably the Lean Production literature).

- **Drawbacks:** The option requires more time in planning and coordination between different departments. Re-engineering of some tasks and activities may take place.

D4 – Option IV. Allowing for more production control through increase in lead-times:

- **Benefits:** Savings in main curing energy levels, these are not specifically identified (depending on the quality of the executed solution). However, these could reach up to 34.54 MJ/ m^2 of production (hollowcore). There are also economic savings due to lack of errors and overheads associated with accelerating production and less pressure in work.
- **Drawbacks:** These include threats of late delivery, negative impacts on competitiveness and customer satisfaction, reduced production volumes and profitability.

D4 – Option V. Ignore the problem and pass it on to the shop-floor personnel:

- **Benefits:** Less cost and work pressure on departments other than shop-floor.
- **Drawbacks:** Limited chances of substantial environmental improvement, and continuous loss through waste and energy inefficiency.

6.7.4 Cement and additive content within concrete mix (D5) and Accelerating hardening and curing through changes to mix content (D6)

Solutions for the D5 and D6 decision-areas are combined together (considering that both affect the final concrete mix). Four solution options were identified for these two decision-areas.

D5/ D6 – Option I. Reduce cement content and use a partial replacement material (PFA, GGBS, etc):

- **Benefits:** There could be substantial savings in CO_2 emissions. Reducing cement content by 2% can reduce emissions by 17.6 kg of CO_2 per one tonne of product. This is around 0.051 eco-points per tonne of product. There are also economic savings; as the cost of by-products (such as PFA and GGBS) is less than that of cement.
- **Drawbacks:** Possible additional transport impacts (depending on the source of the replacement materials). More time and energy may be needed to help in curing.

Moreover, the chances of making a profit might not be high enough to justify the action as there can be some workability and technical difficulties.

D5/ D6 – Option II. Reduce cement content and increase levels of lime dust[58] in the mix:

- **Benefits:** There could be substantial savings in CO_2 emissions. Dropping cement content by 2% can reduce emissions by 17.6 kg of CO_2 per one tonne of product. This is around 0.05104 eco-points per tonne of product. There might be some economic savings (depending on the cost of lime-dust compared to cement). Improved performance in fire can be an additional benefit.
- **Drawbacks:** Possible additional transport impacts (depending on the source of the replacement materials). Moreover, the chances of making a profit might not be high enough to justify the action.

D5/ D6 – Option III. Reduce cement content and use plasticizers:

- **Benefits:** There can be substantial savings in CO_2 emissions. Dropping cement content by 2% can reduce emissions by 17.6 kg of CO_2 per one tonne of product. This is around 0.05104 eco-points per tonne of product. There might also be some economic savings
- **Drawbacks:** Plasticizers are known to be expensive ingredients in concrete production. There are also limitations to the use of plasticizers as this may affect workability. In addition to this, plasticizers can have a substantial impact reaching 0.38 kg of CO_2 per 1 kilogram of admixture (Rouwette and Schuurmans, 2001).

D5/ D6 – Option IV: Reduce cement and allow more curing time for products:

- **Benefits:** There can be substantial savings in CO_2 emissions. Dropping cement content by 2% can reduce emissions by 17.6 kg of CO_2 per one tonne of product. This is around 0.05104 eco-points per tonne of product. There are some economic savings as expenditure of sourcing cement will drop.
- **Drawbacks:** there will be limitations to the maximum number of possible orders/ castings per day. Furthermore, this will increase the accelerated curing energy; any additional hour of curing costs around 0.8375 GJ to 0.47 GJ per bed – this is around

[58] Lime-dust can be used as filler in the concrete mix (Bailey, 2005). It can help in reducing the amount of cement, as well as the aggregates, used.

0.000374 to 0.000667 TOE/ tonne of production, which is around 0.00101 to 0.00179 eco-points per tonne of product (which is low compared to upstream energy savings).

6.7.5 Reuse and recycling of materials and products (D7)

Two solution options were identified for this decision-area.

D7 – Option I. Use of discharged water and wet (un-set) concrete residue internal recycling and reprocessing systems:

- **Benefits:** There will be environmental savings in water use reaching between 0.000548 to 0.000484 eco-points per tonne of production. Savings in wet concrete waste could reach around 0.265 to 0.3 tonnes per casting. This is around 0.00106 to 0.0018 eco-points per tonne (depending on product depths and cast bed length). Moreover, there are substantial economic savings (up to 40%) in water costs.
- **Drawbacks:** The initial cost of such system can be substantial. Furthermore, there are conflicting reports of impacts on quality of concrete produced.

D7 – Option II. Reuse of local crushed concrete in production:

- **Benefits:** Successfully recycling and reusing hardened concrete waste content can save around 0.046 eco-points per tonne of production from waste. There is already a quality protocol for use of recycled concrete (Bailey *et al*, 2002).
- **Drawbacks:** there are reports of limitations on use of concrete manufactured from recycled aggregates, although this is discredited by some studies (Addtek, 2000). Moreover, there are claims that the use of crushed concrete as aggregate requires extra water, and this will require additional use of cement (Bijen 2002). Increasing cement content by 2% can increase emissions by 17.6 kg of CO_2 per one tonne of product. This is around 0.05104 eco-points per tonne of product.

6.7.6 Type of production systems employed (D8)

Three solution options were identified for this decision-area.

D8 – Option I. Change the major production systems employed to more environmentally acceptable ones (casting system, curing fuel, internal transport machinery, etc):

- **Benefits:** Considerable savings can be made if some major production systems were replaced: savings in internal transport energy can possibly be around 38.88 MJ/ tonne.

Savings in curing energy may reach 1.3-2.94 GJ per casting (19 to 44%), this reduction would occur if fossil fuel boiler-based systems were switched to electricity. Savings in energy due to casting can vary between 3 – 11.4% (depends on product being cast). Moreover, there are savings in waste due to casting, reaching an average of 2.5 tonnes per casting.

- **Drawbacks:** These include economic obstacles including high modification cost, possible new capital equipment, and possible impact on major economic objectives (such as speed of manufacture and lead times). Other impacts include re-engineering of operational and some managerial processes and tasks.

D8 – Option II. Carry out a few changes to some of the employed systems (such as changing the length of the curing beds, or installation of a power control and bed heating control facilities for the curing):

- **Benefits:** Increasing the length of casting beds from 100m to 150m can help in reducing concrete waste (at bed ends) from 3% to 2% of gross production (this takes place when beds are lengthened). Moreover, there are savings in energy due to power control. These have not been calculated (It is unknown if these reach 40% of curing energy).
- **Drawbacks:** Economic impacts include costs from possible new capital equipments or extensions to production systems and buildings. There might also be some impact on major economic objectives considering that compromises might need to be carried out for some of these objectives. There could be additional tasks in operating the new power control system.

D8 – Option III. Maintain the major production systems and invest in operational and maintenance systems:

- **Benefits:** Several energy savings could be made; these can reach up to 40% for curing energy.
- **Drawbacks:** More tasks, systems, and labour involvement.

6.7.7 Operation of curing beds, concrete bullets (skips), gantry systems, and internal transport equipments (D9)

Five solution options were identified for this decision-area.

D9 – Option I. Abandoning accelerated curing and leaving products to cure naturally:

- **Benefits:** Savings could possibly reach around 56% to 62% of total factory energy (with offices and internal transport energy included in these ratios).
- **Drawbacks:** Severe impact on production times, delivery/ lead times, and production per annum. This will have a substantial impact on profitability.

D9 – Option II. Reduce timing for accelerated curing and use other means of curing (such as accelerators):

- **Benefits:** There are savings in curing energy consumption; a reduction of one hour of curing saves around 0.47 GJ to 0.8375 GJ per bed (this is around 0.000374 to 0.000667 TOE per 1 tonne of production, which is around 0.00101 to 0.00179 eco-points per tonne of product).
- **Drawbacks:** Most manufacturers prefer to use plasticizers (not accelerators) Most accelerators available in the market contain calcium chloride, which may affect corrosion in the concrete. Furthermore, the environmental impacts of plasticizers can be relatively high (reaching 0.38 kg of CO_2 per 1 kilogram of admixture) – the same may apply to accelerators.

D9 – Option III. Development of a pre-programmed curing energy control system rather than using an ON/ OFF system:

- **Benefits:** proper control of energy for precast can lead to reductions of 27 kW – such savings can cut electrical curing energy by 18%. There can also be substantial economic savings exceeding £7.73 per casting[59].
- **Drawbacks:** Basic systems for power control cost over £2,000.

D9 – Option IV. Only heat beds with casts. Keep beds unheated when not used:

- **Benefits:** There will be some basic savings in energy consumption (See Figure 6.20). These are not specifically known. However, such measure might contribute to savings reaching up to 40% of curing energy. The savings in curing energy will also lead to savings in cost.
- **Drawbacks:** This might require additional coordination work to save energy, taking more tasks and more working hours. An automated system might save efforts but the capital investment cost could be substantial.

[59] This has increased substantially since 2002.

D9 – Option V: Use advanced heat insulation (electric covering blanket system, etc):

- **Benefits:** Such technologies operate at lower safe voltages reaching 24 to 48V. The system also consumes less energy (Mangat and Catley, 2005). Some of the manufacturers of such systems claim savings for companies reaching £200,000 pa[60].
- **Drawbacks:** In addition to unknown effects on production/ delivery time, there is the cost of installation of the new system.

6.7.8 The layout of the factory (D10)

Two solution options were identified for this decision-area.

D10 – Option I. Modifying the layout of the factory and bringing stockyards and production halls much closer:

- **Benefits:** There would be savings in internal transport energy, possibly reaching around 38.88 MJ/ tonne; this is 0.0025 eco-points/ tonne for hollowcore and beams.
- **Drawbacks:** The economic impact can be high, this is due to modification costs, possible costs and inconvenience caused by re-engineering of some processes and tasks, in addition to costs of some new capital equipment.

D10 – Option II. Use of more energy efficient and flexible internal transport systems (a combination of cranes and forklifts):

- **Benefits:** There would be savings in internal transport energy, possibly reaching around 38.88 MJ/ tonne; this is 0.0025 eco-points/ tonne for hollowcore and beams.
- **Drawbacks:** There will be substantial costs for such new capital equipment.

The following matrix (Table 6.16 A and B) summarises the 29 solutions suggested in the thesis.

[60] Inditherm Plc. Heating Solutions for Challenging Environments – http://www.inditherm.com/

	Decision Area	Solutions
1	**Supply chain structure and suppliers choice for manufacturer (D1)**	Option I. Maintain impacts associated with the supply chain and concentrate on means of transport (more efficient vehicles, use of rail, etc.)
2		Option II. Consider sourcing distance as a factor in choosing suppliers and jobs to be taken
3		Option III. Use more energy efficient raw material trucks.
4		Option IV. Ignore impacts from transportation
5	**Product depths manufactured by the factory (D2)/ Levels of customisation of products (D3)**	Option I. Replace the concrete casting system employed
6		Option II. Tackle customisation impacts through reuse and recycling of sawn and discarded portions.
7		Option III. Maintain customised waste. Instead work on increasing production per unit of energy consumed.
8		Option IV. Ignore the problem and invest in other energy saving activities.
9	**Size and flow of jobs/ orders coming to the shop-floor (D4)**	Option I. Consider production for stock to maintain stable flow in production.
10		Option II. Modify the way jobs are set and organised (such as never casting products using less than the full length of the bed).
11		Option III. Additional tasks for managers to work with shop-floor in reorganising orders to enable productive flow.
12		Option IV. Allowing for more production control through increase in lead-times.
13		Option V. Ignore the problem and pass it on to the shop-floor personnel.
14	**Cement and additive content within concrete mix (D5)**	Option I. Reduce cement content and use a partial replacement material (PFA, GGBS, etc).
15		Option II. Reduce cement content and increase levels of lime dust in the mix
16		Option III. Reduce cement content and use plasticizers.
17		Option IV: Reduce cement and allow more curing time for products.
18	**Accelerating hardening and curing through changes to mix content (D6)/ Reuse and recycling of materials and products (D7)**	Option I. Use of discharged water and wet (un-set) concrete residue internal recycling and reprocessing systems
19		Option II. Reuse of local crushed concrete in production.

Table 6.16 (a) Environmental solutions for the ten problematic decision-areas.

	Decision Area	Solutions
20	**Type of production systems employed (D8)**	Option I. Change the major production systems employed to more environmentally acceptable ones (casting system, curing fuel, internal transport machinery, etc)
21		Options II. Carry out a few changes to some of the employed systems (such as changing the length of the curing beds, or installation of a power control and bed heating control facilities for the curing)
22		Option III. Maintain the major production systems and invest in operational and maintenance systems
23	**Operation of curing beds, concrete bullets (skips), gantry systems, and internal transport equipments (D9)**	Option I. Abandoning accelerated curing and leaving products to cure naturally
24		Option II. Reduce timing for accelerated curing and use other means of curing (such as accelerators)
25		Option III. Development of a pre-programmed curing energy control system rather than using an ON/ OFF system.
26		Option IV. Only heat beds with casts. Keep beds unheated when not used.
27		Option V: Use advanced heat insulation (electric covering blanket system, etc).
28	**The layout of the factory (D10)**	Option I. Modifying the layout of the factory and bringing stockyards and production halls much closer
29		Option II. Use of more energy efficient and flexible internal transport systems (a combination of cranes and forklifts)

Table 6.16 (b) Environmental solutions for the ten problematic decision-areas.

The description offered for each of these 29 solutions is generic – this is to allow for other applications that might use the same approach and offer the same benefits. It should be noted that none of these solutions was based on bias or preference towards manufacturers. As explained in Chapter Eight, many of these solutions were considered controversial by the interviewees. However, these were other elements that could have been considered in the study – these include solutions that offer benefits in later stages of the hollowcore and prestressed beam life cycle, and solutions associated with products used with hollowcore and prestressed beam, such as lightweight aggregate blocks and aerated blocks with a fly ash content. However, these cannot be considered within the scope stated in Chapter One.

6.8 Conclusion

The environmental profiles produced (using Life Cycle Analysis) for the five PFF factories were explored, analysed, and discussed in this chapter. Results from these environmental profiles do not seem to differ significantly from other results extracted from studies carried out in Europe and North America. This makes many of the results and findings produced in this study representative of the *status quo* of the precast flooring sector either within the UK, or in industries in other developed countries. However even if this means that the environmental performance of the UK precast flooring sector is as good as its counterparts in other countries, it does not mean that the UK manufacturers (or at least the PFF manufacturers) are currently aware of the need to successfully combine their environmental and business economic improvement needs, nor are they necessarily aware of ways achieve this.

The main finding of this stage of research is that environmental impacts associated with precast flooring production are directly, and indirectly, linked to specific measures and conditions in the precast factories. Many of these environmental impacts can increase/ decrease considerably due to a change in these conditions and measures. Looking at the links made between the environmental impacts and some departmental decisions in production, it is clear to see that manufacturers cannot attain their economic objectives without triggering major environmental impacts.

Therefore, it was necessary to identify the main decision-areas where the major environmental impacts occur (Section 6.6.3), and those responsible for these decision-areas (Section 6.6.2), to establish a range of possibilities to present to the industry:

A group of 29 different environmental solutions (or remedies) were identified for the problematic decision-areas. However, one main threat that might jeopardise the action-research approach of the study is the manufacturers' understanding of the problem and their reaction to the results of the LCA, and their attitude towards an offered environmental solution. It is very important to understand how manufacturers perceive sustainability and environmental impacts and whether the positive comparisons of the LCA results against other international competitors are satisfactory, present a benchmark, or offer cause for concern. After all, it is quite possible that decision-makers within the industry might not be keen to improve their businesses through a structured approach to sustainability, as many are being more driven by costs and economic benefits. Therefore, prior to the exploration of the environmental solutions and the means of modifying the conventional decision-making framework to allow for environmental improvement, it was necessary to look at the views of decision-makers and their perceptions toward sustainability and boundaries between business needs and sustainability needs.

It should be noted that the following stages of the research only recognise the main environmental impacts identified in 6.6.1. The organisational tasks discussed in these stages are limited to the 10 decision-areas identified in 6.6.3. Only those managers responsible for these decision-areas are considered and have participated in the focus groups and interviews described in Chapters Seven and Eight, which follow.

CHAPTER SEVEN: RESULTS, ANALYSIS, FINDINGS, AND FEEDBACK FROM FOCUS GROUPS

Chapter Seven: Results, analysis, findings, and feedback from Focus Groups

This chapter analyses the major results of the focus groups stage in the study. Primary data was collected from three focus group sessions that included members of the Precast Flooring Federation (PFF) Technical and Marketing committees (Sessions I and III respectively) and the PFF Council (Session II for Strategic managers) in the period between January and June 2005[62].

As explained in Chapter Two, following the results of the LCA study, it was possible to identify the main decision makers influencing the environmental performance of precast flooring manufacturers. One of the main factors associated with the aim of the study is the manufacturers' understanding and perceptions of sustainability. Identifying the main environmental impacts does not necessarily mean that the manufacturers will simply adopt environmental improvement solutions and techniques to eliminate these impacts; the consent of manufacturers is an important factor. Such consent should be driven by a combination of pull and push factors, understanding the influence of these drivers could offer a clear picture of how to implement sustainability. The focus group sessions were designed to tackle this issue.

The sessions included managers from nine member companies in the PFF. The focus groups concentrated on the four crucial environmental impact areas identified in Chapter Six (6.6.1). The focus groups also dealt with the constraints associated with the 10 main decision-areas identified in 6.6.2. A survey was also completed by the participants during each session. The results of the survey are demonstrated and discussed in Appendix N. A brief description is offered in Section 7.1

The members of the focus groups offered substantial information on many issues associated with their perceptions of sustainable development principles in their sector, and their understanding of the boundaries between business objectives and sustainability needs (see research methodology description in Chapter Two). The chapter also analyses and discusses the implications of the results received from focus groups' participants.

[62] A sample transcript is available in Appendix M

Appropriate findings and feedback are then taken to the following stage of the study (Chapter Eight), and the main discussion chapter (Chapter Nine).

7.1 The focus groups survey

The survey used during the sessions was completed by 30 respondents: 10 members from each of the Technical, Strategic, and Marketing focus groups. It should be noted that the ratings given by the respondents (See Appendix N) were indicative and, therefore, not statistically analysable. The questions asked in the three sessions were not always identical, but the same issues were covered in each session and the same style of feedback was received. This section is organised in accordance with the sequence used for the survey questions (See Appendices D and L).

As explained in Appendix N, the results of the survey were not conclusive; although all respondents agree on the importance of sustainability, some of the replies offered in the survey were worrying: No more than 40% in the three sessions believed that there is an actual unexaggerated threat to the environment. It was also possible to detect some level of contradiction and inconsistency in answers (See Q3 in Appendix N). In most of the answers, it was noticed that Marketing managers offered the most optimistic replies. It was not possible to clearly verify why this took place. The tendency of Marketing managers to offer politically correct explanations and the fact that the Marketing managers' session was carried out two weeks prior to the *Live-8* international concerts and the Gleneagles *G8* summit events (in Summer 2005) might have had some influence on respondents' opinions[63].

7.1.1 Assessing the industry using the Dunphy *et al* (2003) model

The results received from the three focus groups do not seem to present a single, constant pattern. Nearly all group votes, except those associated with the importance of sustainability, included a combination of impressions (from *low*, to *medium* and *high*). This clearly points to the fact that managers hold different views on the issue of sustainability. It also points to the fact that it is not possible to offer a single classification based on

[63] This should be interpreted in conjunction with events when the study was conducted and the growing influence of sustainable development (as identified in the introduction to Chapter Three).

Dunphy[64] *et al* (2003) for each group (or company). In this section each group session is looked at separately, and a view on the general classification of the industry is then given.

Using the Dunphy classification characteristics demonstrated in Chapter Three, it appears that the focus group members offered a collection of views that range mainly between four categories in the Dunphy model; these are Denial, Non-responsiveness, Compliance, and Efficiency. Tables 7.1, 7.2, and 7.3 break down the replies of each focus group in accordance with the Dunphy model. A final average is offered in the last row of each table. Figure 7.1 shows the final results for the three managerial categories.

Questions included	Rejection Category (%)	Non-responsiveness Category (%)	Compliance Category (%)	Efficiency Category (%)	Strategic pro-activity (%)
Question 1	0	0	33	33	33
Question 2	11	28	28	17	17
Question 3	33	13	13	20	20
Question 4	0	4	32	32	32
Question 5	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Question 6	33	33	33	0	0
Question 7	32	32	23	14	0
Question 8	29	29	29	10	5
Question 9	26	26	16	16	16
Question 10	19	19	13	25	25
Total/ rate	**20**	**20**	**24**	**18**	**16**

Table 7.1 Classification of Technical focus group members using the Dunphy *et al* (2003) Model.

[64] See the Methodology chapter (Chapter Two) and Chapter Three for more on why the Dunphy *et al* (2003) method was preferred.

Questions Included	Rejection Category (%)	Non-responsiveness Category (%)	Compliance Category (%)	Efficiency Category (%)	Strategic pro- activity (%)
Question 1	0	0	33	33	33
Question 2	11	22	22	22	22
Question 3	25	6	6	31	31
Question 4	4	0	32	32	32
Question 5	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Question 6	26	26	26	11	11
Question 7	12	12	27	42	6
Question 8	9	9	9	39	35
Question 9	0	0	25	38	38
Question 10	11	11	33	22	22
Total/ rate	**11**	**10**	**27**	**30**	**22**

Table 7.2 Classification of Strategic focus group members using the Dunphy *et al* (2003) Model.

Question's Section	Rejection Category (%)	Non-responsiveness Category (%)	Compliance Category (%)	Efficiency Category (%)	Strategic pro-activity (%)
Question 1	0	0	33	33	33
Question 2	13	19	19	25	25
Question 3	18	41	41	0	0
Questions 6, 11	7	7	7	40	40
Question 7	15	15	15	15	38
Question 8	25	25	33	8	8
Question 9	25	25	25	13	13
Questions 4, 7, 6, 10	0	0	7	47	47
Total/ rate	**13**	**17**	**23**	**23**	**26**

Table 7.3 Classification of Marketing focus group members using the Dunphy *et al* (2003) Model[65].

[65] It should be noted that Questions 8 and 9 in the Marketing focus group were placed in a different order to questions in the other two focus groups. Question 9 can be found in section 8 (Appendix M), Question 8 can be found in section 9.

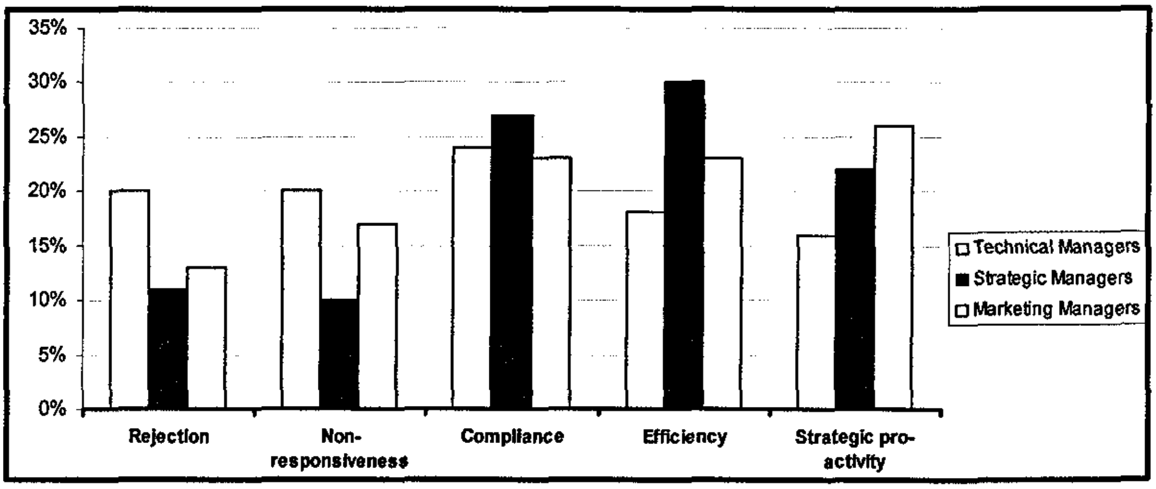


Figure 7.1 Classification of the three decision-maker categories using the Dunphy model (Dunphy *et al*, 2003).

The results from Tables 7.1, 7.2, 7.3 show a variety of classifications for the different answers given by various group members. Marketing managers seemed to be the most optimistic, followed by Strategic managers, and then Technical managers. It is possible that the views in each session were affected by specific factors. In the Technical session, unawareness might have had an impact on ratings (as explained in Section 7.2). In the Strategic session, the personality of one respondent was so dominant it might have affected the other respondents' ratings. The Marketing session was organised a few days prior to the 'G-8' summit (where sustainable development was a high-profile agenda) and many of the comments (as explained in Section 7.2) were not realistic and lacked consistency.

However, it is clear that many of the final ratings cannot be taken for granted given that 30 respondents (with divergent views) participated in making these ratings. Anderson (1992) argues that traditional organisational research has been based on the 'illusion of manageability', relying on a consensus view of organisation (or in this case an industry sector) life which, according to Anderson (1992), results in the 'reification of managerial dominance'. In order to avoid this, the ratings will not be used to prototype or identify specific categories of manufacturers. However, it is possible to use these results, along with other qualitative results, to question the context in which environmental improvement measures can be introduced to each decision-making category within the organisation.

7.2 Focus Groups qualitative/ quantitative analysis and discussion

Results from qualitative discussions and points raised in the three focus groups offer some significant findings, sometimes in contrast to those found in answers to the specific survey questions asked via the focus groups. In order to achieve the objectives set for the focus groups, the results were classified into six main categories, all of which are associated with the main objectives of the research. Results for each category are investigated in this section.

7.2.1 Manufacturers' awareness

The focus groups produced different results in terms of awareness and perceptions of sustainable development. The basic impressions on awareness were generally positive and, the discussions revealed that most (if not all) respondents basically understood and recognised the importance of sustainability for the industry; all respondents agreed that sustainable development was an important issue (30 out of 30).

7.2.1.1 Lack of knowledge

Awareness (especially basic awareness) and knowledge should not be considered as the same aspect. Being aware of the general importance of sustainability does not necessarily mean that respondents have the knowledge to appreciate the full impact and importance of the subject. There were several indications of lack of knowledge, including long periods of silence during answers with many members preferring to offer short and general answers or not participating at all. There were also several comments where those involved admitted that they were not aware of the impact of the issue, for example one comment was made in the Strategic group session:

'*...we are production-based, all of us, and we're not environmentalists. So, it's only our opinion; of information that we're given; seen on the news; seen on the ads.*'

Other comments suggested confusion about the whole issue. The following comment was made in the Strategic focus group session:

'Realistically, we don't know; we just take advice from whatever perceptions are given to us on individual basis.'

The lack of awareness also provided worrying effects when many of the respondents addressed the main environmental impacts in terms of cost and economic efficiency. This problem is further covered and addressed in section 7.2.4

Another aspect that might complicate the problem is how lack of knowledge can affect the perceptions of those interviewed. One comment made by a respondent in 7.2.2.1 shows the negative effect of misunderstanding the concept of sustainability. There is another problem of denial which is directly linked to this; this problem is mostly associated with a small group of respondents (mostly in the Strategic Group). There were several responses that reflected the image in which respondents want themselves to be perceived by others (knowledge and care for sustainable development requirements). However, in depth results show the contrary. In one example, the members of the Strategic group agreed that sustainability was important and the governmental tools used were suitable, and most of them agreed that the issue of sustainability was not being exaggerated (see sections 1, 2, and 3 in Appendix N). However, very few of them (no more than 30%) rejected the suggestion that there were no convincing reasons to pursue and promote sustainability (see Section 10 – Appendix N). Another example can be found in answers given by the Marketing/ financial focus group for Question 4 (Section 10 – Appendix N) where respondents confirmed that they were aware of the principles of sustainability, however replies given to the Drivers category showed substantial misconceptions.

7.2.1.2 Confusion in answers offered

The problem of lack of knowledge also had other negative effects on the overall results. Some of the replies received showed a considerable level of confusion and inconsistency. Many of those involved in the sessions were not aware of the basic principles of sustainable development; the considerable differences in answers provided by the first and second focus groups (in questions 7, 8, and 9 – Appendix N) offered some indications of the level of awareness within the industry:

- The two groups disagreed on the question set to explore the moral obligation potential (Q7). This can represent a problem as many of the organisations involved identify sustainability and environmental improvement as parts of their strategies and mission statements. A member of the Strategic focus group noted that this could possibly be due to lack of awareness of those interviewed in the Technical group.

- There is also confusion in answers given by the two groups over the corporate image and customer service potential of *sustainability* (Q8).
- There are substantial differences in answers provided by the two groups on the existence of competitive advantages in adoption of sustainable development principles (Q9).

These contradictions in answers suggest that the respondents (especially those in the Technical Focus Group) may not have a proper grasp of the concept of sustainable development or prospects of environmental improvement. However, results from other questions also showed that the same may apply to the other groups as manufacturers' replies showed some confusion about sustainability and purposes behind governmental regulations (also highlighted in 7.2.1).

This issue of confusion, and the inability of the industry to develop a rational overall understanding and action, has been highlighted in the literatures; it is one of the main reasons why there is an apparent lack of enthusiasm across the industry[66]. This confusion was also detected in most replies dealing with the Aggregate Levy (explored below). In addition to awareness problems, many of those interviewed have views on the introduction of sustainability, and many of them offered negative views on some of the issues addressed.

7.2.2 Manufacturers' general perceptions

The focus groups offered mixed results on acceptability and perceptions of sustainable development. It appears that their views were consistently influenced by their insistence on considering issues in the context of business economics or administration.

In spite of the indications of low levels of awareness and knowledge, the manufacturers did have their own personal views (some of these can be considered as strong or controversial). Although none of those interviewed were known to be environmental experts or enthusiasts, 20% of those participating in the two first focus groups believed that the sustainability issue is being publicly exaggerated. This should cast deep doubts on the manufacturers' intentions towards sustainability implementation and whether they would

[66] *Editorial*: Confused message on sustainability, *Construction Products*, March 2005 (pp7, 10-14).

accept introducing any environmental improvement measures. As noted earlier (and as detailed in section 7.2.5.2), the manufacturers identified several aspects and measures crucial to their business case, which they believed should never be affected or compromised by any sustainability measures.

One reply provided by a respondent in the Marketing focus group shows clearly how manufacturers perceive this issue. When asked about implementing sustainability even if no economic benefits were evident, a respondent referred to a presentation he attended on the implementation of sustainable development:

'....I was attending a presentation about sustainability, and the conclusion of the presentation was if you don't make a profit, then it's not sustainable'

This comment might show that there is a misconception among manufacturers on the triple bottom line concept of sustainability. Moreover, it might simply reflect the strong views consistently expressed by manufacturers on the limitations and the 'red lines' restricting the implementation of sustainability. These red lines are identified in Section 7.2.5.

Section 7.2.1 also showed how lack of knowledge and confusion might have played a major role in shaping perceptions. Another possible factor that might have influenced results is bias. There are several indications that some of those interviewed are simply biased. One of the strongest indications is that found in replies given to Question 2 for the three focus groups conducted, and Question 6 in the third Marketing focus group, where strong views were expressed, but no economic or functional justifications were offered.

However, it should be noted that there were several positive views and comments by the respondents in the different focus groups. In many of the controversial questions (such as Questions 2, 3, 5, 7, 8 and Question 6 in the Marketing focus group), more than half the groups' members approved measures that could affect their profitability. In the second focus group, some of the respondents even went as far as suggesting adjustments to laws in order to impose more constructive pressure on manufacturers.

However, by looking at the views offered by different respondents during the three focus groups and ensuing discussions, it is possible to understand the main influences on such opinions. These are explained in the following sections on governmental tools and policies, drivers, and red line areas (or constraints).

7.2.3 Perceptions of governmental tools employed

Assessing the performance of the industry in complying with governmental regulations (on aspects associated with sustainability and environmental performance) is not a specific objective for this study. However, understanding the perceptions and reaction of manufacturers toward these governmental tools might offer information and findings on how manufacturers understand and integrate governmental sustainability requirements into their conventional decision-making framework.

The survey replies offered were slightly sceptical. The replies from the Technical focus group were the most negative; this might indicate that their replies (on this perspective) were the most genuine. The Marketing focus group addressed only one aspect associated with governmental measures employed (Question 3). In their replies, none of the participants agreed that governmental measures used to address sustainability were suitable, instead most of their replies were under the '*I don't know*' category. In the same question, it is believed that a comment from one participant, stating that they do not do something unless they are '*kicked*', might have influenced the opinions of many of those involved in the Strategic focus group. Actually, the general perceptions of Strategic managers were not as optimistic as shown in Question 3; the answers given to Question 5 shows that 7 out of the 10 participants in that group believed that the way sustainability was imposed using taxes and levies was wrong and harmful to the industry.

The main factor driving discussions on governmental tools and levies was the Aggregate Levy; discussions on the Aggregate Levy occupied around 10 to 15 minutes of the second focus group session period. The reason is mainly economic; manufacturers are required to pay an additional £1.60 for every tonne of virgin aggregate they use in concrete (a cost passed on from their suppliers). Comments from some respondents (at the first focus group), described it as the "*most severe action undertaken by government*" and "*I would question if it's justified*", showing how some very specific factors (such as the Aggregate Levy) can be behind a huge shift in views toward threats to the environment.

The content of the discussions on the Aggregate Levy and the means identified by respondents to deal with the issue might show how manufacturers think about some of the sustainability measures (seeking economic resolutions). Delegates concentrated on issues such as passing the cost of the levy or absorbing it through more efficiency (i.e. recycling). This might show how the industry was considerably affected by that levy. It may also raise the question of governmental and regulatory use of economic tools to raise industry's attention to sustainability.

There were many views from manufacturers about why the levy was introduced, some suggested that it's no more than an extra financial benefit for the government. Others pointed to political powers from environmental and civil society lobbies. However, most manufacturers realised that the measure was taken by the government to force manufacturers to react. Many organisations had been successful in avoiding the tax through passing its economic impacts through the supply chain, as one respondent in the second focus group expressed: '*It depends on who is selling and who is buying*'. However, there were several changes due to the levy; as noted in the second focus group, the price of recycled aggregates had risen since the introduction of the levy.

The issue of fairness of the aggregate levy and the impact on companies (of differing sizes) was also raised by some of the members. There were also complaints about the '*all take*' culture implemented by the government. The discussion above clearly pointed to two main factors (or findings) that may have a considerable influence on the direction of the entire research:

The first factor is associated with the views of manufacturers and how they look at economic gains and losses in assessing and addressing every aspect associated with the business (including sustainability aspects). This was very evident in discussing most of the regulations associated with environmental performance, notably in discussing the Aggregates Levy. This may have effectively set the bar for any environmental solution or measure to be adopted.

The other important factor is the considerable flexibility and understanding shown by many of the members (mainly in the Strategic and Marketing focus groups) in exploring the different problems and constructively discussing governmental measures, social responsibility, and moral obligation requirements. This definitely shows that managers are still prepared to go further beyond the red-lines to address the issue. However, the earlier findings still show that there are limitations as far as some manufacturers are concerned.

7.2.4 Drivers to sustainable development

There was a slight divide on the main push/ pull factors influencing the implementation of sustainability and environmental solutions. While respondents of the first two focus groups agreed that regulations and taxes are the main driver for sustainability, respondents in the third session aim at three main drivers, these are moral obligation, corporate image and customer focus, and regulations and taxes.

The tendency of most members in the third session (Marketing managers) to give a *medium* grade (to the influence of regulation and taxes) has affected the general vote considerably. However, with 18 *high* votes (out of a possible 30), regulations and taxes are apparently the most influential drivers.

Results on moral obligation and social responsibility were *low* in the first focus group session (Technical managers). One of the main reasons for such a result was the inability of Technical managers, as middle management employees, to address issues not associated directly with profitability, i.e. that there are no profits in '*Doing the right thing*'. Indeed, when the Technical focus group was asked to explain 'doing the right thing' there were laughs. One participant in the Strategic focus group noted that the Technical managers' reply might simply be due to lack of awareness. Results from Strategic and Marketing managers were much more sensible; delegates of the Marketing session even extended the debate further to include other ethical matters including noise control and relationships with neighbouring communities.

'Customer focus' does not seem to be a strong driver in implementing sustainability. The votes given by the Strategic focus group were the most moderate, however their replies should not be described as enthusiastic about the concept as 50% of their votes were given to the *medium* category. Furthermore there were no comments from the Strategic focus group session members on how sustainability could serve customer requirements. Replies from the other two sessions were very negative with only 16% of the respondents (in the two sessions) believing that sustainability could be considered as a customer service objective. This can be due to several reasons, one of which is the prevalent culture in the UK where customers do not push for sustainable products (one of the members of the first focus group noted that this might be suitable for specific types of customers/ projects), however with the wide base of customers served by the sector, it is not possible to establish a comprehensive strategy to market sustainable products. Another member (in the same session) noted that even if they were involved in a project requiring sustainability solutions, this would still not be a driver for them to employ sustainability as a Strategic customer focus or benefit, suggesting that:

'If there was a need for a BREEAM certificate for their property (like in the gherkin: Norman Foster's. That's where they get that BREEAM certificate saying that they're complying with ... whatever!!) That's a statement for them; for their reputation, but for us we have to comply with what they want, that decision is made way down the line before we even get involved in it'

Moreover, some of the controversial activities causing major environmental impacts are influenced by other upstream partners within the supply chain (such as clients and architects). The issue of customisation was raised during the second session; there is a high tendency from clients and architects to produce complex designs requiring bespoke products. One respondent compared this with the culture in mainland Europe where modular design is preferred[67]. There is obviously no strong demand for sustainability from the downstream, however this is set to change with the increased laws and coming changes to Part L and many other Building Regulations. The use of sustainability as a competitive advantage in the industry is imminent, though not immediate. Such action could make a considerable change in the industry (depending on the level of economic potential and viability).

Further conflicts in opinions were also detected in questions on perceiving sustainability as a competitive advantage in hollowcore and prestressed beam marketing. Only Strategic managers were optimistic about such a possibility. However, apart from comments in the Marketing focus group, there were no explanations offered about how such advantage would materialise. In spite of the positive reply, Strategic managers also believed that there might be some difficulties in selling the concept of sustainability (compared to other competitive types of flooring), because customers might not be interested. These were completely opposed to the views expressed by Marketing managers who cannot see a

[67] The problem of customisation proves to be a major efficiency obstacle to UK. A recent study of the construction industries of 13 European countries placed UK near the bottom of the efficiency leaguer. The main reason was mainly associated with how projects are handled between different partners and lack of contractors' influence on how buildings are designed and specified that those in the UK. The lack of industrialised approach in the UK was identified as one of the main obstacles (Williams, 2006).

strong competitive advantage in hollowcore or beams, but they still believe that they can sell sustainability. It was not clear whether Marketing managers offered such votes due to their beliefs about sustainability (given that many of their votes were more optimistic than others), or whether they were referring to their abilities to sell the concept. The contradictory replies from these two session groups, in addition to the unclear reply given by Technical managers, offer a confused result over all.

Another aspect covered in the push/ pull factor questions is a question about the viability of sustainability and whether there is a lack of convincing factors. The replies from members of the Strategic and Technical groups show clear divides among members of each group. Indeed, most of the votes in the Technical group session were divided between the two extreme categories (*Low* and *High*). The votes in the Strategic session were also divided with 30% going for each of the lower categories (*Low*, *Medium*, and a respondents' created '*I don't know*' category). Removing the '*I don't know*' category still shows no consensus among members of the group. In general, replies from members of the Strategic session seemed to be more optimistic.

Replies from the third Marketing group were more comprehensive as the question had been redesigned and broken down to account for four main aspects: these are '*I don't know*', '*distraction and waste of time*', '*I don't care*', and '*cost burden*'. The Marketing session members denied being unaware of sustainability requirements with no more than 12.5% of the votes going to the *Medium* category (to be read in conjunction with the discussion raised in 7.2.1.1). Very few members in the Marketing session thought that handling sustainability might result in a distraction and '*waste of time*'. This indicates clearly that the Marketing session members were more interested and concerned about the subject. The same applies to the '*I don't know*' category. However, many of those interviewed thought that there was a cost burden in adhering to sustainability requirements (this is discussed further in section 7.2.5).

In general, it was clear that most of the factors driving the implementation of sustainability are compelling. The main driver for sustainability was regulation and taxes, other drivers include moral and image obligations. This might be a deterrent for manufacturers from voluntarily implementing sustainability; with the lack of demand from customers, lack of foreseen economic benefits, and lack of influence from dominant partners in the supply chain, it is very difficult for the industry to accept the concept of modifying their conventional systems to incorporate the principles of sustainable development and environmental improvement. However, as explained in previous sections, not all replies from focus groups were sceptical towards the concept. Moreover, it is still possible to look for other measures to promote such change. These are demonstrated briefly in 7.3, and explained in more detail in Chapter Nine.

7.2.5 Looking at sustainability aspects through economic means

On many occasions, manufacturers addressed sustainability matters using pure economic and monetary terms. This should not be taken as a mistake given that analysing, and justifying, environmental performance aspects through economic means is widely used in different sustainability practices (Heerwagen, 2000). However, on many occasions there has been a failure by focus group respondents to recognise the non-economic benefits arising from sustainable development and environmental improvement measures.

7.2.5.1 Reasons behind manufacturers' views

There is a collection of clear and justified reasons why manufacturers might sometimes tend to assess crucial sustainability and environmental improvement measures using conventional economic views. These include the following:

Respondents might sometimes make such mistakes unintentionally; this occurred at least twice in the sessions. In the first focus group respondents were asked to brainstorm the most severe impacts (respondents were given a prompt sheet with helpful information). One of the respondents noted that transportation should be the main impact; he noted that they know it is an influential aspect due to the high costs associated with logistics and this should imply high environmental impacts and energy consumption. The other example was in the second Strategic focus group. The facilitator enquired about means used to save energy and he was informed by a respondent that they usually choose to carry out most of their energy intensive activities in the early morning as the prices of energy are cheaper at these times (the interviewee later corrected himself). However, these examples can be considered as genuine mistakes where no implicit messages were made.

However, on many occasions during the three focus group sessions, the debates have drifted and addressed the conventional economic subjects and measures associated with some sustainability and environmental impacts; the severity of the Aggregate Levy took a considerable portion of time in the first and second sessions. The same applies to discussions on the main obstacles to sustainability. Question 15 (see section 15 – Appendix N) was always handled and addressed from an economic view. Even when members assessed some of the environmental solutions for obstacles or governmental constraints, they always referred to the low returns on some of these solutions, such as production of recycled aggregate, or energy reduction and saving systems, therefore avoiding or missing out on the main reason behind these solutions, which is environmental improvement.

However, the most alarming reason for this was the unwillingness of some members of the groups to compromise on the economic needs and objectives of their organisations by any means. For some of the manufacturers (as explained in 7.2.5.2), the business case appeared to dominate the manner in which sustainability was embraced. Chapter Nine explains how it is possible to take advantage of such reasons in promoting sustainability within the industry, by using the conventional language used by the manufacturers.

7.2.5.2 Red line areas in implementation of sustainable development and environmental improvement

During the sessions, it was possible to identify a group of measures and aspects which can be considered as fundamental or 'red line areas' for respondents participating in the three focus groups. It is quite possible that the key to the acceptance, or rejection, of any problem solving framework in the industry lies with these 'red line areas'. These include the following:

- **Preferring economic interests over environmental interests:** In all the aspects discussed within the chapter or in section 7.2.5, it is evident that economic interests are always favoured over environmental interests. With no convincing demand from customers, or other partners within the supply chain, there are no immediate Strategic benefits in sustainability. However, it should be noted that this view mainly depends on the context in which environmental interests are being addressed.
- **Radical changes affecting product content (especially cement content):** Data received from respondents show that manufacturers look at cement content to address two main issues: technical requirements (strength, and workability), and the cost of cement and how this can be reduced by the use of cheaper alternative materials (such as PFA). However, it is very difficult to carry out changes to the cement content to fulfil any other requirements. The respondents confirmed more than once that this is a red line area.

- **Large-scale investments affecting production systems (means of internal transport, etc.):** It was noticed that there is considerable resistance to any suggestions affecting major production systems used. This is mainly for two reasons: (1) Many of these production systems have very high capital and maintenance costs, so it is not possible to ignore such fundamental elements for the sake of measures (such as environmental improvement) that are not firmly linked to the business case. (2) Manufacturers are concerned about the possible effects of radical change to major production and management systems employed in factories. In one example, associated with changes to the transportation systems employed in some factories where considerable energy is consumed, one respondent in the first focus group noted '*I think we're all trying to be as efficient as we can, but I don't think that anyone will go for a sudden change*'.
- **Business and production systems enabling customisation:** As noted earlier in Chapter Six, most of the hollowcore concrete waste usually results from operations and activities associated with hollowcore's customisation. This issue (customisation waste) was raised in the focus group sessions; there was some intense opposition to any suggestions by the facilitator to deal with customisation (as a major source of environmental impact). One member of the Strategic focus group insisted that customisation: '*works both ways*'.

7.2.5.3 Long-term rewards against short-term gains

Preferring long-term benefits to short-term gains does not seem to be an adequately appealing principle for the Marketing focus group members. There are plenty of environmental advantages incorporated in precast elements and products, but many of these advantages are not fully quantified. Accordingly if there is a short-term economic gain in abandoning a specific long-term environmental benefit, the middle-management will probably favour the short-term economic gain. The inability to properly address and market long-term environmental and economic benefits (including benefits associated with the potential for competitive advantage, thermal mass leading to operational energy savings, etc) will always influence how manufacturers look at trade-offs between short-term gains and long-term environmental/economic benefits.

Therefore, the following fact has to be accepted as a conversion in precast manufacture: short-term economic gains are the major objectives in the production process for precast flooring. However, it might still be possible to take advantage of such a fact:

environmental benefits directly linked to these gains (including energy consumption and some streams of waste generated) can be easily embraced by the industry. But, some specific measures directly linked to possible short-term economic losses and long-term environmental benefits (such as concrete waste associated with customisation) are very hard to address and justify. It appears that the most logical and rational option is to invest in a collection of solutions not directly in conflict with the short-term economic gains.

Many of the aspects mentioned in this section (7.2.5) could severely affect environmental improvement prospects. However, most of the negative effects discussed can influence the manner and context in which environmental improvement measures are addressed. It is still possible (as explained in Chapter Nine) to take advantage of manufacturers' economically-driven views to endorse sustainable development and environmental improvement criteria.

7.3 Conclusions

The purpose of the focus groups was to understand manufacturers' perceptions on the introduction of sustainability to the industry. The focus groups also explored the boundaries set by manufacturers between environmental and economic needs. It is clear that respondents in the focus groups expressed a variety of opinions on the subject. Although all respondents agree that sustainability is an important matter, a minority of them have questioned whether the issue is being exaggerated. Further analysis showed some lack of knowledge and unawareness on behalf of those interviewed. Moreover, results show that the push/ pull factors for sustainability were mostly compelling. Manufacturers also identified some red line areas that should never be compromised for the sake of sustainability.

These results may seem negative to an environmentalist or sustainability enthusiast. However, these represent the views of many across other businesses and industries (Friedman, 1970; Pava and Krausz, 1996; Mathur and Mathur, 2000). It should be noted that these views should not deter the researcher from looking at the broader picture, but the following factors should be considered when looking at these study results:

- As noted in several parts in this chapter, the business case appears to dominate the manner in which any measure or principle is introduced. The industry recognises a collection of red lines that should not be violated by a subject such as sustainability or environmental improvement.
- Precast flooring manufacture is considered as a medium-delivery low-technology industry where nearly all the activities carried out are repetitive. The conventional organisational structures and decision-making frameworks used in the industry, based on specialities and standardised decisions, could be severely affected by radical changes to tackle aspects such as sustainable development.
- Due to the low energy consumption levels and environmental impacts compared with other industries such as cement, and due to the low pressure on the industry (apart from the Aggregate Levy), it is clear that the industry has not looked at the broader picture and does not feel the urgency to carry out any wide-scale comprehensive environmental reviews. This is set to change given the rising prices of fossil fuels and raw materials.

Moreover, it should be noted that not all results were negative. The Dunphy model (Dunphy *et al*, 2003) classification shows that some manufacturer groups have the potential to accommodate and respond to more advanced applications of sustainable development.

Furthermore, some organisational knowledge aspects could have an effect on results: Although many of the companies involved have environmental policies and strategies, it is clear from replies provided by some respondents that there is a lack of organisational and rationalised knowledge and awareness of the subject. Unlike financial, economic and productivity information, there is a lack of consistent and cross-departmental analysis for environmental impact information across the organisations. The information on environmental improvement and sustainability is not usually organised in a manner that any conventional business can adhere to, react to, or take advantage of.

All the factors mentioned above had substantial influence on the results received in the study. However, reading these results in conjunction with the factors and measures mentioned above, it appears that the reason behind some of the negative results is not associated with the nature of the environmental impacts identified or environmental solutions; the reason is mostly associated with the manner in which the issue is being presented. The way sustainability is presented, as an unfamiliar concept or burden that needs to be dealt with, is definitely unappealing. There are several positive aspects that link environmental performance criteria to the business case of precast manufacturers, many of the environmental solutions identified in Chapter Six can have a positive economic effect. These should be addressed and presented in a sensible manner that enables manufacturers to look in more detail at the economic prospects and business potential of some environmental improvement criteria. Ideally, this might not be the most appropriate way to implement sustainability. However, it is a sound mean to commit businesses to the principle. Chapter Eight is associated with the possible shape and content of the most suitable environmental solutions and remedies for the industry. Specific solutions were discussed with a number of decision makers in the industry and the possible impact on the conventional decision making framework was explored. The results are explained in detail in that chapter.

CHAPTER EIGHT: RESULTS, ANALYSIS, FINDINGS, AND FEEDBACK FROM SEMI-STRUCTURED INTERVIEWS

Chapter Eight: Results, Analysis, findings, and feedback from semi-structured interviews

Following the Focus Groups, it was necessary to investigate the most appropriate approaches to deal with the ten problematic decision-areas identified earlier in the research. It was also important to assess the applicability of the 29 environmental solutions (quantified in Chapter Six) and decide which objectives are vital to manufacturers and whether some objectives could be compromised to allow for more environmental solutions. Moreover, it was necessary to reinforce the findings of the Focus Groups and further investigate the perceptions and views of the main decision-maker groups in the industry. Thirteen semi-structured interviews were carried out with different managers and decision-makers in three precast flooring organisations. As noted earlier, the interviews only handled aspects associated with the ten main decision areas (i.e. environmental effects, solutions, etc.). The chapter explores and analyses the results received from these qualitative semi-structured interviews. The replies offered by the interviewees were tabulated and categorised using codes such as A-1, C26, B-193, etc. These codes are used repeatedly in different sections of this chapter. The results of this chapter can be read in conjunction with the question forms used in these interviews (See Appendix E).

8.1 Interview Results and Analysis: Overview of the interviewees' organisations

The interviewees offered information on the nature of their activities, changes to their practices, and main objectives targeted by their organisations. Information was also offered on their basic perceptions of sustainable development and environmental improvement. Manufacturers' views are necessary to help assess the degrees to which systems are applicable and the context in which sustainability is addressed and dealt with in the industry.

8.1.1 Changes in manufacturing and business practices

Changes in this specific section include different aspects associated with managers' work within the identified decision-areas. It should be noted that no specific questions were dedicated to this category. However, answers to the responsibility questions[67] (and some of the supply chain, production systems, and product mix questions) yielded valuable information, See Table 8.1.

			A
			Possible changes to practices and systems
1	Technical	**PFF1 manager**	Changes in the mix are very rare - aggregate types mostly
2	Technical	**PFF2 manager**	Change in raw materials (and mix) are highly-strategic decisions that take place once every 10 years (maybe more).
3	Technical	**PFF3 manager**	Change to mixes does not usually happen as there are standardised mixes that they need to comply with.
4	Marketing	**PFF1 manager**	The supply chains are quite stable with few suppliers introduced occasionally. We need to be responsive to the leads in the business (pull/ push).
5	Marketing	**PFF2 manager**	They have agreements and alliances with national customers across the country. However, the upstream of their supply chain is part of the general director's job.
6	Marketing	**PFF3 manager**	Not Applicable
7	Operational	**PFF1 manager**	No changes were mentioned - However, there is a possible update of machinery use.
8	Operational	**PFF2 manager**	Few system changes are being introduced - including the introduction of a vacuum suction system (and a boiler curing system years earlier).
9	Operational	**PFF3 manager**	After the opening of the new factory, it is expected that the old factory will be re-generated, this will offer a chance to change.
10	Strategic	**PFF1 manager**	Not Applicable
11	Strategic	**PFF2 manager**	None of us usually gets the chance of setting a brand-new factory (or system). Most of the time we look at improving our existing factories – There are lots of system changes that can take place.
12	Strategic	**PFF3 manager**	Believes that their supply chains can stay stable for the time being - many other changes were carried out in the new factory.

Table 8.1 Possible changes to practices, production arrangements, and supply chains.

In general, the replies point to stability within the supply chain (A-2 and A-4) and production systems with very few changes introduced occasionally mainly to tackle wear and tear or ageing systems. The concrete mixes are quite consistent. According to replies from interviewees in (A-2) and (A-3), it is very difficult to change mixes for environmental reasons.

[67] See Appendix E for information on the forms of questions asked and prompt sheets used.

Moreover, some inherent difficulties were identified by the Technical, Operational, and Strategic managers (A-11). One of the main problems is ageing equipment, the PFF1 factory is the oldest and largest within the sample considered. Introducing a new solution (such as use of PFA) caused problems in the older factory as some machinery could not accept PFA. This problem has been solved by PFF2 in the past by building new production halls with more advanced equipment. However, the problems of ageing shop-floor equipment continued to cause substantial and inherent difficulties. There are also difficulties in changes to the supply chain due to the huge logistical modifications that need to take place.

The strategic long-term agreements that some manufacturers have with their supply chain partners can have several implications on the environmental profile: some high-profile clients might impose specific targets and benchmarks on their contractors (McGeorge and Palmer, 1997). These targets can work both ways by either supporting or deterring sustainability and environmental improvement measures. However, replies from Strategic managers (A-11 and A-12) show what can be described as a system renewal cycle: a possible cycle of change in factories (for production systems, supply chains, etc.) with different stages and levels. This appears to affect most manufacturers; all three factories involved are in different stages of change and replacement of production systems:

- **PFF1:** This factory has not implemented many changes over the years. However, PFF1 has made changes and introduced new systems in their other factories. They are assessing the possibility of making such changes at this factory.
- **PFF2:** is constantly introducing newer systems and tasks; this process has been taking place for the last three years. They have passed the planning and policy setting stages and are now implementing a change and renewal strategy.
- **PFF3:** Instead of making changes at their old factory, they decided to build another factory (although the purpose is production volumes rather than efficiency). The lessons learnt in the new factory will be employed when the older factory is renewed. PFF3's strategy seems to be one step ahead of PFF1's, and one step behind PFF2's.

8.1.2 Organisations' objectives

The managers interviewed identified the main objectives that they look at when handling decisions associated with their respective critical decision-areas. The following table (Table 8.2) shows the responses and preferences of the managers interviewed.

			A	B
			Main Objectives	**View on economic objectives**
13	**Technical**	**PFF1 manager**	Minimising Costs, lead times and production control	Looking mainly at efficiency and cost reduction measures (sustainability is not the main driver).
14		**PFF2 manager**	Minimising Costs, lead times, quality and raw materials, and production control.	Looking at the three main production objectives in addition to resources - lower rating for control and managerial measures.
15		**PFF3 manager**	Minimising Costs, lead times, marketing, and volumes.	Looking at the main objectives in addition to the market share as a goal.
16	**Marketing**	**PFF1 manager**	Minimising costs, quality and raw materials, production control (Lead times not major objective as due to stocks)	All the objectives available in the survey (Lead times not major objective as time based problems can be solved via stocks)
17		**PFF2 manager**	All objectives	All the objectives available in the survey.
18		**PFF3 manager**	Not Applicable	Not Applicable
19	**Operational**	**PFF1 manager**	Profitability, lead times, costs, and market share	Looking mainly at efficiency and cost reduction measures (sustainability is not the main driver).
20		**PFF2 manager**	Profitability, market volume, cost reduction, quality, and time.	Cost, quality, time, resources - lower rating for control /managerial measures.
21		**PFF3 manager**	Production volume and market share, and costs.	Looking at the main objectives in addition to the market share as a goal.
22	**Strategic**	**PFF1 manager**	Not Applicable	Not Applicable
23		**PFF2 manager**	Market demands, quality, costs, productivity, customer focus + time.	Profitability through replying to market demands, quality and customer focus.
24		**PFF3 manager**	Productivity, lead times, costs and overheads (all ahead of quality).	Looking mainly to increase shares in markets (and other business objectives).

Table 8.2 Interviewees' perceptions of company objectives (see Appendix E).

Several findings can be established from ratings and comments offered by different decision-makers. Due to the limited number of marketing and strategic managers (two interviewees each), it was not possible to offer an interpretation of their preferences between different objectives.

8.1.2.1 Analysis and findings from replies given by Technical managers

The following table (Table 8.3) shows that there were some preferences for objectives associated with costs (either operational or capital); objectives associated with lead-times and quality were slightly less favourable.

Economic objectives	Very important	Important	Not important
Objectives associated with costs	100%	-	-
Objectives associated with times (mainly lead-times)	66.6%	16.7%	16.7%
Objectives associated with quality & clients	50%	50%	-
Objectives associated with functionality	27.3%	45.5%	27.3%
Objectives associated with production volumes	33.3%	66.6%	-

Table 8.3 Choices of economic objectives by Technical managers.

The relatively low ranking for quality was justified by one Technical manager (A-15) claiming that standard mixes have been employed for over a decade: '*You're not looking for a gold watch*'. One of the Strategic managers (PFF2) disagreed and confirmed that they highly value the quality of their products.

8.1.2.2 Analysis and findings from replies given by Marketing managers

The rating of objectives was somewhat undermined by the two Marketing managers. They tended to rank the vast majority of objectives as '*very important*' (this included 20 out of the 22 objectives ranked by the two managers). The only objective not to receive such a high ranking was the one associated with lead-times, which was mainly due to the availability of stocks usually kept to deal with urgent time-based requirements (A-16). Problems with the rankings can be explained in different ways, including the following:

- **Rejection:** The ranking can simply be considered as a rejection to compromise on any of the economic objectives to allow for sustainability. This should be considered as a major upset to any attempt to improve the environmental profiles under a Sustainable Development context[68].
- **Structuration Theory:** Garfinkel's sociological studies in the 1960s showed that when people responded in unexpected ways to everyday questions or situations, other actors could react quite angrily to this breach of the collective understanding of '*normal behaviour*' (Gauntlett, 2002). The normal behaviour in this case is the profit-achieving-organisation and its reluctance to compromise on its economic objectives to address sustainability issues voluntarily (even if these issues might eventually lead to the well-being of the organisation).

[68] Refer to the definition of the concept of Sustainable Development in Section 3.1

8.1.2.3 Analysis and findings from replies given by operational managers

As with Technical managers, Operational managers gave higher ratings for objectives associated with cost, similar ratings were also given to objectives associated with production volumes and functionality. This is normal given the nature of the downstream tasks performed by Operational managers.

Economic objectives	Very important	Important	Not important
Objectives associated with costs	50%	50%	-
Objectives associated with time	25%	62.5%	12.5%
Objectives associated with quality & clients	36.4%	54.5%	9.1%
Objectives associated with functionality	41.7%	50%	8.3%
Objectives associated with production volumes	50%	50%	-

Table 8.4 Choices of economic objectives by Operational managers.

8.1.2.4 Analysis and findings from replies given by Strategic managers

The Strategic managers offered comprehensive information on considerations made when specific decisions are made. The managers gave most of their ratings to strategic economic gains. However, it should be noted that the strategies set by the two organisations (PFF2 and PFF3) were different; this reflected on their ratings as they only agreed on 4 of the 11 objectives rated. The PFF3 manager noted that they are simply looking to increase their production volumes. Whereas PFF2 was involved with a range of clients in long-term arrangements, therefore client satisfaction would probably be the most important objective. The PFF2 manager also referred to the importance of minimising costs (this is due to the limited funds offered to each factory by the parent company).

It is clear that cost-based objectives were the most crucial to the managers interviewed. This is a fact that could be considered or ignored. However, ignoring this fact would severely affect any prospects of environmental improvement. Considering this aspect by taking advantage of it might be the most sensible option. Another important aspect that should also be considered is how managers look at objectives associated with their jobs. It is noticeable that Operational and Strategic managers offered high ratings to objectives and measures directly associated with their respective tasks. This might indicate, at least for Operational managers, that decision-makers only look at the objectives that enable them to complete their jobs without any major problems and without looking at the bigger picture.

8.1.3 Organisations' Perceptions of sustainability

During their interviews, the interviewees offered several comments that could help in understanding their perceptions of sustainability. Specific quotes/ comments are presented below and were tabulated to reflect views.

			A	B	C
			Importance of sustainability for interviewee	**Awareness of environmental impacts**	**View on tackling sustainability**
25	Technical	PFF1 manager	Having a good environmental profile is not the driver -	Not much. Mainly from info provided by interviewer.	'However, maybe we should look at that issue.
26	Technical	PFF2 manager	Attempting to measure environmental aspects against economic impacts	Admitted that they weren't fully aware of impacts.	Positive, with worries on profitability objectives.
27	Technical	PFF3 manager	Understands philosophy that everyone is trying to address sustainability - but economics overweigh all these.	Sympathetic to the cause, but they've got very little regard to that, because business has to continue.	Wouldn't mind to pursue sustainability principles as long as there is a commercial viability.
28	Marketing	PFF1 manager	Most efforts are driven by economics rather than sustainability. However, it's a happy by-product!	they knew about the environmental impacts associated with their decisions	Happy to be the most sustainable, but not if it made us the most expensive (not as important as price)
29	Marketing	PFF2 manager	We need to look at environmental performance, it affects their costs.	No comments were made specifically	Positive as long as linked to efficiency aspects. Some efforts already took place
30	Marketing	PFF3 manager	Not Applicable	Not Applicable	Not Applicable
31	Operational	PFF1 manager	Although cost is a major issue, there is possibility for change and sustainability solutions.	Was aware of many of the environmental impacts at the factory (at least those associated with his work).	Can be carried out as long as cost is approved by the management
32	Operational	PFF2 manager	Keen to adopt new solutions, but positive economic performance is major factor.	Respondent was the most knowledgeable interviewee on environmental impact issues.	Can be carried out - a hypothetical percentage to ratio of profit lost for an environmental systems: 2%
33	Operational	PFF3 manager	Understands the vitality of the issue. Measures done: recycling, reusing water.	Not surprised, knew earlier that work causes impacts. Responsible (with others)	Can be carried out - through renewal of systems and pursue of efficient machinery.
34	Strategic	PFF1 manager	Not Applicable	Not Applicable	Not Applicable
35	Strategic	PFF2 manager	Still in the early days on sustainability, looking at effects on commercial operations	He didn't realise that most impacts come from cement.	Worries on profitability, and other commercial objectives.
36	Strategic	PFF3 manager	Obliged due to regulations, Still keen to embrace the issue (it comes as 3rd or 4th best - directly behind cost and profitability issues).	Awareness of some impacts. Was surprised by their performance in terms of transportation.	They do look at the issue - however, they do have financial and economic priorities.

Table 8.5 Interviewees' perceptions of sustainability

8.1.3.1 Analysis and findings from replies given by Technical managers

The results of perceptions of sustainable development were consistent with results received in the Focus Groups. The results were generally negative, with replies from PFF1 and PFF3 managers (A-25 and B-27) as the least enthusiastic about the subject. Their replies showed considerable rejection to the concept of looking at sustainability as a driver. The replies of PFF2's manager (A-26 to C-26) were more positive. However, his reply (A-26) still classifies sustainability as a cost burden. PFF2's Technical manager's subsequent replies suggest that the problem was more associated with lack of awareness.

With many of the managers admitting that they do not know much about sustainability (B-25 to B-27); it appears that the problem of interviewees is mainly associated with remoteness from the entire issue. Looking at their answers to the awareness questions, in addition to earlier replies on economic viability, it is possible that bias is one of the main causes of the negative replies.

8.1.3.2 Analysis and findings from replies given by Marketing managers

The two managers used pure economic means to assess and interpret the concept. The PFF1 Marketing manager referred to sustainability as '*a happy by-product*' (A-64). The PFF2 manager (A-29 to C-29) addressed some of the environmental solutions suggested as efficiency measures, and ignored the long-term benefit (and main target) of such solutions, which is to reduce environmental impacts. Such views could limit any attempt to directly address the wider issues in sustainability. There are many reasons for such replies; again bias could be one of them.

Both managers interviewed were members of the Marketing Focus Group. The level of rejection and negativity in both interviews casts doubt on many of the positive results received earlier in that focus group, which included high ratings for competitive advantage as a driver to sustainability (see section 8.1).

8.1.3.3 Analysis and findings from replies given by Operational managers

Although they acknowledge the importance of sustainability, Operational managers admit that there will always be economic considerations for the type of actions taken. The term sustainability was not used by the interviewees; they referred occasionally to their different energy and waste reduction efforts as 'efficiency and performance' efforts.

The responses from Operational managers were slightly less ambiguous than those from their colleagues. One interviewee (C-32) suggested deductions from their net profits (2%) could be dedicated to environmental solutions that were likely to generate viable return.

8.1.3.4 Analysis and findings from replies given by Strategic managers

In spite of similarities in comments directly addressing environmental problems, the results received from Strategic managers were, to some effect, different. PFF3 manager stressed that sustainability is one of the top measures considered by his organisation (A-36). He even put it as the third or fourth top objective. However, looking at the environmental activities carried out across PFF3 and comments given by their Technical manager (B-27), sustainability does not seem to be the motive behind many of the activities and efforts carried out in their factories; cost saving and regulations seem to be the main objectives.

The reply from the PFF2 manager (A-35) was genuine. By admitting that they are still in the early stages of '*trying to realise the benefits of environmental and sustainability issues to the business*'. This clearly shows that PFF2 is likely to consider sustainability and environmental issues within an economic context, which might contradict with suggestions given by PFF2's Operational manager (C-32).

In spite of some strong statements, such as (A-28), most of the replies given were relatively moderate. There is a possibility that many of the negative results received from Technical and Marketing managers are influenced by bias against non-profit achieving principles (such as sustainability). This can be demonstrated by referring to their answers to the awareness questions combined with replies in 8.1.1 and 8.1.2. There are also indications that Operational and Marketing managers tended to translate and interpret some environmental issues in different contexts. The theory of Structuration (Giddens, 1986) might be useful in explaining how and why such mechanisms and understandings might have developed across precast flooring organisations.

8.2 Interview Results and Analysis: responses on the ten identified decision-areas

During the interviews, the interviewees discussed several issues associated with the ten decision-areas identified in Chapter Six. It should be noted that only four to five of these ten areas are directly and exclusively associated with each decision-making category considered in this stage of research.

8.2.1 View on supply chain structure and suppliers' choice for manufacturers (D1)[69]

Managers from two categories (Marketing and Strategic managers) were asked to offer views on this decision-area. It was also possible to obtain some feedback from other decision-makers (See Appendix E).

			A
			Supply chains and suppliers' choice
37	Technical	**PFF1 manager**	PFF1 is slightly constrained: buying in-house materials through parent company. Most of the parent company products and quarries are located close to factories. Indeed, two factories are located in quarries.
38	Technical	**PFF2 manager**	Not Applicable
39	Technical	**PFF3 manager**	Not Applicable
40	Marketing	**PFF1 manager**	We knew about transport costs (and environmental impacts) and it's a major consideration (close to our heart).
41	Marketing	**PFF2 manager**	Any manufacturer will try to draw his factories closer to the market, they have the best location possible (East Midlands).
42	Marketing	**PFF3 manager**	Not Applicable
43	Operationa	**PFF1 manager**	Not Applicable
44	Operationa	**PFF2 manager**	Not Applicable
45	Operationa	**PFF3 manager**	Not Applicable
46	Strategic	**PFF1 manager**	Not Applicable
47	Strategic	**PFF2 manager**	In a perfect world, factory should be closer to market, or closer to raw materials, or both + as major aggregate supplier, we use our own aggregates when possible
48	Strategic	**PFF3 manager**	Accepts high levels. However, he notes that these are offset by reduced impacts from finalised products transportation to construction sites.

Table 8.6 Environmental impacts associated with transportation, supply chain, and suppliers' choice.

[69] Results and analysis should be read in conjunction with Section 6.5.1.3 and Appendix E

The replies offer extensive information on how organisations arrange their resources, and how managers perceive environmental impacts associated with raw materials' transport and suppliers' choice. Replies from the managers involved show how specific supply chain arrangements can have different effects on manufacturers. Organisations in general locate nearer to their clients or suppliers in the Midlands (A-47). Larger organisations in particular have policies to use their own aggregates (A-37 and A-47) and they also prefer to locate next to their suppliers. Smaller organisations such as PFF3 are more flexible, they are located away from their suppliers and nearer to their clients in the South. However, PFF3 share their new production site with a sister transportation company who undertake their site deliveries. Both Strategic managers acknowledged the impact of site cost on location, the new PFF3 factory is located on land already owned by the parent company. PFF2 also looks at land ownership; when they decide to locate factories in the South (where land is more expensive) they look for '*disadvantaged*' sites (i.e. brownfield sites).

8.2.2 View on product depth and customisation levels in manufacture (D2/ D3)

Managers from three categories (Marketing, Operational, and Strategic managers) were asked to offer views on this decision-area and the environmental impacts occurring due to these decisions (See Appendix E). It was also possible to obtain feedback from other decision-makers.

			A	B
			View on Product depths	**View on Levels of customisation**
49	Technical	**PFF1 manager**	Designers will stick to the depth if they can. Close depths (150mm and 200mm) have roughly the same concrete (stretching the slab to greater depth). PFF1 has machines capable of producing a range of depths.	Looking for systems such as vacuum suction (machine that runs down the casting bed, blasts water into the uncured cast product to blow a hole in the product and then sucks out the waste material). Another solution: reuse of discarded portions in other projects/ orders.
50		**PFF2 manager**	Not Applicable	Due to high levels of detail within cast elements, customised waste is not main part of the problem, it is part of production.
51		**PFF3 manager**	Not Applicable	Not Applicable

Table 8.7 (a) Replies to questions on product depth and customisation impacts

Although many of the managers interviewed were not able to respond to the product depth impact question, feedback on the related customisation question was much more extensive.

			A	B
			View on Product depths	**View on Levels of customisation**
52	Marketing	**PFF1 manager**	The relationship between products' depth and energy is complicated. Other influences: temperature, cement levels.	We knew about the amount of customisation waste. However, resource efficiency is measured in economic terms.
53	Marketing	**PFF2 manager**	Cannot see how product depths can be changed only to improve the environmental profiles.	Most waste comes from customisation. it depends on customer requirements. Recycling can be an option - although not in this factory.
54	Marketing	**PFF3 manager**	Not Applicable	Not Applicable
55	Operational	**PFF1 manager**	Few efficiency problems as every depth requires different machines (depending on depths required).	Aware that work detail affects environmental impacts (notably waste). Splays and angles are now very common in buildings.
56	Operational	**PFF2 manager**	Energy consumption is not entirely consistent with depths or volumes of products.	Not surprised with customisation waste. Total is 10% concrete waste, 2% rejects rate - so bespoke waste is 8%, yard waste: minimal.
57	Operational	**PFF3 manager**	Not Applicable	No specific comments were received on this aspect.
58	Strategic	**PFF1 manager**	Not Applicable	Not Applicable
59	Strategic	**PFF2 manager**	No specific comment were made	Admits that most waste comes from bespoke and detail: '*well! Customisation costs us money, and produces a great amount of waste*'. Surprised with figure: 2.5 tonnes/ cast.
60	Strategic	**PFF3 manager**	No specific comment were made	Decided to abandon vacuum suction (due to more waste). This led to fewer operations + more savings due to reduced handling and overheads - this outweighs any savings from autoscrap. Also working on other waste strands.

Table 8.7 (b) Replies to questions on product depths and customisation impacts

8.2.2.1 Manufacturers' perceptions of product depth effects on profiles

Most interviewees were reluctant to consider product depth as a cause of environmental impact that needs to be tackled. Their argument was understandable given that depth could also have a positive environmental effect in later stages of a product's life-cycle (more depth means longer spans and less columns). The only interviewee to acknowledge such impact was PFF1's Operational manager, who added another measure that can be troublesome at the shop-floor – the replacement of machinery when different depths are required during the same shift. Only PFF3 have no machine replacement problems as their machinery can flexibly produce different depths.

Other interviewees offered several reasons for rejection, some argued that energy consumed on different product ranges is due to other factors apart from depth (A-52 and A-56). It is possible that interviewees rejected the context in which the issue was explored.

Depth is obviously an important measure that cannot be compromised easily, however the interviews also show that depth can be controlled (or manipulated) by different production levels through specific choice preferences made to serve functional requirements. These include the following:

- Feedback from Marketing Managers showed how market requirements/ preferences affect depths manufactured. The choice of project type has a major influence on job specification. Shallower depths (which appear to be causing higher energy averages) are mainly influenced by a manufacturer's preference for housing projects.
- The interviewed PFF1 estimator revealed that directly after achieving their weekly targets, they can become '*choosy*' about the type of jobs accepted. They would prefer jobs with fewer design requirements and more repetition in shapes and specifications.
- PFF1's Marketing manager revealed that they have specific measures (and preferences) employed to control the flow of jobs coming to their shop-floors. If they felt they are getting lots of jobs with one specific depth, they would try to target jobs with a slightly different depth to ensure that no bottle-necks occur in the shop-floor.
- PFF1's Technical manager noted that they (mainly designers) usually try to fit specific depths (brought to them by clients) to their standardised ranges of depths. This offers designers yet another opportunity to modify depths.

It was not possible to explore the likelihood or practicality of using variation of product depth to improve the environmental performance. However, the other problem causing most of the rejection is the context in which such change is suggested.

8.2.2.2 Manufacturers' perceptions of product customisation effect on profiles

Replies on customisation waste were more consistent, all replies (including the justifications offered in B-60) acknowledge that most concrete waste is generated due to customisation and bespoke design. The reply of PFF2's Strategic manager might reflect this, he noted '*Well, Customisation costs us money and produces a great deal of waste*'. Operational managers also showed signs of dissatisfaction with levels of waste production. However, other interviewees tried to offer justifications for this considerable amount of concrete waste. PFF1 Marketing manager indicated that waste-by-design is already being accounted and paid for (B-52). Similar views were given by PFF2's Technical manager (B-50). PFF1 managers also noted that it is already being used as secondary aggregate, they also argued that it is possible to take advantage of the cementitious properties within crushed concrete in reducing recycling impacts and environmental profiles. PFF2's marketing manager was somehow blaming customer requirements and the prevalent culture of highly-customised designs producing more waste-by-design waste. Others, including PFF3's Strategic manager, referred to activities carried out in factories to deal with this type of waste, these include use of vacuum suction, reuse of cut portions and parts, division of products to reduce losses, and concrete waste recycling.

Apart from the main customisation problems, two managerial concerns have emerged from the answers given above. There are clear differences in the approach and manner in which two groups of managers (Marketing and Operational) expressed their views on the problem of customisation. This shows that there could be a communication problem between the two groups in addressing the issue. The other problem is associated with additional negative effects from long-term agreements between PFF2 and their clients where PFF2 is obliged to accept jobs with variable levels of customisation, which generates substantial amounts of waste. Unfortunately, most of the measures discussed by interviewees target the reuse of generated waste, but there are no specific activities targeting elimination at source. It is clear that, despite a tacit acknowledgement of significance of customisation waste, many of the interviewees accept customisation waste as a '*necessary evil*' and therefore only are empowered to reduce it if possible, not remove it wholesale.

8.2.3 View on size and flow of jobs (orders) coming to the shop-floor (D4)

Managers from three categories (Technical, Marketing, Operational managers) were asked to offer views on this decision-area (see Appendix E). It was also possible to obtain feedback from other decision-makers. See Table 8.8.

Despite some negative reluctant remarks from PFF1 Technical manger in A-61 (and PFF1 Marketing manager in A-64), all three Technical managers agreed that there are problems with energy consumption levels. PFF2 Technical manager addressed the difficulty of employing every single bed in the hall as casting beds are too close to each other. PFF1 Technical manager referred to the ageing systems in production and curing. This proves that there are fundamental problems within the production systems employed depriving manufacturers from the economies-of-scale advantage.

In spite of surprise and disagreements from PFF2's Operational manager (A-68), Operational managers are generally aware of impacts associated with curing energy. All the factories considered employ efficiency measures to reduce curing energy. However, manufacturers' awareness focuses on productivity and economic efficiency, as can be seen in responses from PFF2 and PFF1 Operational managers where '*efficiency*' and cost-based charts were discussed. Other measures include manipulation and changes to the curing cycles for products. PFF2 seemed to be the most advanced in this regard, which is due mainly to the enthusiasm of their Operational manager.

			A
			Size and flow of jobs taken to the shop-floor
61	**Technical**	**PFF1 manager**	Recognising the problem - however, having a good environmental profile is not the driver - the driver is productivity and efficiency.
62		**PFF2 manager**	Surprised by outcome as they have one of the highest levels of productivity (Net production per bed).
63		**PFF3 manager**	No comment was specifically offered
64	**Marketing**	**PFF1 manager**	These are efficiency matters: Less environmental impact is a happy by-product.
65		**PFF2 manager**	Orders' and size issue is not only an environmental issue, it is an efficiency issue. It all depends on the market and they need to be flexible.
66		**PFF3 manager**	Not Applicable
67	**Operational**	**PFF1 manager**	Concerned. However, they are on top of some of the energy aspects mentioned
68		**PFF2 manager**	Was surprised with the fact that economies of scale have a substantial impact on energy consumption patterns reaching up to 40%.
69		**PFF3 manager**	PFF3 practice control over their curing energy, as soon as temperature reaches specific limits the amount of energy is maintained and then switched off. This was the respondent's decision to control energy consumption, and therefore costs.
70	**Strategic**	**PFF1 manager**	Not Applicable
71		**PFF2 manager**	On flow: we try to reflect the complexity of the project. We all like, in a perfect world, to tackle the simplest of jobs and not to tackle the complicated jobs - We need to look at the capacity and the impact of accepting specific jobs over a certain amount of time.
72		**PFF3 manager**	Not Applicable

Table 8.8 Views on size and flow of jobs taken for production at the shop-floor.

8.2.4 View on cement content within product concrete mix and acceleration of curing through material content (D5/ D6)

Managers from one category (Technical managers) were asked to offer their views on this decision-area (Appendix E). It was also possible to obtain feedback from other decision-makers. The replies received vary in content and level of perception. Due to the limited number of replies, it is not possible to analyse results based on management categories or factories considered.

			A
			View on Concrete mix and Cement content impacts
73	Technical	**PFF1 manager**	Not surprising - Most of these impacts are already linked with good business sense. The amount of cement used does not affect energy going to curing
74		**PFF2 manager**	Surprised with the impacts coming from Cement content in the given graph
75		**PFF3 manager**	Using additives in such aspect will mainly depend on the cost of the additives, as long as it doesn't have negative economic or negative impact on the product.
76	Marketi	**PFF1 manager**	Acknowledges that cement content can have an impact on curing.
77		**PFF2 manager**	Not Applicable
78		**PFF3 manager**	Not Applicable
79	Operational	**PFF1 manager**	Acknowledges that cement content can have an impact on curing.
80		**PFF2 manager**	*They might add/ omit cement to help in curing aspects – they tend to take more* cement out of mix sometimes as cement cost is more than energy costs.
81		**PFF3 manager**	Not Applicable
82	Strategic	**PFF1 manager**	Not Applicable
83		**PFF2 manager**	He didn't know how cement impacts contributes to environmental profile + There are ways to reduce cement. *In a new factory: add more curing energy + add more beds.*
84		**PFF3 manager**	Not Applicable

Table 8.9 Views on concrete mix and cement content impacts

It should be noted that the graph[70] (See Figures 6.23 - repeated) used in the interview had a strong effect on some interviewees as many of them, including PFF2's Strategic manager (A-83), were not fully aware of the significant effect and scale of environmental impacts associated with cement content. There were some contradictions in comments made on the issue: PFF1 Technical manager (A-73) made an incorrect comment on how cement content never contributes significantly to curing times (and energy), contradicting comments given by his colleagues at Marketing and Operational departments (A-76 and A-79). Moreover, PFF2's Operational manager's comment on taking more cement from the mix (A-80) contradicts with earlier comments from the company's Technical manager on the consistency of the proportions of the concrete mix for more than a decade (A-2).

Any possible solution for this will involve some change in production processes, notably curing. PFF1 Marketing manager explained several options such as minimising the amount of cement and allowing for more curing time, this will require increasing the numbers of curing beds to maintain production volumes per shift (mentioned also by PFF2's Strategic manager in A-83).

[70] See Appendix E, (Figure 4) for cement content.

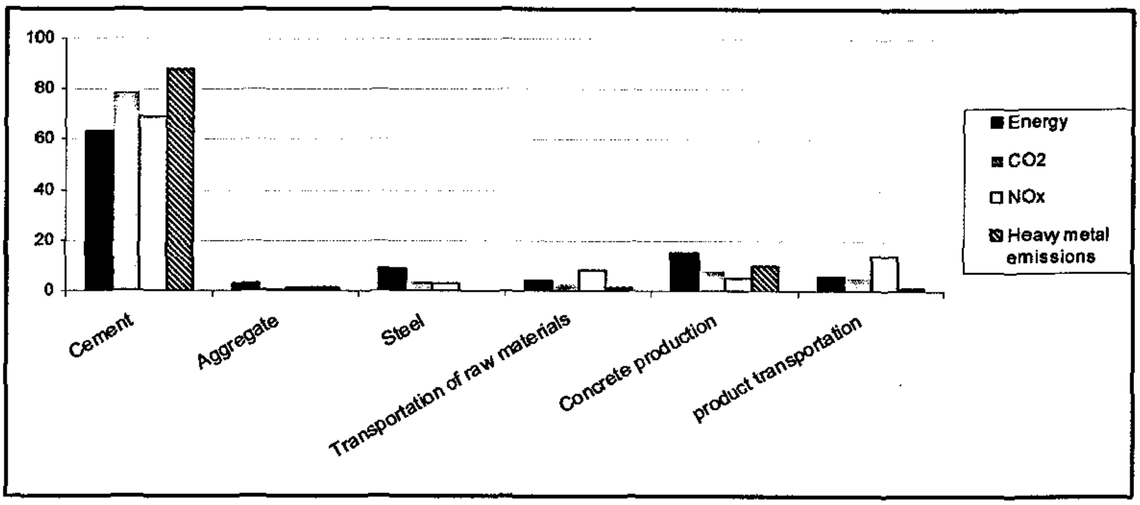


Figure 6.23 Environmental impacts associated with hollowcore production (%) - repeated (Vares and Hakkinen, 1999).

8.2.5 View on reuse and recycling of materials and products (D7)

Managers from three categories (Technical, Marketing, Operational managers) were asked to offer their views on this decision-area (see Appendix E). It was also possible to obtain feedback from other decision-makers.

			A
			View on reuse and recycling of materials and products
85	**Technical**	**PFF1 manager**	Not surprising - already linked with good business sense - there are some machinery limitations. Policy: if we can't use in the product, we pass it to other industries
86		**PFF2 manager**	It was identified - however we need proper cost analysis and feasibility testing. He doesn't see customised waste as a main part of the problem.
87		**PFF3 manager**	Already recycle water, mainly due to strong commercial viability.
88	**Marketing**	**PFF1 manager**	Prevented by Quality Protocol from putting more recycled content into the product. Thinks is being addressed. We know that it's a recyclable product.
89		**PFF2 manager**	Not Applicable
90		**PFF3 manager**	Not Applicable
91	**Operational**	**PFF1 manager**	Not Applicable
92		**PFF2 manager**	Not surprised with the customisation waste figure. They have a 10% concrete waste rate and a 2% rejects rate - so the percentage of customisation waste is 8%
93		**PFF3 manager**	Not Applicable
94	**Strategic**	**PFF1 manager**	Not Applicable
95		**PFF2 manager**	We know we have to recycle as much as we can (providing recycling facilities on any site). No notes were made on whether these can be reused into the product.
96		**PFF3 manager**	Not Applicable

Table 8.10 View on reuse and recycling of materials and products

The interviewees' replies were generally more positive on the concept of recycling and product reuse. Precast manufacturers have made substantial progress in waste recycling and all factories included recycle their industrial concrete waste, one PFF1 factory (not included in the research) has even tried to reuse their recycled aggregate in production. The PFF2 factory also recycled waste and has tried to reuse recycled water in production. The same applies to PFF3 where a water recycling system was used, PFF3 was also considering other recycling applications (which cannot be revealed due to confidentiality requirements). In spite of recycling failures in some of the PFF2 and PFF1 factories (due to quality concerns), the interviewees are still encouraged by the prospects of recycling (A-88). This might be due to the economic return and potential savings in the process (in addition to the significant impact caused by the Aggregate Levy).

8.2.6 View on type of production systems employed (D8)

Managers from two categories (Strategic and Operational managers) were asked to offer views on this decision-area (Appendix E). It was also possible to obtain feedback from other decision-makers.

			A
			View on type of production systems employed.
97	Technica	**PFF1 manager**	When a new cast system is chosen, research is carried out first (based on cost)
98		**PFF2 manager**	Not Applicable
99		**PFF3 manager**	Not Applicable
100	Operational	**PFF1 manager**	No specific comments. However, it was mentioned that the factory is old and much equipment should be replaced soon.
101		**PFF2 manager**	Several changes were made (from electrical to boilers). Moreover, manual handling of the curing system was introduced and resulted in substantial energy savings in summer.
102		**PFF3 manager**	He knew about this aspect. He also noted that some of the extruders used in the older factory are ageing and will require replacement.
103	Strategic	**PFF1 manager**	Not Applicable
104		**PFF2 manager**	All the options given will come to cost versus benefit, we will have to look at how any sustainability activity can help us in terms of our commercial operations.
105		**PFF3 manager**	New casting and curing systems are used in the new factory - however productivity (fewer men in operations, reliability, etc.) was the main motive.

Table 8.11 View on types of production systems employed.

As noted earlier, and as reported by PFF2 Strategic manager in (A-107), changing production systems is not an easy (or low cost) task. Manufacturers will always need to look at costs; PFF2 prefer energy efficient motors due to potential savings, the same applies to PFF3 Strategic manager's answers (A-108 and A-36) confirming that all their environmental efficiency systems are known to have high potential for cost efficiency. However, alterations to capital equipment (to more energy efficient systems) can be so expensive that change cannot be justified.

8.2.7 View on operation of curing beds, concrete bullets, gantry systems, and internal transport plant (D9)

Managers from one category (Operational managers) were asked to offer their views on this decision-area (see Appendix E). It was also possible to obtain feedback from other decision-makers.

			A
			View on operation of curing beds and systems.
109	**Technical**	**PFF1 manager**	Curing beds are sometimes left heating without being replaced as manufacturers need to maintain heat in the bed in order to cast again and not to lose an entire day reheating + PFF1 is already implementing some energy reduction initiatives [anonymised].
110	**Technical**	**PFF2 manager**	Sometimes it is hard to employ every single bed within the hall as beds are too close and work around all beds hinders general progress (due to lack of space).
111	**Technical**	**PFF3 manager**	Not Applicable
112	**Operational**	**PFF1 manager**	Some orders require more resource or produce more waste. Some jobs take longer time due to detail or inability of machines to cope.
113	**Operational**	**PFF2 manager**	There are no clear problems with the system that we have - a Quality manager was hired to look at this issue.
114	**Operational**	**PFF3 manager**	Due to the relatively small number of beds (seven beds) and casting machinery at the older factory, it is easier for PFF3 to control their production parameters and avoid significant environmental impacts of failing to fully utilise mass production measures.
115	**Strategic**	**PFF1 manager**	Not Applicable
116	**Strategic**	**PFF2 manager**	A whole range of factors can influence what systems to be used. Energy is an issue and will continue to be given the increase in price + We're not huge users of energy.
117	**Strategic**	**PFF3 manager**	Not Applicable

Table 8.12 View on operation of curing beds and systems

Most of the issues addressed in this category are associated with ageing equipment or specific deficiencies in product handling from one operation to another. Although most manufacturers could not provide sufficient accounts of this deficiency, the introduction of specific solutions to this problem (in Section 6.7) enabled the Operational managers to identify what was meant by this specific category.

There are indications (similar to those in 8.1.2.4) that the decision-makers involved have different perceptions on efficiency problems causing environmental impacts: replies of Operational managers show that there are no major problems with the manner in which the shop-floors operate, However, they do not seem to oppose suggestions that the problem could be associated with other upstream activities (such as jobs processing, planning, etc.).

8.2.8 Views on factory layout (D10)

Managers from one category (Strategic managers) were asked to offer their views on this decision-area and environmental impacts occurring due to these decisions (see Appendix E).

			A
			Views on factory Layout
118	**Strategic**	**PFF1 manager**	Not Applicable
119		**PFF2 manager**	Was not surprised by the figures – he always knew that they had a problem with re-handling and that their stockyard activities were costing them
120		**PFF3 manager**	Factory layout is an important issue that they use to improve productivity.

Table 8.13 Views on factory Layout

The PFF3 Strategic manager noted that product handling and location of the stockyard relative to the production hall is an important element. The PFF2 manager believes that the main problem with this aspect in their factory is the wet-cast elements that require high levels of re-handling (affecting their levels of energy consumed in internal transport). One advantage of interviews is the analysis of specific aspects in more depth to avoid errors in research analysis. One of the earlier findings developed from the LCA was associated with the impact caused by factories' layouts on average energy consumption levels for internal transportation (see section 5.5.2.3). The PFF2 Strategic manager reply shows that there are specific re-handling problems in some of the factories considered (mainly the PFF2 factory).

8.3 Interview Results and Analysis: Environmental solutions

In this section, decision-makers offer their views on how the environmental decision-areas can be tackled, and what solutions should work (See Appendix E). The replies of interviewees range from negative (focusing mainly on profitability), to careful and calculated, positive and very encouraging replies. It should be noted that nearly all respondents tried to explicitly or implicitly 'frame' the problem in an economic sense recognising the conventional business constraints. The answers (including ratings and comments) given by the interviewees were tabulated and categorised using the same coding system employed in 8.1 and 8.2

8.3.1 Solutions dealing with raw materials supply issues

Four solutions were identified and quantified for the interviewees to assess and rate. Tables 8.14(a) and 8.14(b) include the main questions and replies.

		A	B	C
		Technical Managers		
		PFF1 Manager	PFF2 / PFF3 Managers	
121	Maintain impacts associated with the supply chain impacts and concentrate on means of transport (more efficient vehicles, use of rail, etc.)	The rail option is interesting; he noted that the same solution is used in one one facility (anonymised). However such a solution will be limited due to the limited rail infrastructure in and around the region (anonymised).	Not applicable	Not applicable
122	Consider sourcing distance as a factor in choosing suppliers and jobs to be taken	It is policy to locate near aggregate suppliers. If not possible: a location close to transport + good road links. Most of the parent company quarries are located close to PFF1 factories	Not applicable	Not applicable
123	Use more energy efficient raw materials transport trucks.	**Never.** Our haulage is outsourced (don't own fleets). Each factory has a haulage contractor. PFF1 have control over the contractor to impose something like transport energy.	Not applicable	Not applicable
124	Ignore impacts from transportation and concentrate efforts on something else	**Likely.** PFF1 is slightly constrained: They have to buy in-house materials through the parent company	Not applicable	Not applicable

Table 8.14 (a) Raw material suppliers issues.

The replies from PFF1 Technical manager matched the replies given by his colleague at the Marketing Department. PFF1 seemed to be more flexible on raw materials transport options. However, considering earlier comments by the same Technical manager (A-37), there were restrictions on PFF1's suppliers' choice. Replies offered by the two Strategic managers seem considerably different, this is mainly due to their different strategies and economic interpretations of supply chain and raw material transportation. Indeed the words '*environmental*' or '*sustainable*' were never even mentioned in interviewees' replies.

		A	B	C
		Marketing Managers		
		PFF1 Manager	**PFF2 Manager**	**PFF3 Manager**
125	Maintain impacts associated with the supply chain and concentrate on means of transport (more efficient vehicles, rail, etc.)	Due to the location of the factory, rail use is not possible.	No Comments (not his speciality)	Not Applicable
126	Consider sourcing distance as factor in suppliers and jobs choice	**Doable**. They've already worked on reducing the amount of travel (mileage).	No Comments (not his speciality)	Not Applicable
127	Use more energy efficient raw materials transport trucks.	They can agree with their partners combination of pleasing clients and being competitive. However, sustainability is not the major driver. There is work on reducing numbers of lorries travelling.	No Comments (not his speciality)	Not Applicable
128	Ignore impacts from transportation and concentrate efforts on something else	**Likely**	No Comments (not his speciality)	Not Applicable
		A	**B**	**C**
		Strategic Managers		
		PFF1 Manager	**PFF2 Manager**	**PFF3 Manager**
129	Maintain impacts associated with the supply chain and concentrate on means of transport (more efficient vehicles, rail, etc.)	Not Applicable	If opportunity arose: use other means rather than road. Limestone quarries are in areas (Midlands) well connected to rail.	**Likely**. Some options, including rail, were examined. However, due to the limited demand on raw materials, this solution was not feasible.
130	Consider sourcing distance as a factor in choosing suppliers and jobs to be taken	Not Applicable	**Doable**, there is a commercial benefit.	**Never**. There are many factors (other than sourcing distance). Would ship materials from India if they have to.
131	More energy efficient raw materials trucks.	Not Applicable	**Doable**	**Never**. Difficult to impose - these are usually outsourced.
132	Ignore transportation and concentrate efforts on something else	Not Applicable	**Doable**	**Likely**

Table 8.14 (b) Raw material suppliers' issues.

According to Strategic managers, in addition to PFF1 Marketing and Technical managers, rail use is preferred and widely used for factories. However, a lack of rail infrastructure nearby causes the entire concept to fail for this purpose (A-125). The amount of supplies to be brought by rail should be economically justified. Sourcing distances are also a main consideration for some manufacturers. However, this is looked at in conjunction with the cost of raw materials; two of the manufacturers (PFF3 and PFF2) imported steel from Mainland Europe, PFF3 Strategic managers notes that he would '*ship materials from India*' if he had to; suggesting the very low significance of sustainability in management and decision making. PFF2 and PFF1 believed it is possible to demand their haulage contractors to use energy-efficient trucks. The PFF3 reply was negative, this was due to an arrangement they had with their transport contractor, which is a sister 'PFF3 Group' company (see section 8.2.1). Comparing different replies (per company) is not reliable due to different numbers considered per each company. However, there is evidence (from qualitative replies) that different managers rated solutions in accordance with their circumstances and supply chain/ transportation arrangements.

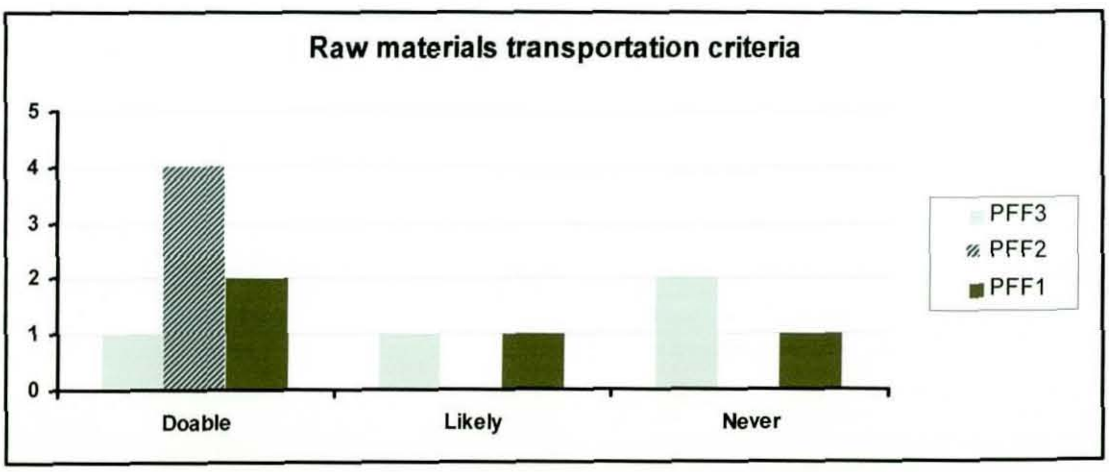


Figure 8.1 Raw materials transportation criteria (solutions' rating).

8.3.2 Solutions dealing with impacts from product depths, shapes, and customisation waste

Four solutions were identified and quantified for the interviewees to assess and rate. Tables 8.15(a) and 8.15(b) include the main questions and replies.

Although customisation is a major issue (that the industry deals with in different ways based on potential savings), eliminating waste might not be an appealing option for PFF1

Technical manager as the economic return might not justify the costs (A-133). However, ratings received by other managers (who are more involved) were more positive. Marketing managers were reluctant to consider customisation as a priority (A-136). They were even more hesitant (compared to Operational managers) to address this in the survey. Another issue raised by PFF1 Marketing manager (A-137), as well as PFF2 Strategic manager, is the rise in fuel prices at the time when this research was conducted. Although such rise can be taken as an environmental advantage (as a contra-indication to increased fossil fuel consumption), fuel prices would have considerable influence on how manufacturers deal with and think of their energy consumption.

		A	B	C
		Technical Managers		
		PFF1 Manager	**PFF2 Manager**	**PFF3 Manager**
133	Replace the used concrete cast system	For new cast systems, research based on cost is carried out (costing for over three years studied)	Not Applicable	Not Applicable
134	Tackle customisation impacts through reuse and recycling of discarded portions	Discarded portions are reused in other orders (using a colour coding system). There is also a bed planning system which looks at matching slab end shapes and narrow slab end cuts.	Not Applicable	Not Applicable

		A	B	C
		Marketing Managers		
		PFF1 Manager	**PFF2 Manager**	**PFF3 Manager**
135	Replace the used concrete cast system	**Never**. The current system is the most suitable given efficiency and volume	**Doable**. Was done before in the factory – (not only for environmental reasons).	Not Applicable
136	Tackle customisation impacts through reuse and recycling of discarded portions	**Doable**. However, Auto-scrap is already being accounted for (and paid for), Shouldn't be taken as waste.	**Likely**. Recycling can be used (although they couldn't carry that out!) –likely at some time in the future	Not Applicable
137	Ignore waste. Instead work on increasing production/ energy.	This is an efficiency factor, not a top agenda. With increased fuel costs it might become one	**Doable**	Not Applicable
138	Ignore problem and invest in other energy saving activities	No specific comment given	**Never**	Not Applicable

Table 8.15 (a) Dealing with impacts from product depths, shapes, and customisation waste

Although their ratings coincided for only one item, the two Strategic managers agree that casting systems can be replaced (B-143 and C-143). However, they never explained whether this could be done to serve the environmental cause. The managers also agreed on the benefit of tackling customisation to serve commercial purposes, PFF3 Strategic manager believed that they could serve their efficiency requirements through looking at other streams of waste. However, there is a fundamental difference in strategies implemented by the two managers: The PFF2 Strategic manager appeared to have a firm line between implementing specific solutions that can be considered as environmental, and dedicating a strategy to embrace environmental improvement. The PFF3 Strategic manager's strategy was fuzzier; his version of an environmental strategy mainly (and maybe only) would target solutions where an economic return and savings is the main purpose.

Although Operational managers were the most knowledgeable on the subject, they were somewhat hesitant in rating: over 40% of their ratings were given to the '*likely*' category (refer Figure 8.2). The replies from Strategic managers were very similar to those offered by Operational managers. One main justification for this is the manner in which both categories interpreted questions on customisation as efficiency measures. Marketing managers seem to recognise that the questions targeted the environmental cause, therefore most of their answers were negative (Figure 8.2). All answers provided by the three management categories supported the fact that environmental solutions would be considered for their economic viability.

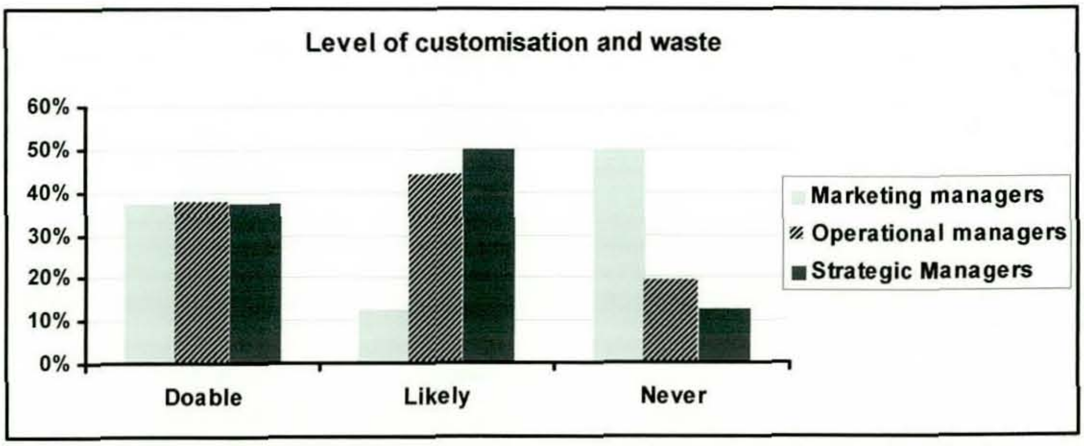


Figure 8.2 Levels of customisation and waste (solutions' rating).

		A	B	C
		Operational Managers		
		PFF1 Manager	**PFF2 Manager**	**PFF3 Manager**
139	Replace the used casting system	**Likely** (I'm not the one taking these decisions anyway!!)	**Likely**. Was carried out when a new production hall was built in factory.	**Doable**. Was implemented in the new system (changing from slip-form to extrusion).
140	Tackle customisation impacts through reuse and recycling of discarded portions	**Likely**. They are seriously looking at means of recycling their concrete waste and using it back in the product.	**Likely**. Such system was introduced earlier but never worked out. Should work for a new plant + They can minimise waste through casting two halves of slab to minimise rejects and cut-offs per casting + vacuum suction.	**Doable**. Already recycling systems are used + Some concerns regarding the use of recycled aggregate and whether the quantity recycled is adequate to support a continuous daily-production business case + additional cost.
141	Maintain customised waste. Instead work on increasing production per units of energy.	**Likely**	**Doable**. They already keep performance charts for tonnage per units of electricity.	**Doable**
142	Ignore problem/ invest in other energy saving efforts	**Never**	**Never**	**Never**
		A	**B**	**C**
		Strategic Managers		
		PFF1 Manager	**PFF2 Manager**	**PFF3 Manager**
143	Replace the used concrete cast system	Not Applicable	**Doable**	**Likely**. Will be carried out for the factory in the future.
144	Tackle customisation impacts through reuse and recycling of discarded portions	Not Applicable	**Likely**. We have to look at how any sustainability activity can help us in terms of our commercial operations.	**Likely**. A water recycling facility is already in place.
145	Leave waste. Instead work on production per units of energy consumed.	Not Applicable	**Likely**. We have to look at how sustainability activity can help commercial operations.	**Doable**. However there are measures more important than production per units of energy.
146	Ignore problem and invest in other energy saving activities	Not Applicable	**Doable**	**Never**

Table 8.15 (b) Dealing with impacts from product depths, shapes, and customisation waste.

8.3.3 Solutions dealing with impacts associated with size and flow of jobs processed to the shop-floor

Five solutions were identified and quantified for the interviewees to assess and rate. Tables 8.16(a) and 8.16(b) include the main questions and replies.

		A	B	C
		Technical Managers		
		PFF1 Manager	**PFF2 Manager**	**PFF3 Manager**
147	Consider production for stock to maintain stable flow in production	Already happening: If the order required covers less than total length of the bed – the remainder of the cast will be kept in stock.	Not applicable	**Doable**. T-beams are produced for stock.
148	Modify the way jobs are set (such as: never cast with less than the full length of the bed).	It is already happening: If the order required covers less than the total length of the bed – the remainder of the cast will be kept in stock.	Not applicable	Not Applicable
149	Additional work with shop-floor in reorganising orders to enable productive flow	**Likely**. Weekly meetings are already carried out between factory and sales managers where forward workloads are discussed, delivery periods examined, etc.	Not applicable	**Likely**. If economic viability and workability is not affected
150	Allowing for more production control: increase of lead-times	**Likely**. They already had some suggestions to increase curing times and increase beds to maintain flow and lead-times.	Not applicable	**Doable**.
151	Ignore the problem/pass it on to the shop-floor	Will not happen – Out of desire to improve efficiency (mainly)	Not applicable	**Never**. Not a good business practice.
		A	**B**	**C**
		Marketing Managers		
		PFF1 Manager	**PFF2 Manager**	**PFF3 Manager**
152	Consider production for stock to maintain stable flow in production	**Doable**. It is always easier to deliver from stocks, due to design alterations.	**Never**. We're not in the business of manufacturing for stock.	Not Applicable
153	Modify the way jobs are organised (such as: cast the length of the bed).	Not Applicable	Every bed is cast to the full length. Enough orders to cast the whole bed (always).	Not Applicable
154	Additional managers' work with shop-floor in reorganising orders to enable productive flow	They are still looking for more ways to improve their planning process.	**Doable**. They have a flexible type of management with no clear boundaries between different departments.	Not Applicable
155	More production control through increase of orders lead-times	Look at different aspects: (increasing beds: more time+ less energy).	**Never**. Only if involved with clients early in the process - which not the case.	Not Applicable
156	Ignore problem/ pass it on to the shop-floor	**Never**. The aim is always reduce cost + boost profit.	**Never**. The aim is always reduce cost and increase profit.	Not Applicable

Table 8.16 (a) Dealing with impacts of size/ flow of jobs taken to shop-floor.

The Technical managers offered positive replies accepting the suggested operational solutions, this was mainly due to debates and efforts undertaken within their organisations to address some operational issues. The Technical managers seemed to prefer the safe '*Likely*' category. Replies from Marketing and Operational managers never reached such levels (see Figure 8.3); the Marketing managers' replies were the most eager to express stronger views (in favour or against). The Operational managers, who were the most knowledgeable and experienced, offered different replies with a slight preference for the '*Doable*' category.

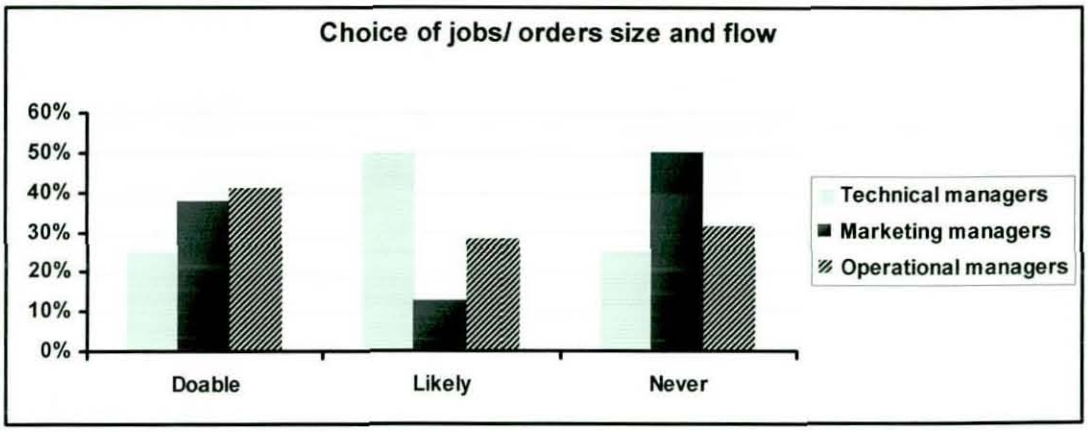


Figure 8.3 Choice of jobs/ orders size and flow (solutions' rating).

PFF1 Marketing manager (A-155) revealed some creative solutions and alternatives to tackle environmental effects of handling and flow of jobs and orders transformed into specific casting batches at the shop-floor. Many of these solutions were mentioned in a brief submitted earlier to their management team. The same solutions were also mentioned by PFF2 Strategic manager (A-83 and B-169).

Answers from Operational managers were consistent, especially on the operation of curing beds. However, there was a tendency to accept solutions that never involve any main changes to production characteristics. Operational managers want to maintain their full bed lengths, their accelerated curing systems, and their lead-times. However, there is also a certain level of limitation and powerlessness in their replies (A-139).

		A	B	C
		Operational Managers		
		PFF1 Manager	PFF2 Manager	PFF3 Manager
162	Consider production for stock to maintain stable flow	**Never**. T-beams are manufactured for stock. Detail work is different for hollowcore.	**Never**. Only limited to pre-stressed beams - details and reinforcements for hollowcore vary a lot.	**Never**. Already maintain stocks of T-beams. Only produce when there is demand: between stock and demand production.
163	Modify way jobs are organised: only cast with the full bed length	**Doable**. They still use the full length of the beds even if the order was 3-4 metres shorter.	**Doable**. New IT system targeting how jobs are set and how the beds can be employed fully.	If a specific length is needed, the entire bed should be cast using the same strand. Then, they will have to mix/ match between jobs.
164	Additional work with shop-floor: reorganising orders to enable productive flow	**Likely**. They already work with planning and sales Departments.	**Doable**. They already work with QA managers and other practitioners to improve performance and efficiency.	**Likely**
164	Allowing for more production control through increase of orders lead-times	**Never**	**Likely**. Increasing lead times depends on clients, avoiding liquidated damages is more important.	No clear answer: **Doable/ Likely**.
165	Ignore the problem and pass it on to the shop-floor personnel	**Never**. T-beams are manufactured for stock. However, the extra detail work is different for hollowcore.	Not applicable	Not Applicable

Table 8.16 (b) Dealing with impacts of size/ flow of jobs taken to shop-floor.

8.3.4 Solutions dealing with cement and concrete mix content

Four solutions were identified and quantified for the interviewees to assess and rate. Tables 8.17(a) and 8.17(b) include the main solutions and replies. Figure 8.4 shows the managers answers broken down per company involved.

Nearly all replies on cement content were restricted by economic boundaries. Apparently, this is why the last option (row 165) was rejected by the majority. Restriction to economic boundaries was evident in other replies offered by Technical managers. PFF1 Technical manager (A-162 to A-165) understood all the suggested options as efficiency or cost reduction measures. Even the commercial potential of employing sustainability was ignored in comments made by the manager. The PFF3 Technical manager (C-162 to C-165) expressed similar worries about economic viability; similar signs of inability to recognise the need for environmental improvement could also be detected. Replies from the PFF2 Technical manager (B-162 to B-165) were somewhat similar. However, more justifications were offered and the purpose of the solutions was properly recognised; he also offered more positive ratings for solutions given.

		A	B	C
		Technical Managers		
		PFF1 Manager	PFF2 Manager	PFF3 Manager
162	Reduce cement content and use a partial replacement by-product (PFA, GGBS, other).	Already implemented at PFF1 (on the basis of cost reduction) a few problems with machinery	This can be achieved as long as the product's different qualities are tested (such as impact on curing retardation, etc.)	**Likely**. PFA was used before - needs reasonable suppliers. Moreover, economic viability to be carried out.
163	Reduce cement content and increase fined-lime levels in the mix.	Only when fine lime is cheaper than the cost of using PFA	This can be achieved as long as the product's different qualities are tested (such as impact on curing retardation, etc).	**Likely**. No comments were offered.
164	Reduce cement content and use plasticizers/ accelerators	**Doable**. if cost of plasticizers can be less than cement – However, there are limitations	Not sure if plasticizers can do the job of cement effectively – the main role of admixtures is to accelerate the gain of strength, but it doesn't increase that strength.	**Likely**. Depending on workability and economic viability.
165	Reduce cement and let cast products take more curing time.	Cannot be implemented due to weak economic return – however, it is being looked at.	Time is important and cannot be easily compromised through reduction of cement - however, this was done before	**Never**

Table 8.17 (a) Dealing with impacts associated with cement and concrete mix content.

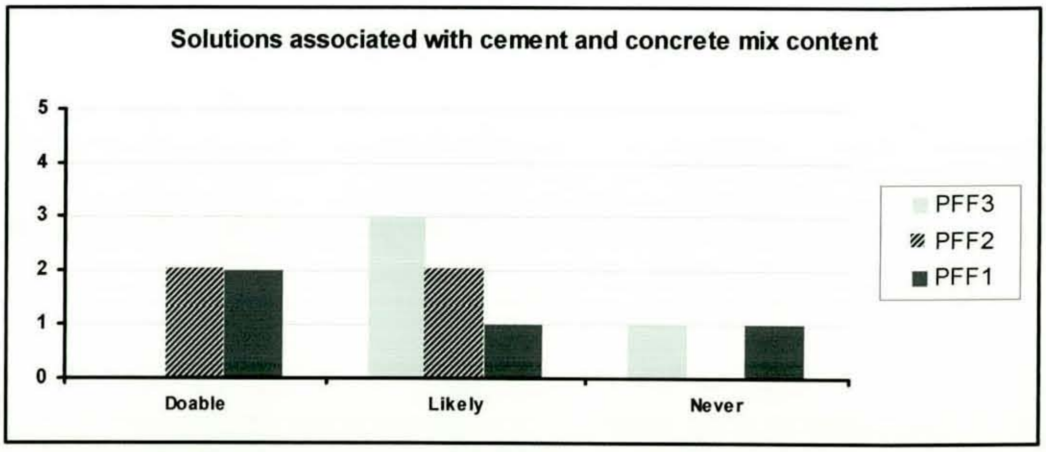


Figure 8.4 Solutions associated with cement and concrete mix content.

It was noticed that Technical managers were more open to ideas which were implemented by their companies previously (including the PFF1 and PFF3 managers' views on use of PFA, and PFF2 manager views on natural curing of products). This points to two fundamental human characteristics affecting Technical managers' (and manufacturers in general) acceptance of environmental solutions; these are fear of change (which is justified by the level of risk in the industry) and bias (from new ideas and suggestions). A few further comments were made in interviews carried out with PFF2 Strategic manager and PFF1 Operational manager and are shown below.

		A	B
		PFF1 operational Manager	**PFF2 Strategic Manager**
166	Reduce cement content and use a partial replacement by-product (PFA, GGBS, other).	The problem wasn't exactly with the chemical content of PFA or GGBS. The problem was with the ageing machinery.	Not Applicable
167	Reduce cement content and increase fined-lime levels in the mix.	Not Applicable	Not Applicable
168	Reduce cement content and use plasticizers/ accelerators	It is possible to use additives as a means to reduce curing energy consumption.	Worried that reducing cement using a specific chemical (admixture) might increase environmental impacts instead of reducing them.
169	Reduce cement and let cast products take more curing time.	Not Applicable	**Doable**. Suggested adding more beds to allow products to cure naturally.

Table 8.17(b) Dealing with impacts associated with cement and concrete mix content.

8.3.5 Solutions dealing with reuse and recycling of concrete industrial waste

Four solutions were identified and quantified for the interviewees to assess and rate. The following tables (Table 8.18) include the main solutions and replies.

		A	B	C
			Technical Managers	
		PFF1 Manager	**PFF2 Manager**	**PFF3 Manager**
170	Use of discharged water, concrete residue internal recycling systems.	Very positive reply for reuse of discharged water and concrete residue – trials carried out at PFF1 show encouraging results.	**Doable**. Already tried to use discharged/ recycled water in production. Didn't work: due to nature of the factory.	**Doable**. Already implemented.
171	Reuse of local crushed concrete in production.	Can be achieved, shortfalls can be challenged: technical protocol paper shows that cement in recycled aggregate mix is no more than typical mix. Saving is the objective	**Doable**. There is a BRE protocol document that allows this - No serious attempts yet.	**Doable**.
		A	**B**	**C**
			Marketing Managers	
		PFF1 Manager	**PFF2 Manager**	**PFF3 Manager**
172	Use of discharged water/ concrete residue recycling and reprocessing systems.	We were restricted by our BSI/ ISO 9001 from putting any more recycled content into the product.	Recycling can be used (although they couldn't carry that out!) –this will be **likely** some time in the future	Not Applicable
173	Reuse of local crushed concrete in production.	No recycled content into production (prevented by BSI/ ISO 9001 being addressed). We know that it's recyclable: some of the cement within the crushed concrete might still have some life.	Not Applicable	Not Applicable
		A	**B**	**C**
			Operational Managers	
		PFF1 Manager	**PFF2 Manager**	**PFF3 Manager**
174	Use of discharged water and concrete residue internal recycling and reprocessing systems.	Not Applicable	**Likely**, such system was introduced in the past (never worked efficiently). It should work for a brand new plant.	Not Applicable
175	Reuse of local crushed concrete in production.	Looking at means of recycling re-using back to product. Trials carried out (replacement of aggregates) were very successful	Re-using crushed concrete will require lots of work and storage space that might not be cost effective.	Not sure if the amount of crushed concrete will enable a stable and consistent production.

Table 8.18 Solutions associated with reuse and recycling of concrete industrial waste.

Technical and Operational managers were positive, The Technical managers expressed high levels of commitment to recycling and waste minimisation (see Section 8.2.5). However, there were some concerns expressed by Operational managers (B-175 and C-175) on practical and logistical difficulties affecting the viability of recycling, the same concerns were also expressed by PFF2 Strategic manager. Unfortunately, it was not possible to quantify the Operational managers' ratings. PFF2 Strategic manager also expressed a commitment to recycling: '*We know we have to recycle as much as we can*'. Unfortunately, replies from the Marketing managers were not as positive in this regard.

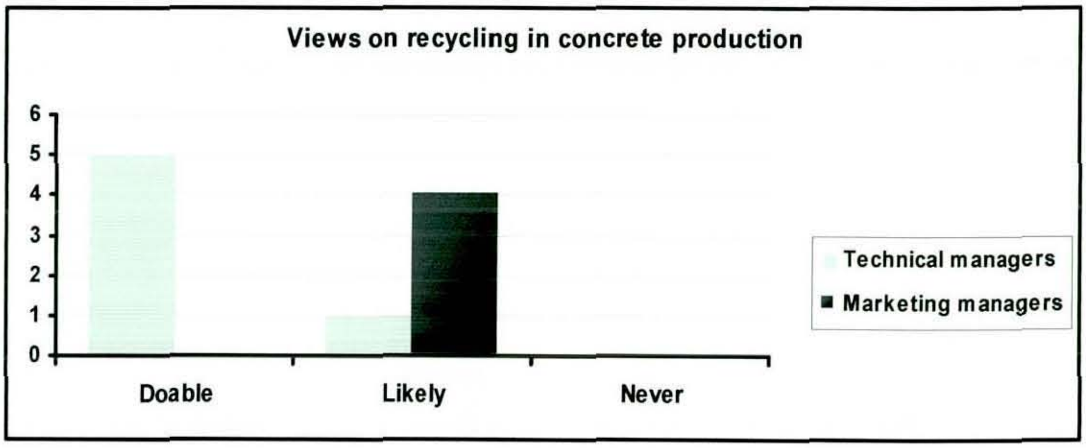


Figure 8.5 Solutions associated with recycling and reuse of products (solutions' rating).

Figure 8.5 shows the Technical and Marketing managers' ratings and views on products recycling; the results show some vital details associated with managers' acceptance of new ideas. Although most of those interviewed were unsuccessful in employing recycled waste, they are still optimistic and committed to the issue. PFF2 and PFF1 Technical managers referred to a protocol paper (A-171 and B-171) and trials undertaken by BRE on use of recycled aggregate in concrete (also cited by Bailey *et al*, 2002); this represents another motive for managers[71].

[71] Also covered in Section 3.2.1.4

8.3.6 Solutions dealing with production systems employed

Three solutions were identified and quantified for the interviewees to assess and rate. The following table (Table 8.19) include the main solutions and replies.

		A	B	C
		Operational Managers		
		PFF1 Manager	PFF2 Manager	PFF3 Manager
176	Change the major production systems employed to more environmentally acceptable ones (casting, curing, etc.)	**Doable**, considering that some casting and curing systems might be more efficient than others – some systems range back to the 1950s – 60s	**Never**. In the operating factory: making major changes to systems employed for environmental reasons only is not possible - carried out for a new factory: as part of our new strategy to use energy efficient systems.	**Likely**. As part of their strategy: once the new factory is working, this site will be refurbished, major production systems will be replaced.
177	Carry out few changes to some of the employed systems	**Likely**. But PFF1 will be looking at a relatively huge cost.	**Doable**. Already some changes were carried out (refer interview).	**Likely**. Some of the mobile plant elements can be replaced
178	Maintain production systems, invest in operational systems.	**Likely**. Curing can be controlled properly with the right system, monitoring.	**Doable**. Already some activities were carried out (refer interview).	**Doable**

		A	B
		Strategic Managers	
		PFF2 Manager	PFF3 Manager
179	Change major systems to environmentally acceptable ones (casting, curing, etc.)	**Never**	Confirmation that if there are any energy efficient systems, they will go for it.
180	Carry out few changes to some of the employed systems	**Likely**. Whether we do them is obviously something different.	They are trying to lengthen their casting beds. They know that a 150m bed is more efficient than a 100m bed.
181	Maintain major systems and invest in operational and maintenance systems.	**Likely**. Whether we do them is obviously something different.	**Doable**

Table 8.19 Solutions associated with production systems employed.

Replies from the Operational managers show the phases (or strategies) of change identified earlier in the study[72]. There is a level of frustration in PFF1 Operational manager's comments, who addressed the problems associated with efficiency and machine ageing on several occasions. In other parts (A-139) he admits that it would not be his decision '*anyway*' as this might involve huge costs. With a predetermined strategy on systems

[72] See Section 8.1.1

change, the PFF2 manager seemed more aware of the viability of solutions presented as many of these were already looked at by his organisation. This might be why his answers were more certain (Figure 8.6). PFF3 Operational manager's replies also reflected their system renewal strategy.

PFF3 Strategic manager's replies seemed more positive on sustainability compared to the PFF2 Strategic manager who stated that no systems would be replaced simply for another environmentally acceptable one (A-179). However, it is important to note that although the PFF3 manager supported the environmental cause (A-36), he never offered clear views on the line separating environmental needs from economic requirements. Both managers, however, offered economic interpretations to the environmental solutions.

It should be noted that there were clear differences in views expressed by PFF2 Strategic manager (A-179) and his Operational manager (C-32) on acceptability of energy efficient systems. It is possible that the difference is based mainly on their personal interpretations of the question.

Compared to Operational managers, ratings offered by the Strategic managers are similarly open to change and modification. However, choosing the '*Likely*' category in most questions might cast doubts on the sincerity of the rating, some of the qualitative replies certainly point to different ratings.

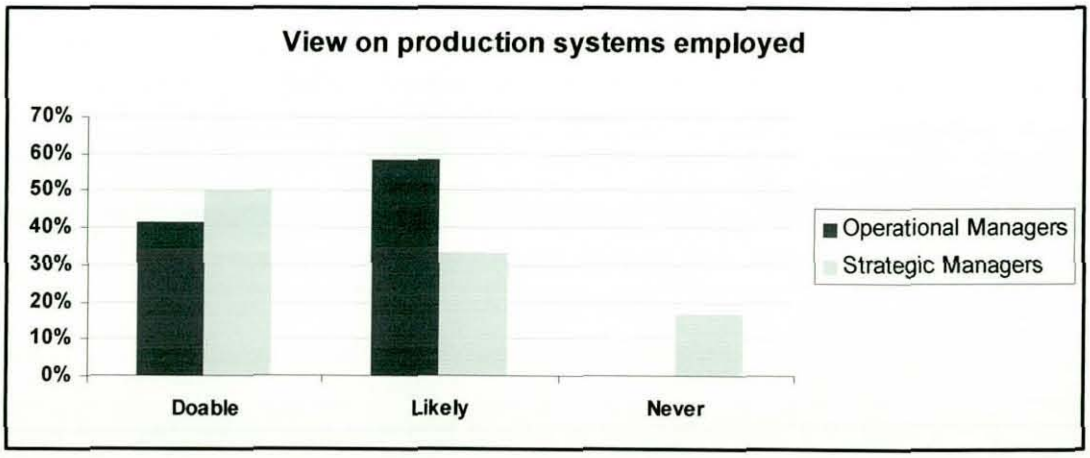


Figure 8.6 Solutions associated with production systems employed (solutions' rating).

8.3.7 Solutions associated with operation of curing beds and other systems

Three solutions were identified and quantified for the interviewees to assess and rate. The following tables 8.20(a) and 8.20(b) include the main solutions and replies.

		A	B	C
		Operational Managers		
		PFF1 Manager	PFF2 Manager	PFF3 Manager
182	Abandoning accelerated curing and leaving products to cure naturally	**Never**	**Never**	**Never**
183	Reduce timing for accelerated curing and use other means of curing (such as accelerators)	**Likely**. It is possible to use additives as a mean to reduce emissions.	**Doable**. Some measures were already introduced (refer interview).	**Likely**
184	Development of a standardised curing energy control system rather than using an ON/ OFF system	**Likely**. There are no On/ OFF designed systems – but it may be introduced under the [anonymised] initiative.	**Likely**. They've never tried to employ complicated systems for heating (capital and running expenses). A manual ON/ OFF/ ON heating system can damage the products.	This is already carried out: as soon as the temperature reaches a specific limit the amount of energy is maintained and then switched off. It was the interviewee's decision to control energy consumption, and therefore costs.
185	Only heat beds with casts. Keep beds unheated when empty	**Likely**. There are no On/ OFF designed systems – could be under [anonymised].	**Never**	**Likely**
186	Use advanced heat insulation (covering blankets system, etc).	**Doable**. Sheets already used in curing to retain heat/ reduce evaporation in product. There are other types of materials that can offer more benefits.	**Doable**. Although he believes that such system will work much better in a small-scale production system with no more than four beds.	**Likely**

Table 8.20 (a) Solutions associated with operation of curing beds and other systems.

The Operational managers offered rich feedback on the operation of curing/ heating beds (as demonstrated in the table and in Figure 8.7). Ratings offered by the PFF2 manager seem to be the most certain: with one reply under the '*Likely*' Category. However, in spite of differences in ratings between managers, the general comments seem to be similar.

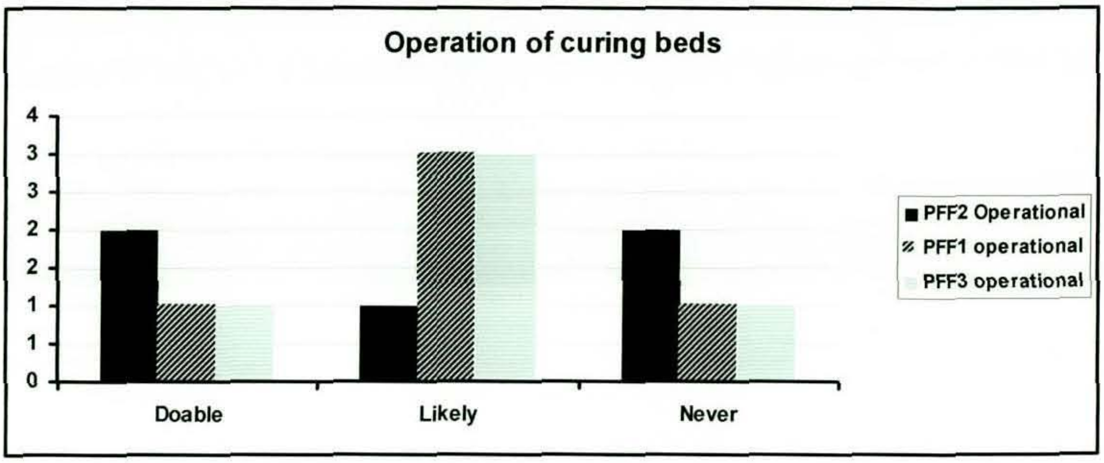


Figure 8.7 Solutions associated with operation of curing beds and other systems (solutions rating).

Other comments were offered by PFF1 Technical manager and PFF2 Strategic manager are presented in Table 8.20 (b).

		A	B
		PFF1 Technical Manager	**PFF2 Strategic Manager**
187	Abandoning accelerated curing/ leaving products to cure naturally	Cannot be implemented due to weak economic return – however, it is being looked at.	Suggested adding more beds to allow products to cure naturally.
188	Reduce accelerated curing time + use other means of curing (accelerators).	Achievable, especially that the cost of plasticizers can be less than cement – there are limitations	Not sure about environmental impact of plasticizer added
189	standardised curing energy control system rather than using an ON/ OFF system	PFF1 is already implementing some energy reduction initiatives [anonymised].	Not Applicable
190	Only heat beds with casts. Keep beds unheated when not used.	PFF1 is already implementing some energy reduction initiatives [anonymised].	Not Applicable
191	Use advanced heat insulation (covering blankets system, etc).	Not Applicable	Not Applicable

Table 8.20 (b) Solutions associated with operation of curing beds and other systems.

8.3.8 Solutions dealing with the layout of factories and internal transport

Two solutions were identified and quantified for the interviewees to assess and rate. The following tables (Table 8.21) include the main solutions and replies.

		A	B
		Strategic Managers	
		PFF2 Manager	**PFF3 Manager**
192	Modify the layout of the factory to bring stockyards and production halls closer.	**Unlikely** – in an existing layout, once you've made a choice – that's it, looks very appropriate but it is difficult if not impossible.	Agrees on keeping stockyards closer to production halls. Implemented in new factory - it also applies to the old factory.
193	Efficient/ flexible internal transport (cranes and forklifts).	**Doable**	**Likely**. We avoid diesel forklift systems indoors - due to H&S concerns from fumes.

Table 8.21 Solutions associated with factories layout and internal transport.

The ratings from the two Strategic managers show totally different results: they do not seem to agree on a single aspect on factory layout suggestions. However, their views do not seem to clash as the conditions of the two factories are quite different: The PFF2 factory is considerably larger, with twelve gantries and four production halls erected over different periods, so the reply of the PFF2 Strategic manager seems to be justified. The PFF3 Strategic manager was more optimistic considering that he was mainly referring to their new factory where such design aspects were raised and dealt with. Moreover, the area of the existing PFF3 factory is much smaller and the production volumes are not as high as the PFF2 factory, therefore any change of layout would be easier. This shows clearly that the two managers' views (and perceptions) may be similar. However, inherent difficulties associated with their factories' conditions had a major influence on their ratings.

8.4 Interviews' Feedback: Feedback from an environmental manager

An interview with an environmental manager within one of the member companies was used as expert feedback on the findings from the interview stage of the research. The SHE advisor (at the parent company of PFF1) gave feedback on the comments and perceptions of the other interviewees (decision-makers).

He explained that the replies show clearly how large-scale organisations deal with environmental aspects associated with their branches and subsidiaries. There is a single department, set at the higher levels of the organisation structure, to deal with sustainability across different member organisations. However, there are reporting mechanisms located at branch and factory levels. This represents a problem as specific environmental impacts caused by factory-specific conditions are harder to detect and eliminate. The structure appears to be causing additional problems, and the interviewee admitted that his company does not present the sustainability issue to their senior management as well as they should. He also referred to difficulties created by the nature of communication between levels of management that does not allow for such interventions.

PFF1 Environmental manager explained the different activities and efforts they have carried out to improve environmental and sustainability performance. The drivers of these activities were mostly compelling (mostly associated with regulations). The PFF1 manager noted that they also have other drivers associated with their image and moral obligations (such as ISO 14001), client satisfaction, and marketing. However, the main production-based initiative at PFF1 parent company was known as [anonymised], described by the interviewee as the main and most effective to date. The initiative includes a variety of efficiency measures implemented across the business targeting reduction of energy consumed. The initiative was apparently driven by savings and minimisation of cost.

The interviewee also explained the difficulties associated with reporting measures implemented across the organisation. He noted that many of the impacts included in the research (such as internal transport impacts) are not accounted for in their reporting systems. This is a fundamental problem given that action will always be difficult without appropriate information. It is possible that this has created a level of frustration for sustainability management within PFF1 parent company. This was apparent when the interviewee was shown Table 5.24 where his company's performance was satisfactory compared to other factories; the interviewee had expected their factory to be the worst in terms of performance.

Another fundamental problem was associated with the general perceptions and views within the organisation; employees' and managers' perceptions can have a significant influence on how improvement measures are implemented and accepted across the organisation. The interviewee described more than once how different managers fail to look at environmental issues without looking exclusively at price and cost parameters, and how difficult it is to address the environmental and sustainability concerns to their senior management. However, the interviewee still believed that there are members of staff (across different management levels) who think 'out of the box' and look at environmental issues from a different perspective.

As for the interviewee's own perceptions, it appeared that some of his comments showed a level of tolerance towards economic interpretations of sustainability solutions. He referred to the huge pressure from costs and overheads and why there should be some tolerance for such concepts. Moreover, in his final comments, the interviewee made the following observation:

'*...environmental and sustainability measures... are being mentioned and covered by media on a daily basis. It became apparent where the government is going and where the industry is going with all this.*'

The interviewee was building up the case for sustainability by demonstrating the economic consequences of not complying with sustainability requirements. Apparently, this will require the organisation to deal with this issue in order to adapt and survive in the future. Comments made by the Environmental manager, in addition to other interviewees, provide a strong indication that addressing environmental concerns using conventional economic mechanisms could be the most appropriate means to persuade manufacturers to improve their environmental performance and reduce environmental impacts.

8.5 Main findings and Conclusions

This analysis explores the different aspects and measures associated with the ten major decision-areas triggering most of the environmental interventions associated with the production and processing of precast pre-stressed concrete flooring elements (Hollowcore and pre-stressed beams). The semi-structured interviews revealed significant findings on manufacturers' perceptions of specific decision-areas and environmental impacts associated with these decision-areas.

The replies show that organisations operate in a stable environment where changes are not being introduced frequently. This does not necessarily mean that manufacturers do not want to carry out changes; with the high costs of system change, it is very difficult for organisations to make alterations. Change therefore takes the form of long cycles mainly targeting wear and tear or expansions in production. Replies also show that the most popular objectives were the ones associated with savings in costs and overheads. The ratings (see Tables 8.3 and 8.4) clearly reflect the characteristics employed in decision-making in the industry. However, this does not necessarily mean that manufacturers would compromise on other objectives to serve the sustainability and environmental cause. It was possible to detect early and strong indications of rejection of sustainability in the ratings offered by the Marketing managers. One of the main reasons suspected for such rejection is thought to be associated with the Structuration Theory (Giddens, 1986); managers seem to think that sustainability is a violation of their profit-achieving-organisation concept.

In general, the views and perceptions of sustainability were relatively moderate and similar to the ones established earlier in Focus Groups (See Chapter Seven). However, the negative replies from Marketing managers were the most shocking (given their positive ratings at the Focus Group stage). In general, negative replies covered several aspects and measures; from aspects associated with general sustainability (see PFF3 Technical and PFF1 Marketing managers comments in A-27 and A-28), to aspects associated with energy consumption (see PFF1 Technical manager comments in A-61), and aspects associated with customisation and industrial concrete waste (see PFF2 Technical manager comments in B-50). Most of these rejections were associated with the economic red-line areas identified earlier in the Focus Group stage. Furthermore, this was not only associated with the direct costs incurred, but also with long-term economic effects that can influence opinions (including long-term agreements across the manufacturers' supply chain). However, in many instances manufacturers were still keen to explore the reasons behind some of the rejections and address some impacts, such as the customisation waste, calling it a 'necessary evil' that cannot be eliminated, but can be modified and reduced.

It was slightly difficult to generalise and detect a consensus among manufacturers' on environmental solutions (See Appendix P). This was due to the different aspects covered by the replies and ratings given by the interviewees. However, it was possible to detect some similarities and repetitive patterns in ratings and reasons expressed, these included the following:

- Apparently, solutions incurring the least costs (and helping to make the most savings) were always preferred by the interviewees. The interviewees even preferred some blurry options with unclear economic consequences in favour of the ones which are known to be costly.
- It was also clear that interviewees offered higher ratings for solutions already implemented at one of their factories. For example, the use of sourcing distances in Suppliers' assessment in PFF3 (C-140).
- The interviewees also offered high to moderate ratings for solutions which they have investigated and knew they can implement. A good example is the consideration of recycled aggregates by PFF1 and PFF2 (A-171 and B-171).
- There has been some preference for solutions that do not imply considerable change for their activities and operations; this was noticed mostly in replies given by Operational managers in (A-164 to C-164). Furthermore, the interviewees also preferred solutions that are applicable and that do not cause complications to their markets and supply chains. For example, although a shallow prestressed floor may be both environmentally and economically expensive, the costs may be outweighed by the alternative of making the floor deeper and the whole building taller (higher walls, columns and stairs).

The main characteristic that these options share is familiarity. Manufacturers have apparently favoured the solutions that they (or their business systems) are most familiar with, and solutions that would not require them to carry out considerable change. To some extent, the rating offered in Appendix P could offer a blueprint for a 'Wish List' that manufacturers can use to incorporate sustainability. Moreover, these replies clearly prove the point raised earlier on the Structuration Theory and manufacturers' perception of 'Normal behaviour'. Another main source of concern is the approach of interviewees in the Marketing managers' category; following their reluctance to compromise on economic objectives in favour of the environmental cause, the Marketing managers were the least hesitant to offer '*Doable*' or '*Never*' rankings in their replies. This is unusual given that they were not the most knowledgeable in many of the aspects discussed.

Due to the variety in ratings and preferences in replies, it would not be feasible to recommend specific solution options for manufacturers. However, it is feasible to offer a picture of the strategy that should drive the actions that could be taken by organisations to address and improve their environmental performance. As noted several times in the interviews, all interviewed managers used economic means repeatedly to interpret and assess their environmental solutions, this was taken as a disadvantage and a challenge throughout this chapter. However, this can be looked at from a different angle; it is possible to take advantage of this in selling the concept in a language that manufacturers understand and react with. Many of the findings and replies throughout this analysis (and in Chapters Six and Seven) have already pointed to such possibility as many of the environmental solutions (associated with energy consumption, concrete waste, and raw materials use) coincide positively with economic gains. It is possible to take advantage of such relationship in offering an economic frame for these environmental impacts. Such possibility still needs to be discussed and explored in more detail (see Chapter Nine).

In conclusion, it should be noted that the interviewees have shown more concern and interaction with the concept than during the Focus Groups. Achieving environmental improvement requires a collection of factors; the most important of which are those associated with the drivers, motives, and manufacturers' acceptance and participation. In this research stage it was possible to identify some of the parameters and boundaries for manufacturers' acceptance and adaptability to change. These should be exploited properly to identify the most appropriate means of improving the industry through a structured approach to sustainability and environmental improvement.

CHAPTER NINE: GENERAL DISCUSSION

Chapter Nine: General Discussion

The preceding literature review and analysis chapters demonstrate that the production of precast concrete flooring elements (hollowcore and prestressed beams) generates a range of environmental impacts. The use of the BRE Eco-point system identifies energy use, materials use (raw materials and concrete waste) and upstream cement impacts (associated with the cement content in the mix) as the main elements affecting the environmental profiles for such products. These environmental impacts are associated with specific systems and activities associated with decisions undertaken in various periods (sometimes prior to the construction and operation of the precast factories) and executed by different managerial levels within precast concrete flooring organisations: in Chapter Six, ten decision-areas were identified as the most influential in terms of environmental impacts. These environmental impacts could be tackled (or offset) by the utilisation of solutions identified and quantified in this research. However, decision-makers have views of and visions on the concept of sustainability and the routes and context in which some of these solutions should be assessed and implemented.

The aim of this study has been to "evaluate the impact of sustainable development and environmental protection measures on the business case of precast concrete flooring production systems". Using the findings established in the three preceding chapters, this chapter aims to identify and assess the most appropriate context and routes to introduce sustainable development and environmental improvement criteria into the decision-making process. This chapter explains how economic factors and objectives dominate the manufacturers' concerns and conventional decision-making structure. It also explains how environmental impacts and economic parameters can be looked at in a different context, by uncovering the nature of the relationships between economic and environmental variables. Three main routes, to include environmental improvement concerns within the decision-making framework, are identified and demonstrated.

9.1 General organisational structure and behaviour

From the wealth of primary and secondary information gathered and analysed in the preceding chapters, it is possible to build up a picture of the industry, its levels of change and renewal, its conventional decision-making structure, and its main key performance indicators. Through such a picture, it is possible to explore the most appropriate means to address and adopt environmental improvement and sustainability measures.

9.1.1 The nature of organisations' structure and operations

The precast flooring organisations included in the study employ a conventional business structure with several tiers of management and a collection of specialised departments. The interviews show that these structures are usually stable with few changes (introduced only occasionally) to the formation of departments and specific technical or operational aspects associated with the decisions taken: such changes (to the managerial structure) were mainly seen in two of the companies included (PFF2 and PFF3). However, the nature of these changes only addressed a few aspects associated with resource allocation and occasional business re-structuring.

The precast organisations employ what is known by Rush (2005) as a 'Functional Matrix' where the various functional departments prevail over specific projects' characteristics in the formation of the organisation structure. Such a structure will have a specific influence on how projects are managed and led, how project teams are formed and team members communicate and how projects are assessed and organisational learning occurs. However, many researchers argue that this might be the most appropriate arrangement given the levels of products and projects complexity (Rush, 2005).

It was possible, from feedback offered by respondents in this research, to develop an understanding of the nature of the organisation structure within precast flooring organisations. The following diagram (Figure 9.1) was developed and based on that understanding. As explained in Chapter Six, the departments (shown below) are the ones directly associated with the major environmental impacts identified and quantified in the study. In addition to senior management, the study identifies a layer of middle-management departments responsible for specialised decisions. These are Estimating, Design, Planning, Technical, and Marketing (Financial) management departments.

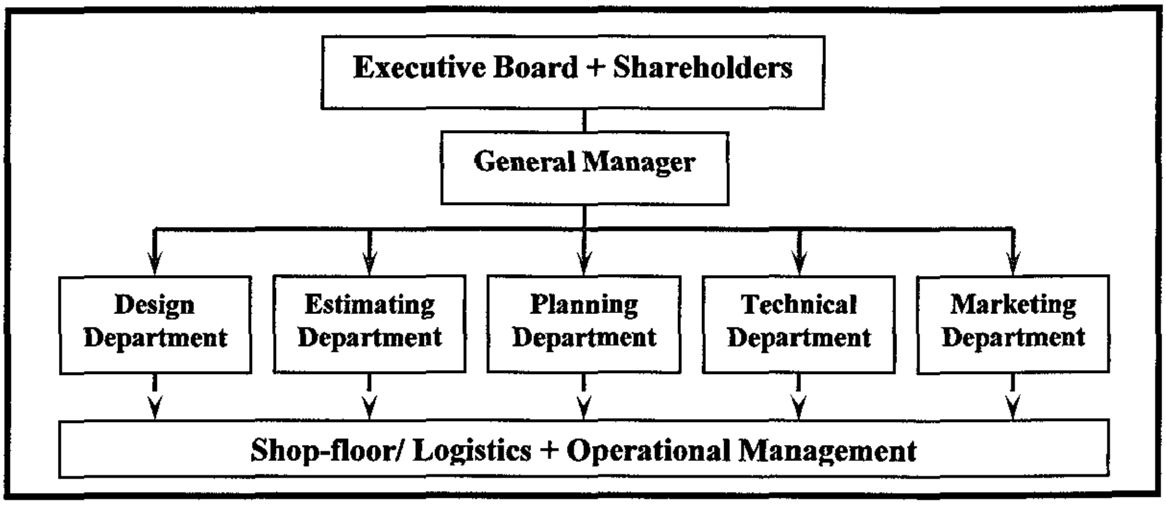


Figure 9.1 Typical organisational structure for a precast concrete manufacturer.

Feedback from interviewees shows that the organisational structure will differ from one manufacturer to another; some of the PFF manufacturers are SMEs with virtually flat organisational structures where the same managers can be directly running more than a single department. On the other hand, a subsidiary of a major holding firm might include more than a single tier including groups of operational and middle-management departments, the general manager of the subsidiary, high-level specialised departments and CEO of the parent company. This is different to SMEs where the activities of design and technical advice may be carried out by the same department.

9.1.2 Exploring economic objectives, gains, and performance indicators

Manufacturers look at a specific set of indicators and financial statement elements to view and measure their own success. These are linked directly to the profitability levels and economic objectives they target in their decisions and activities. This section identifies and demonstrates the importance of these elements. The construction industry's KPIs (see section 3.3.2) are used as a context to explain manufacturers' performance priorities. KPIs were introduced to the construction industry following the Egan report, *Rethinking Construction*, which challenged the industry to measure its own performance over a range of its activities and meet a set of ambitious improvement targets (KPI Working Group, 2000).

9.1.2.1 Emphasis on organisation budget

Budget plans are usually set to demonstrate how manufacturers can reach profit targets, reduce costs, and maintain desired levels of liquidity. Manufacturers look at the following financial statement items and ratios to assess their budgetary performance:

- **Turnover:** As noted in section 4.4.2, many practices measure the development and extent of their activities through the growth in turnover. Being selective in jobs (i.e. excluding jobs with high customisation levels) can have a severe effect on scales of production and, therefore, levels of turnover. It should be noted that other aspects (below) are also essential in terms of budgetary performance.
- **Cost of Sales:** As explained earlier, the cost of sales is linked directly to costs of raw materials (Table 4.1); this makes it fundamental to decisions associated with suppliers' choice, raw materials transportation, and concrete mixes (proportions of raw materials) employed. Table 4.1 clearly shows why manufacturers cannot afford to compromise on the cost of sales for the sake of sustainability (or any other principle).
- **Expenses:** Expenses include the different costs of machinery, wages, maintenance, and many other items of expenditure incurred by organisations. This is a fundamental aspect for manufacturers (as demonstrated in Chapter Seven) as objectives linked to expenses were identified as most crucial.
- **Profit margins:** This is often the main budgetary performance indicator. Through reducing costs and boosting turnover, manufacturers are able to achieve their ultimate goal (which is to increase profitability). The interviews showed that managers will agree largely to any measure (whether beneficial or harmful to the environment) that improves their profit margin without severely affecting their turnover.
- **Funds offered by parent companies (or equities, loans, etc.):** organisations usually receive additional funds and injections from parent companies or banks to reinforce liquidity or improve performance (and increase profits). Replies offered by one Strategic manager show clearly that such funds need to be employed wisely (see Section 8.1.2.4).

9.1.2.2 Emphasis on time requirements

The main time measurement unit for the manufacturers is lead-time (see section 4.4.1); the need to shorten project lead-time can affect a company's finances in different ways. These include capital costs on machinery and systems (SAP systems, accelerated curing systems, internal transport and handling equipment, etc.), financial expenses (and gains) associated with delays due to variations and late changes required by customers following the completion of design or production. Moreover, time is linked to economic benefits associated with the avoidance of liquidated damages and early receipt of retentions, but these do not directly show in financial statements; retentions reach nearly 3% of revenue from projects (Murdoch and Hughes, 2001). This is an incentive for manufacturers to accelerate production. In addition, there are several transaction cost items associated with time.

9.1.2.3 Emphasis on quality and prevention of defects

Although there were a few negative comments by respondents at the interviews (see Section 8.1.2.1), quality is a major consideration for manufacturers. Reduction of waste and defects, and the maintenance of the quality of concrete produced, are some of the main competitive advantages that should be maintained. These affect a company's finances in different ways, including wages of technical staff, running costs of laboratories, and other miscellaneous costs associated with waste and quality. There are some hidden losses associated with concrete waste caused by defects considering that 5-8% of production could be lost for this waste stream (see Figure 6.8).

9.1.2.4 Emphasis on other KPI aspects

Other indicators include efficiency, Right-First-Time, Health and Safety and other requirements that affect expenses in different ways. Efficiency and Right-First-Time costs are mainly capital and operating expenses of systems required to maintain economies of scale or implement some modern managerial systems (such as Total Quality Management); expenses may also include wages for efficiency and productivity managers. Health and Safety costs are perceived financially as costs of avoiding penalties, damages, and action plans against the businesses (Rikhardsson, 2005). All these KPI requirements are considered by manufacturers and their decision-making frameworks.

9.1.3 Exploring economic objectives and gains within processes associated with project handling

The findings in Chapters Six, Seven, and Eight show that different decision-makers operate in a stable environment where major changes are not being introduced frequently. Some of these organisations also have a stable economic environment and secure long-term arrangements with clients. These organisations employ standardised processes in production and handling of jobs and orders, which shed light onto how different departments work with each other. Figure 9.2 is based on descriptions offered by respondents from the semi-structured interviews.

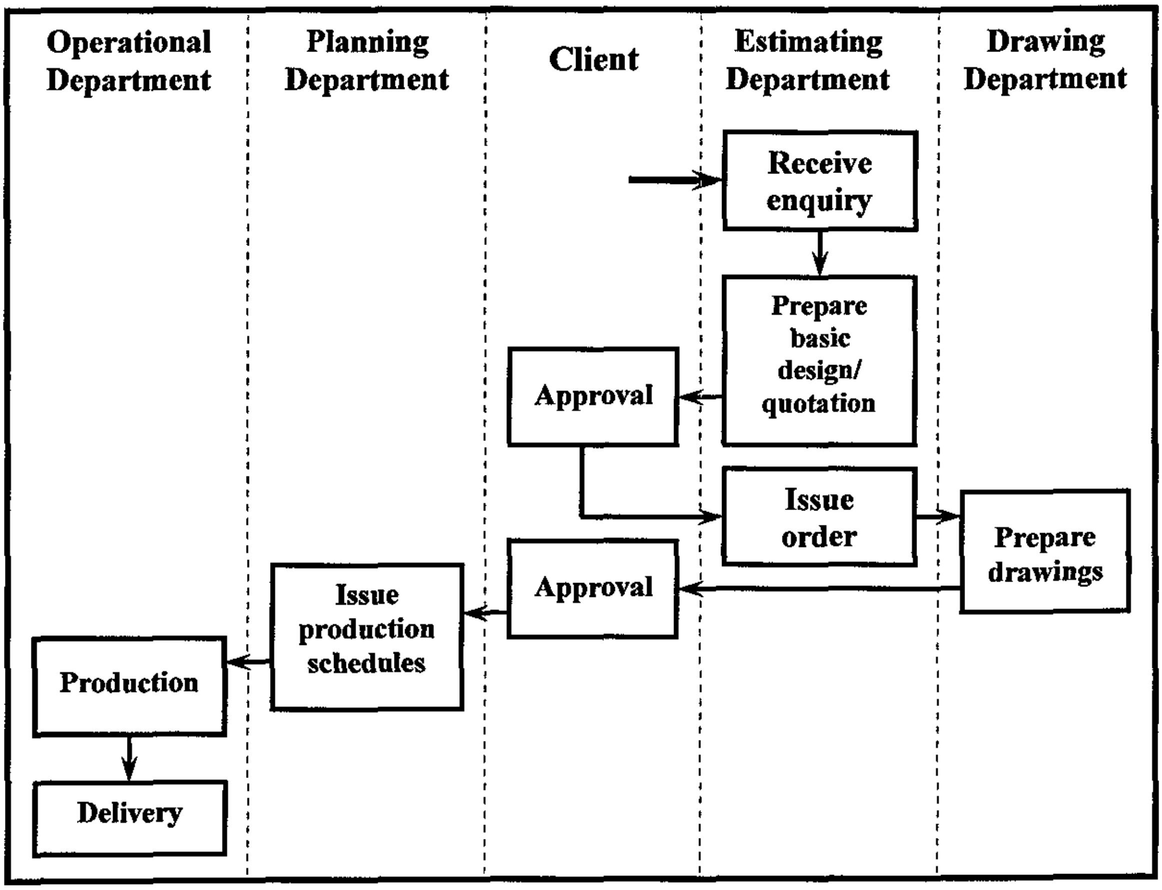


Figure 9.2 Flow diagram showing the jobs and orders handling process.

The interviewees noted that enquiries usually come to the Estimating Department; a preliminary design and a quotation would then be produced and submitted to the customer. When approved by the customer, the Estimator issues and passes an order to the Drawing Office which prepares the working drawings. These then need to be approved by the customer. On approval, units are approved for manufacture through the Planning Department. *Production Schedules* (known in some companies as "*Bed Sheets*") are set based on predicted and actual workloads and specific customer requirements for delivery; a complicated system may also be employed for this.

Apparently, profitability and economic gain have always been the main objectives and end goals for the industry. The objectives identified by Levitt (1982), and Richardson (1991), in Chapter Five, have proved to be the most essential for the industry. Every activity or process will target a specific economic objective such as reduced time or increased quality (and the end goal is maximum profitability). This is demonstrated below.

- The decisions taken by the Estimating Department on what jobs to quote for, or what enquiries to positively reply for, are influenced by profitability. They are required to bid (or offer quotations) for a specific number of jobs per week; accordingly achieving the weekly turnover target. They may become 'choosy' about the type of jobs they accept: the preference criteria are mainly based on avoiding jobs that take considerable time in design or orders, upsetting the mechanisms of mass production.
- The decisions taken by the Technical Department are mainly functional. According to interviewees, their decisions might be influenced by savings in Cost of Sales and expenses (minimising the amount of reinforcement in the product), or machine employability (such as accepting orders with different depths to avoid bottle-necks in casting machines' use)[73]. Some of their decisions might target reduction of costs of raw materials (cost of sales) through the reduction of cement and use of alternatives. Furthermore, their decisions might target some expenses (such as raw materials' transportation expenses, or minimising the cost of sawing) through change of types of aggregates being used.
- The decisions taken by the Planning Department also target profitability. The way jobs are organised usually targets efficiency and maximum utilisation of production systems employed (which is similar to objectives targeted by operational managers). A distinction should be made between efficiency and effectiveness: Ruth (2005) notes that modern economics concentrate more on efficiency than on effectiveness[74], which might be one of the reasons why some specific streams of materials or effort waste arise undetected when economically driven decisions are implemented.

The same principle applies to departmental decisions undertaken on an occasional basis. A decision to use a specific system will always target specific profit-driven objectives such as costs, production time, or quality. The same applies to decisions targeting factory locations, factory layouts, or production volumes. All decisions seem to be linked to one or more 'cash flow statement' or 'profit and loss account' functions. This shows how most (if not all) environmental impacts can arise as by-products from different operations due to these decisions.

[73] It should be noted that such act was only considered theoretically.
[74] See Glossary.

9.2 General organisational structure and environmental impacts

As noted in Section 9.1, the conventional decision making process employed in precast flooring organisations mainly considers a specific set of objectives, elements, and parameters that target only maximum profitability. The lack of consideration of environmental impacts within the conventional decision-making process means that the manufacturers have no actual control over their environmental profiles. Moreover, although most of the environmental impacts usually occur during physical production, handling, and processing at the shop-floor level, many of the environmental impacts occurring in production are triggered by decisions undertaken in other departments and levels within the organisation structure.

For example, take the environmental impacts associated with curing energy consumption (Figure 6.13). These range between 458 MJ/m^3 and 595.3 MJ/m^3 for PFF1 and PFF2 (Hollowcore). A fault in job organisation at the Production Department may result in leaving one bed (out of 12 beds) heating but unutilised; adding an unnecessary 42 MJ/m^3 to 54 MJ/m^3 onto the energy consumption figure. The choice of jobs with high levels of customisation by the Estimating Department could complicate manufacturing processes and increase concrete waste generation by more than 2.5 tonnes per cast (Figure 6.8). Using the ten decision areas identified earlier, it is possible to a considerable number of environmental impact scenarios. This shows clearly the significant influence of economically motivated decisions on the environmental profile.

To offer a more complicated and representative context to this already complex relationship, the following example shows how decisions can affect each other, negatively or positively, and entirely reform the environmental profiles of flooring products. The example was constructed from a similar demonstration made by Elhag *et al* (2006), it is structured in a scenario-based consequential (almost cause-and-effect) manner: exploring the decision to use concrete waste as recycled aggregate (see Figure 9.3).

European precast manufacturers Consolis, and some British Precast flooring manufacturers, claim that the recycled concrete can be used successfully as aggregate in hollowcore production (Addtek, 2000; BRE, 2000). A quality protocol developed from a study carried out by BRE (partly sponsored by PFF) states that concrete waste can replace coarse aggregates and fine aggregates by 20% and 10% respectively.

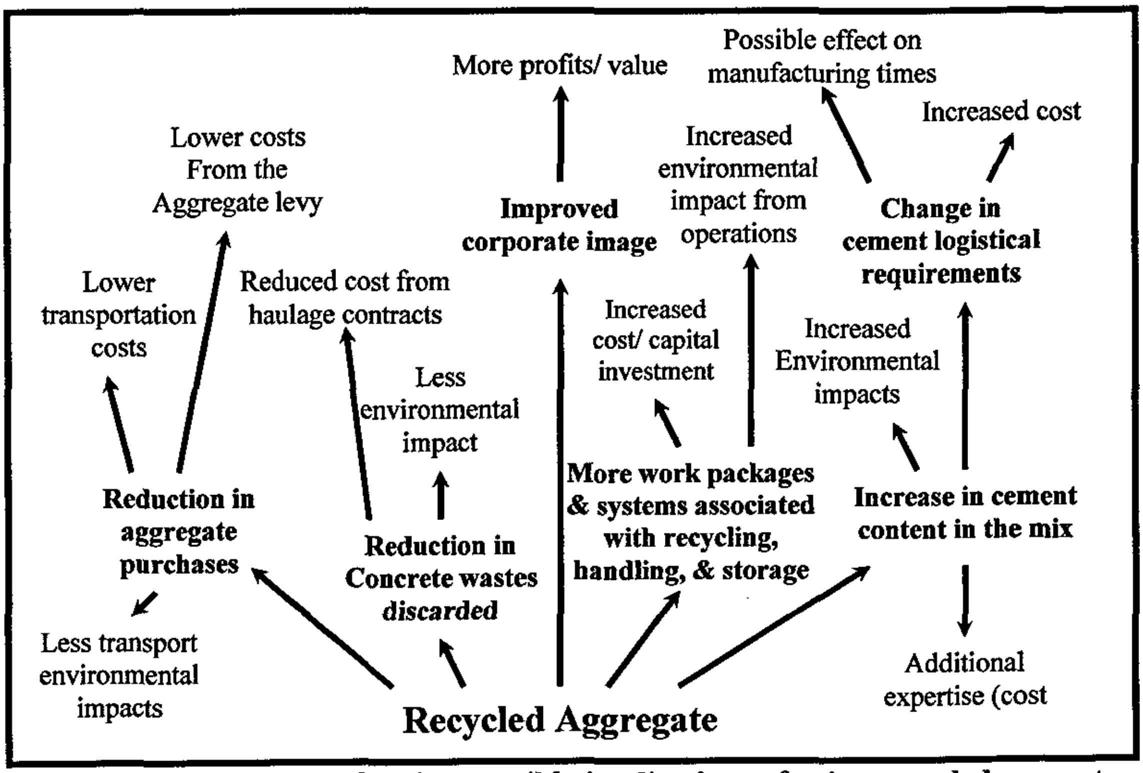


Figure 9.3 A process tree showing possible implications of using recycled concrete as aggregate.

During the interviews, and even in the limited literature covering the use of recycled concrete in hollowcore production (Bailey *et al*, 2002), manufacturers point out that the objective behind using recycled aggregate is economic. Through the avoidance of the Aggregate Levy, reduction of costs associated with virgin aggregates and avoidance of waste contractors' services, manufacturers manage to achieve considerable savings in cost of sales, costs of subletting, and logistics. The amount of industrial waste will decrease significantly. Moreover, by using recycled aggregates manufacturers avoid substantial upstream environmental impacts arising from aggregate production and transport. Such initiative can also help manufacturers improve their corporate image and possibly gain a competitive advantage in the market.

However, the use of recycled aggregate can affect the processes implemented in the industry. The crushed material may need to be stored in bins for a few days prior to use in production (cement within the crushed concrete may hydrate during storage). This can cause substantial complications in logistics and materials management in the factory. With such time and space problems, it is difficult for manufacturers to control their resources and systems efficiently. Furthermore, a product reclamation system will need to be developed. This will require change to several activities throughout the factory and additional processes (such as quality tests to identify the amount of contamination in the crushed concrete) will need to be adopted. The process will also require additional expertise, tasks and work packages associated with the recycling technology (Bailey *et al*, 2002); normal crushing machines are effective at reducing the size of lumps of concrete but they cannot handle large slabs, nor can they eject reinforcement in straight lengths (which can be economically transported to recycling). Bailey *et al* (2002) suggests that manufacturers need to develop special crushers and recycling systems to improve the crushing and reclamation mechanism. This will cause additional costs and possible additional environmental impacts arising from factory-based recycling operations.

Moreover, Bailey *et al* (2002) notes that '*the crushed material was normally drier than freshly quarried sand and therefore slightly more water needed to be added at the mixing stage*'. The study did not identify any needs to increase cement content to maintain the w/c ratio within the concrete mix. However, Bijen (2002) claims that concrete with a recycled aggregate content requires more cement in the mix. Accordingly, it is possible that the cement content in the mix will need to be increased. Considering that production of cement in the UK generates around 880 kg of CO_2 per tonne of cement (Gilbert, 2005). An increase of cement content by 5 kg (per tonne of net production) increases climate change impacts by 4.84 Kg of CO_2 [75]. Moreover, manufacturers will incur additional costs and environmental impacts due to the new logistical requirements of sourcing additional cement.

Figure 9.3 shows a typical sequence of decisions and environmental consequences (for using recycled aggregate), which could be expanded further to include other issues such as possible effects on delivery times or market prospects. The example clearly shows how different environmental consequences of a specific decision can multiply and change the entire environmental profile of products. The example also demonstrates why current conventional systems should be modified to account for the relationship between environmental impacts and economic gains.

[75] Considering that the rate of concrete waste is 10% (of gross production).

However, there is still a good chance to identify a viable and less complicated link between environmental impacts and the decision-making framework. Based on the information gathered from the LCA and the semi-structured interviews, it was also possible to build up a probable breakdown for the influences of decisions on the production systems generating all these environmental impacts (increases in energy use, waste generated, transportation impacts, increases in emissions, etc.). The breakdown worked best on electric and fossil fuel energy consumption levels where most of the energy seemed to be governed by strategic decisions made earlier prior to the production process (see Appendix J). Figure 9.4 shows the breakdown of economic variables (operational and strategic) affecting fuel oil energy consumption. Unfortunately, most of these environmental impacts are no more than by-products of decisions solely targeting profitability; this applies to most impacts forming the environmental profiles of precast flooring. Manufacturers will need to expand their decision making frameworks to account for major environmental impacts. The manner in which these frameworks are expanded will depend on a number of factors.

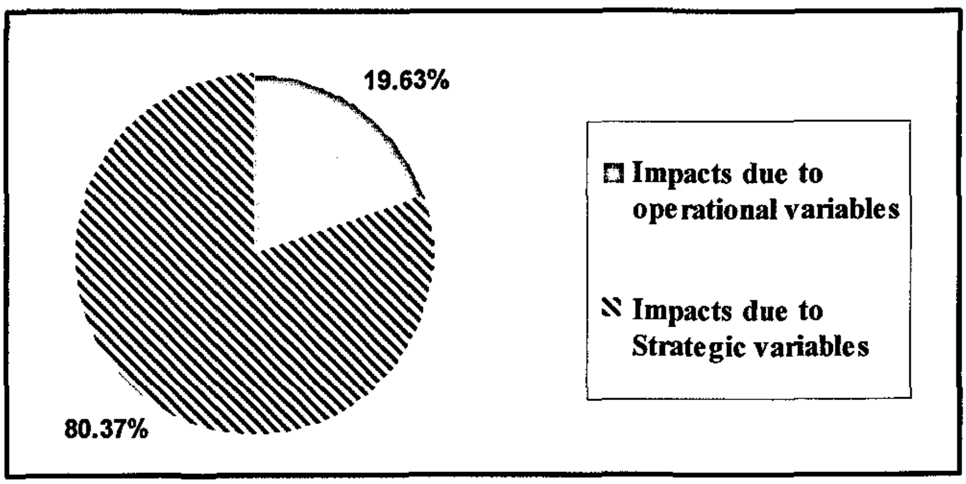


Figure 9.4 Breakdown of strategic and operational variables influencing gas and fuel oil energy consumption in a precast flooring factory (Appendix J).

Figure 9.4 indicates clearly that the organizational perceptions should not be ignored, the managers' perceptions (especially those associated with the strategic level) should be considered, and if possible it should be utilised as an advantage to environmental improvement. As explained in the following section, even if the manufacturers had negative perceptions on the suggestions given, that would not necessarily mean that they were opposed to the principle.

9.3 Identifying manufacturers' perceptions and the influence of economic concerns

Findings on manufacturers' perceptions (from the focus groups and semi-structured interviews) showed a collection of impressions and views regarding the introduction of sustainability to the industry. The lack of sufficient information linking environmental impacts to decision-making frameworks (as explained in Section 9.2), the relative novelty of the subject, lack of awareness, and limited levels of application in the industry might have negatively influenced manufacturers' opinions on sustainability. However, the vast majority of factors and elements influencing manufacturers' views are linked to economic concerns and fear of loss; this link is exposed in the following sections.

9.3.1 Denial and rejection of the concept of sustainability

A worrying level of rejection was observed in several stages of the research. For example, it was evident in the Strategic and Technical Focus Group sessions when 19 out of 30 respondents agreed with (or refused to comment on) a statement that '*threats to the environment are being exaggerated*'. All answers offered (including those in the '*I don't know*' category) could be based on impression rather than actual knowledge. The semi-structured interviews stage offered even firmer indications including the reluctance of marketing managers to compromise on specific economic objectives. Strong views toward the subject were also made: these include the comment made by PFF1 Technical manager that '*Having a good environmental profile is not the driver*' (A-25), or the PFF1 Marketing manager description of sustainability as a '*happy by-product*' (A-64). All these indications point to denial and rejection of the concept of sustainability and environmental improvement as a primary objective.

It might be difficult to understand why such strong views prevail in the industry. However, looking at some answers such as B-27, where PFF3 Technical manager notes that they '*have very little regard for this, because business has to continue*', it is possible to detect the strong concerns of manufacturers regarding the influence of environmental improvement measures on profitability and potential economic gains. This shows clearly that the cause of such rejection is not due to a lack of knowledge and unawareness only.

9.3.2 Bias and other perceptual patterns affecting manufacturers

Some of the answers given in the Focus Groups (mainly in Question 2 for the three Focus Group sessions and Question 6 in the Marketing session) show considerable levels of bias. It should be noted that this bias does not seem to have any rational basis. It appears to be linked to the industry's 'traditional view' and corporate 'normal behaviour'.

Clemens (2005) argues that the traditional view of the corporation is that '*improving the environment hurts the organisation's performance*'. Furthermore, there is other literature that considers investments in green issues as a drag on an organisation's bottom line causing negative effects on general profitability (Pava and Krausz, 1996; Mathur and Mathur, 2000). This might have contributed to a form of bias which is driven mainly by depicting different environmental efforts and activities as a burden on business performance and profitability. Bias can develop from several factors, Bowditch and Buono (1990) identify a collection of factors and perceptual patterns that can affect individuals' perceptions. These include the following

- **Gestalt Psychology:** Manufacturers (respondents) collect information on specific aspects and the information is translated in respondents' minds as structures of '*gestalts*'. Every other detail is fitted, shaped, located, and classified in accordance with these gestalts. Therefore, the manner in which results are assessed, prioritised, and interpreted will always differ from reality. It is not clear whether this might have directly affected the negative perceptions of sustainability, however it was noticed that some of the Operational managers could not differentiate clearly between energy efficiency activities targeting environmental profile reductions and those activities targeting efficiency and savings to energy costs and overheads.
- **Figure-Ground Phenomena:** This can be an influential factor because the view and identification of the problem, and identification of variables affecting the problem, will all be based on the first impressions and visualisations of the respondents (manufacturers) to the problem. This can lead to a distorted diagnosis of the problem (and variables affecting the problem). It is quite possible that manufacturers only recognised the negative patterns associated with sustainability, so it was difficult for them to translate their views to a different context.
- **Closure:** This refers to the tendency of respondents to comprehend incomplete information as if it was complete. This will lead to defects in the identification of the problem and possible means of action. It is possible that manufacturers have mainly

been looking at negative sustainability information without properly looking at the potential available within sustainability and environmental improvement.

Bowditch and Buono (1990) also identify a collection of other factors affecting respondents' judgement and preferences, these include *perceptual distortion*, *stereotyping*, *expectancy*, *perceptual defence*, and the *Halo effect*[76]. It is clear that all these factors (especially the first one) can be linked to manufacturers' eagerness to address economic and profitability concerns ahead of anything else.

9.3.3 Interpreting manufacturers' perceptual patterns using the Structuration Theory

The Structuration Theory offers a particularly helpful explanation for manufacturers' views and reactions to the introduction of sustainability and environmental improvement measures. The concept of 'Normal Behaviour' (Giddens, 1986) can have a substantial effect on manufacturers' views and attitudes towards sustainability. Unlike other factors (explained earlier), the link between this factor and conventional economic gain is vague and not always consistent. However, it is important and helpful to look at this possibility.

The interviews (and Focus Groups) showed strong indications of a specific culture and perception of the principle of '*introducing sustainable development and environmental improvement to the industry*'. It is clear (mainly from results of the Focus Groups) that the explicit acknowledgement of the importance of environmental improvement is being threatened by a negative, implicit bias towards specific environmental principles. The tendency of company managers to agree on a specific issue although many of these issues were never discussed within their organisations and were never part of their strategies, especially when it comes to implementation of sustainable development, can be justified and identified through Giddens' (1986) Structuration theory.

The theory highlights how spatial, temporal, and social contexts in which organisations are embedded shape (and are shaped by) human action (Bresnen *et al*, 2004). The theory notes that social life is more than random, individual acts; one cannot study social life (and attitude) by only looking for 'macro' level explanations. Instead, as Giddens suggests, human agency and social structure are in a relationship with each other, and it is the repetition of the acts of individual agents which reproduces the structure (Gauntlett, 2002).

[76] See Glossary.

This means that there is a social structure (including traditions, institutions, moral codes, and established ways of doing things) within precast organisations. Many of the organisations included in the study already have declared levels of commitment to the environmental cause. However, having commitment to sustainability (as part of a company's mission statement) does not necessarily mean that the internal social structure within the organisation is fully committed to sustainability. The social structures within organisations can change and become different from companies' mission statements when people (including senior managers) start to ignore them, replace them, or interpret them differently. Although none of the organisations involved in the study have tried to address sustainability issues in more detail and take these to the middle-management and shop-floor levels, the individual agents within the organisation (different managers across different departments) have affected the incomplete codes of the organisation's structure through their hostility towards interpretation of sustainability (and probably other aspects not addressing economics in a more direct manner). The social structure within the organisation was altered to become one that cannot easily accept sustainability.

This interpretation might not specifically reinforce the notion that a one-dimensional economic context (for the inclusion of sustainability) should be set to fit with the social structure and human agency of the organisations. However, the interpretation proves that a different context is required to change the manufacturers' perceptions. Instead of challenging the 'Normal Behaviour' and perception of manufacturers, it is possible to take advantage of their attitudes to promote environmental improvement measures.

It is clear that there are several possible interpretations of the comments made by many of the respondents in the Focus Group and Semi-structured interview stages. However, the discussion above clearly shows how economic concerns can be behind the vast majority of factors influencing manufacturers' perceptions. There are many other explicit factors that can affect manufacturers' perceptions. For instance, lack of customer demand was already identified in Chapter Seven as a major factor, Casey (1992) noted that consumers are unwilling to pay more for green products. Moreover, Easterling *et al* (1995) points out that the issue of green marketing needs to be looked at in more detail as there is a gap between consumer intents and customer actions. This does not entirely rule out the occasional requirement by some clients and their architects that products should incorporate recycled material (including aggregates). However, according to the comments made in the focus groups, such requests are known but very rare.

Another important factor (also recognised in the Focus Groups and semi-structured interviews) is the influence from the other business stakeholders (including supply chain partners, local authorities, etc.). This is mainly due to the context in which the relationship between manufacturers and their stakeholders is being assessed: economic business interests usually play the major role in shaping these relationships. Clark *et al* (1994) note that "*the extent to which the interests of business are compatible with, or opposed to, the interests of other individuals, groups, and organisations is a point of much controversy*".

9.4 The relationship between conventional economic gains and environmental improvement needs

It is very important for manufacturers to understand the true effects of environmental improvement measures on their levels of conventional economic gains and losses. The relationships between economic gains and environmental improvement measures vary from one case to another. In order to provide a rational and organised account of this relationship, it was classified into positively parallel relationships, negatively inverse relationships, and more complex relationships.

9.4.1 Positive, parallel relationships

In this case, efforts targeting environmental improvement and sustainability can contribute positively to profitability and economic gain. As noted earlier, this is noticed mostly in energy reduction and waste minimisation activities; two examples are demonstrated below.

The first example is associated with energy savings. Energy savings are beneficial not only to sustainable development efforts, but they can also result in economic savings for the manufacturers. In 2002, PFF1 consumed 783,550 litres of Heavy and Light Fuel Oil for accelerated curing purposes, whereas PFF2 consumed 1,965,645 KWh. Using DTI average prices for 2002[77], it appears that the manufacturers spent around £119,098 and £77,112 respectively on accelerated curing. Reducing the accelerated curing heating time by just

[77] See www.dti.gov.uk/energy/inform/energy_prices/qepupdate.shtml

10% (i.e. one hour to 45 minutes in an eight hour heating cycle) could have saved a considerable £11,910 for PFF1 (£7,711 for PFF2). However, products might need more time to cure. Therefore it is likely that the reduction in the accelerated curing heating time will not reach one hour for most of the year. However, one interviewee noted that during summer it is possible for manufacturers to make more significant reductions in curing energy without adversely affecting shift patterns and productivity levels.

Moreover, if the EU Emissions Trading Scheme had been established at that stage, the CO_2 emissions saved could have provided the chance to sell CO_2 emissions allowances. CO_2 tonnes (under the EU emission trading scheme) still have a fluctuating price (EU, 2003b). However, using the price of €17.8 per tonne (Natsource, 2005), the savings from accelerated curing modifications would have been 261 and 220 tonnes of CO_2 eq. for the two manufacturers. Thus, the two manufacturers would have been able to sell those savings for €4,645 and €3.916 respectively. It should be noted that the savings could still exceed these amounts.

The other example is associated with savings in cement use. In 2002, manufacturer PFF1 used PFA as a partial replacement alternative to cement. PFF1 managed to avoid the use of up to 551.2 tonnes of cement. Considering that the production of a tonne of cement generates around 880 kg of CO_2 (Gilbert, 2005), PFF1 was able to avoid an extra 485 tonnes of CO_2 emissions, which is more than 5.26 kg of CO_2 equivalent for each tonne of hollowcore produced. The cost of 551.2 tonnes of cement was between £30,244 and £45,391 (grey Portland cement)[78]; considering that PFA could roughly have halved the cost of cement, the economic savings would therefore reach £15,122 - £22,645. In addition there could be other savings (as well as costs) associated with transaction costs.

9.4.2 Negative, inverse relationships

These are the relationships most manufacturers are worried about; efforts targeting environmental improvement and sustainability may require substantial expenses and costs affecting profitability and economic gains. Two examples are given below.

The first example is associated with concrete waste. Manufacturers have different pricing categories for projects based on complexity; jobs with high levels of customisation are usually more expensive, such jobs comprise around 50% of orders processed on the shop-

[78] http://www.statistics.gov.uk/downloads/theme_commerce/PRA-20000/PRA26510_20040.pdf

floor. The amount of concrete customisation waste is around 5-8%, which is a significantly high level. In order to eliminate such waste there are two possible alternatives:

1. **Accept jobs with no customisation requirements:** This will definitely limit the number of jobs that could be accepted by factories, but manufacturers will not be able to meet their weekly targets, and the levels of profitability will be severely affected.
2. **Employ a system that does not produce customisation waste (such as wet casting):** Such a system could require substantial expenditure reaching hundreds of thousands or millions of pounds associated with the replacement of the casting system and provision of moulds. Moreover, there are substantial losses (also reaching hundreds of thousands of pounds) associated with the reduced speed and efficiency of the production process and lower rate of orders completed. There are also additional costs associated with the increased handling of wet-cast products (see section 8.2.8).

Both environmental improvement options are inappropriate given the substantial costs associated with the required changes. This example clearly shows that the elimination of customisation waste is unlikely to be accepted by manufacturers in the business. An effective solution for such a problem would probably require manufacturers to persuade the upstream of their supply chain (customers, architects, and clients) to adopt more sustainable designs. This has already been discussed with members of the second focus group and it does not seem to be a feasible option that can be implemented on a wide scale; this is because manufacturers deal with a variety of clients from different backgrounds and with different abilities.

The other example is associated with the choice of raw materials. Many of the manufacturers look at the cost of raw materials as the major factor in choosing their suppliers. Figure 6.24 shows clearly that substantial emissions' savings can be achieved by locating close to suppliers. However, the total cost of raw materials is a major component in the composition of the cost of sales, which comprises more than 80% of a precast company's turnover (see Table 4.1). Therefore, it is unlikely that manufacturers will compromise on the cost of raw materials to minimise impacts associated with transportation.

9.4.3 More complex relationships

It should be noted that the relationships between environmental impacts and economic gains are not always as straight forward and simple as explained in the two sections above. That relationship might have some level of complexity where, as explained in Figure 9.3, a range of environmental gains and losses are triggered by a specific decision.

In addition to the example given in 9.2, there are plenty of examples to demonstrate this; many of the environmental solutions suggested in Chapter Six had positive (as well as negative) economic effects. One of the main issues handled extensively in Chapter Six was the link between some environmental improvement measures and potential long-term economic benefits. In such a case, there are possibilities of short-term expenses and losses (associated with a specific environmental improvement solution) that can be transformed in the long-term into economic gains.

Take the environmental impacts associated with curing energy consumption (shown in Figure 6.14); these range between 407 MJ/m^3 and 595.3 MJ/m^3 for PFF1 and PFF2. The strategic decision of senior management (at PFF1) to avoid investment in new curing systems has helped to avoid considerable expenses associated with the capital cost of the systems, which could reach hundreds of thousands of pounds. However, the decision has led to a considerable (possibly 40%) curing energy loss due to the inefficiency of the ageing system used (this is around 238.12 MJ/m^3 of production). Using 2002 energy prices, this should have cost around £0.58 per m^3, or £35,052 considering the 2002 entire production[79] – this might represent a considerable saving, but it does not justify the substantial cost associated with such dramatic change to the production system. However, the capital cost of the system could be offset and future savings could be possible within the long-term (probably in less than ten years time). Given the possibility of future rises in fuel energy prices, the capital cost of the system might be offset within a shorter period.

It is clear that the economic constraints mentioned above will always affect how different environmental improvement aspects are looked at and perceived in the industry. It is also evident that any suggestion of an environmental solution or an environmental improvement framework will have to be looked at in the context of these constraints.

[79] Product density assumed to be 2350 kg/m^3 – based on the average density for hollowcore produced in the five PFF factories included in the study.

environmental impacts) can be looked at as variables that can be controlled to achieve business improvement through a structured approach to sustainability.

9.5.1 Modifying the conventional view on economic variables affecting the implementation of sustainability

With the use of a different view on economic obstacles and constraints (as variables), there are three main approaches to address and champion environmental improvement in the precast flooring industry. First, manufacturers can choose to ignore the entire issue of voluntary environmental improvement. However, ignoring this could severely affect any prospects of improving sustainable performance considering that manufacturers will only tackle aspects linked and associated with regulations. Secondly, manufacturers could choose to look at economic variables as uncontrollable factors that should be avoided, but this will lead to the avoidance of all main red-line areas. Furthermore, the perceptions of manufacturers on sustainability would not change, making it difficult to address any future environmental improvement opportunities. The third option for manufacturers is to look at economic and environmental variables through a context that enables them to take advantage of the relationships that exist between these variables. This third option is a tricky and difficult path, however there are several findings (established in this and other research) that can be employed successfully to change the image of sustainability in the business and exploit the environmental variables for general business improvement.

Since the two former options are the ones in effect already implemented widely in the industry, this section concentrates on the third option where the research findings can be employed in a particular context aimed at changing views and supporting business improvement through an approach that recognises and embraces sustainability.

9.5 Consideration of different contexts to look at economic and environmental variables

It is apparent that the acceptability of environmental improvement and sustainability promotion activities will always be influenced by economics. Dealing with and managing the relationship between economics and environmental improvement measures will need to be considered in a context different to the one used repeatedly in Chapters Six, Seven, and Eight. These economic factors were referred to as constraints and obstacles (see Chapter Six). However, as demonstrated in Section 9.6, these factors (along with their associated

9.5.2 Taking advantage of findings associated with the preferred economic objectives

Results from the semi-structured interviews show that different decision-makers prefer economic objectives associated with costs and overheads over other productivity objectives. In earlier chapters this was presented as a difficulty given that all the red-line areas cannot be modified to embrace sustainability. However, looking at this finding in a different manner, it is possible to take advantage of this in promoting any environmental solution that may achieve economic (as well as environmental benefits). The same also applies to many environmental solutions with complex relationships between environmental and cost-based economic variables.

9.5.3 Using different contexts for the consideration and inclusion of environmental improvement in business processes

Taking advantage of economic variables can be demonstrated by looking at environmental savings in a different context. There are several cases where environmental improvement aspects can be expressed in a manner more positive and responsive to organisations' business needs.

One example is found in the case of CO_2 emissions associated with various activities in precast flooring production. In their operations, manufacturers have always looked at financial costs and CO_2 emissions separately. The only occasion where these are linked together is in annual reports where the rate between the annual turnover and total CO_2 emissions (arising from different operations with different levels of contribution to value) are compared with rates from earlier financial years. This does not enable manufacturers to explore the actual breakdown of CO_2 emissions across different activities, therefore manufacturers would not be able to see how CO_2 emissions can be reduced by applying considerable care to economic requirements and business improvement. This should not be the case as CO_2 emissions can be engineered to support different efforts of business improvement;

A fine example is found in comparisons between CO_2 emissions associated with raw materials transportation and curing energy. The LCA study findings show that the average amount of CO_2 consumed in transport is 4.42 kg CO_2/ tonne and the average amount of CO_2 consumed in curing is 18.45 kg CO_2/ tonne. However, the expenses and overheads (and other economic effects) associated with the emission of 1 kg of CO_2 in raw materials' transportation are high considering that raw materials transportation is directly associated with the Cost of Sales of a manufacturer. On the other hand, the expenses, costs, and overheads associated with the emission of 1 kg of CO_2 in accelerated curing are much lower considering that it will mainly be associated with the price of fuel consumed per 1 kg of emitted CO_2 (see examples given in 9.4.1).

Another example, also associated with raw material transportation, is found in decisions associated with suppliers (of raw materials) and the transportation means selected. In the first instance, sourcing raw materials from abroad might not seem a particularly sustainable act. However, manufacturers may look at the economic factors at stake and then carry out the most appropriate action (economically and environmentally). For some products such as steel or additives, the economic gains of sourcing from abroad might outweigh the increases in environmental impacts arising from overseas transportation.

A basic sensitivity test (using secondary information) can be used to establish the impact from selecting an international supplier (concentrating mainly on CO_2 emissions). Both manufacturers in this test (PFF2 and PFF4) import steel from suppliers in Spain. The test assumes that the manufacturers decided to change their minds and import steel from other suppliers located in *Origin-B* (an additional 2,000 km by ship), *Origin-C* (additional 5,000 km by ship), or *Origin-D* (additional 16,000 km by ship).

	PFF2- Hollowcore Climate Change impact (CO_2 Kg)	**PFF4- Hollowcore Climate Change impact (CO_2 Kg)**
Status Quo (Spanish Steel)	22.573	18.14
Origin-B Steel used	22.58	18.15
Origin-C Steel used	22.6	18.17
Origin-D Steel used	22.62	18.2

Table 9.1 Environmental impact from differences in choice of international steel supplier.

The results above reveal that the choice of an international supplier for steel, a choice that may potentially save considerable costs of sales, will incur only a minor penalty in CO_2 emissions. This is due to the minimal environmental impact associated with ship travel compared to train or road travel. However, estimations for such transportation impacts should also include travel distances on UK roads and in the international supplier's countries, which were assumed in the example to be the same, but may change the results of the test. Other examples can be given for concrete waste, internal transport energy, or even on fundamental decisions associated with production systems or factory operations.

In all these examples, the contexts in which environmental aspects were being looked at were different, therefore it was possible to compromise and prioritise successfully between environmental and economic variables. However, there are other worries associated with the kind of environmental solutions manufacturers might prefer;

Analysis in Chapter Eight (Semi-structured interviews) showed a preference for specific types of solutions. It appeared that most of these solutions share two main characteristics, these are their effect on economic expenses and major operations (which was partly dealt with above), and familiarity in use and applicability – See Appendix P. Manufacturers would like to see these solutions being implemented and identified within their conventional context, the table provided in Appendix P could work as an environmental 'wish list'. But manufacturers do not want to adopt solutions that would jeopardise their profitability or the way they conduct their businesses.

This shows clearly that the manner in which different environmental solutions are presented, and the form in which these should be included, will still need to be reviewed. Otherwise, there will be a very limited chance of business improvement through a structured approach to sustainability, unless there is a compelling regulatory solution forcing manufacturers to consider integration of business improvement and sustainability objectives. All these options and possibilities of economic inclusion for environmental solutions are discussed below.

9.6 Routes of environmental inclusion in conventional decision-support systems

The general discussion above clearly expresses the need for a different approach to address and incorporate environmental improvement aspects. This approach should help not only in identifying the often changing relationship between environmental and economic variables, it should also help in framing the concept in a language that manufacturers understand and react with. Many of the findings and replies (throughout the analysis and discussion chapters) have pointed already to such a possibility because many of the environmental solutions identified coincide positively with economic gains. It would be possible to take advantage of such a relationship in offering an economic route for the implementation of environmental improvements. It was possible to identify three main routes, these include the following:

- **Route A (simplistic, less-complicated):** This route would not challenge the identified red-line areas. It should enable manufacturers to recognise and implement solutions associated with parallel, positive relationships and quantified links between environmental and economic gains.
- **Route B (Two advanced systems):** Two advanced but separated systems of identification of environmental and economic information are available in this case. The level of integration is limited in the route and so manufacturers will have to make the links by themselves. The environmental information should be based on sufficient LCA information to enable manufacturers to recognise and implement environmental solutions associated with linear, as well as complex, relationships between environmental and economic gains. Manufacturers should be able to recognise the potential in solutions tackling some of the red-line areas.
- **Route C (Fully integrated system):** This route is based on sufficient LCA information fully integrated into the organisation's decision-making framework. Decisions are made after looking at different economic, as well as environmental, consequences. More red-line areas can be tackled and more positive relationships can be identified through the integration system used in this route.

All the identified economic routes (detailed below) abide by the general perceptions in the industry and acknowledge that environmental improvement and sustainability should coincide with the conventional economic needs of the industry. Table 9.2 (at the end of this section) summarises the main characteristics of the routes proposed.

9.6.1 Taking a simplistic less-complicated route in tackling the problem

In this route (route A), economic gains would always be the main objective behind change, manufacturers would look at their economic and environmental variables separately. However, they would need to have a good understanding of the direct parallel and inverse relationships between these different variables. Wherever possible, manufacturers would implement a specific change targeting both economic and environmental objectives.

However, it should be noted that there would be specific limitations – manufacturers would not compromise on their red-line areas; conditions and relationships (where short-term economic gains are weighed against long-term environmental and economic benefits) would always be judged and assessed in accordance with the conventional 'traditional view' of the organisation. Moreover, many of the factors influencing negative perceptions (such as lack of customer demand, or stakeholders' influence) would not be challenged, indeed the manner in which some specific economic aspects (such as the opportunity cost) are looked at would not be changed.

Route (A) might be very similar to other routes and approaches already implemented in precast flooring practices within the PFF membership. It would be possible to make several reductions to the environmental impacts associated with production and processing. For example, it would be possible to make considerable reductions to the curing energy. However, these reductions would mainly occur in the summer when products can cure naturally. Indeed, no other radical changes would be introduced to the system and no advanced studies or investigations would be carried out to identify the complex relationships between modification (or replacement) of curing systems and savings made over a specific period of time (see section 9.4.3).

However, there are several main differences between this route and other routes currently implemented in precast flooring businesses. Although the expected environmental savings would not significantly exceed savings currently made in precast flooring businesses, this route would be based on a substantial amount of quantified information identifying environmental impacts and savings (obtained from energy breakdowns or LCA –

employed as a decision support tool). Therefore the chances of implementing a successful and informed environmental strategy should be much higher than at present.

9.6.2 Employing two separate advanced economic and environmental systems

Route (B) also targets economic gains as the main objective behind any change. However, the way in which environmental information can be incorporated and interpreted is more advanced. In this case, two advanced decision-making frameworks (economic and environmental) are available. Environmental information can be shaped in a manner that allows manufacturers to look at both economic and environmental implications of a specific decision. This would require manufacturers to be more aware of the simple and complex relationships between economic and environmental variables within the business, and of the most appropriate means to utilise these relationships to improve their environmental performance.

This route would enable manufacturers to look at more options to improve their environmental impacts without compromising on their economic objectives; many of the red-line areas (identified in Chapter Seven) could be tackled. Furthermore, the complex relationships between long-term economic and environmental benefits and short-term gains could be looked at where possible. A fine example for this route is found in the precast operations of Marley Eternit (see section 5.3.3). A comprehensive LCA study enabled Marley to identify critical environmental impacts, and these were tackled through the introduction of an environmental system with a framework of initiatives (Carter and White, 2005). Many of these initiatives targeted intangible and long-term economic targets (such as corporate identity and company image).

However, this integration route would still be subject to specific limitations in implementation, unclear conditions and complex relationships would always be judged and assessed in accordance with the conventional traditional view of the organisation. Moreover, many of the factors influencing negative perceptions (mentioned above) would not be challenged or addressed. In addition, there would always be an integration problem between economic and environmental objectives due to the lack of a proper integration framework. The level of care and detail given to economic objectives (and profit-and-loss functions) would not be given to environmental improvement criteria. There could also be a lack appreciation and understanding of the environmental consequences of decisions.

Route (B) should still enable manufacturers to look at more important aspects; the complex relationships between systems renewal and savings in energy consumption, concrete waste, and emissions would not simply be avoided. Manufacturers will be able to tackle the crucial aspects in curing energy (reaching up to 40%), transportation impacts, concrete waste (exceeding 2.5 tonnes/ cast), and many other factors associated with operational as well as strategic variables (see Figure 9.4). It would also possible to look at and assess systems and problem-solving tools (see Chapter Five) that can effectively improve economic and sustainability performance (Lean Production, Value engineering, etc.). Although this route might not enable manufacturers to address and detect some impacts and in spite of the lack of a well coordinated and integrated strategy, the chances of environmental success would still be high.

9.6.3 Taking an advanced step through complete integration of economic and environmental measures

As with the two preceding routes, Route (C) mainly considers the conventional economic gains in the business. However, the environmental impact information in this route is fully integrated within the conventional decision-making system. Manufacturers would be able to identify the direct, as well as the hidden, economic and environmental consequences of a specific decision. This route is different from the Route (B) as the indirect information on environmental benefits and transaction costs can be identified and utilised. Manufacturers would have to be aware of the simple and complex relationships between economic and environmental variables within the business, manufacturers should also be aware of the most appropriate means to utilise these relationships to improve environmental performance.

The way in which environmental information is integrated with the conventional production system may vary; there have been several studies attempting to integrate life cycle environmental and economic variables for different purposes. Obërg (2002), as well as Edwards *et al* (2000), looked at how life-cycle based economic and environmental tools can be integrated in use. Both studies explored the integration of Life Cycle Assessment (LCA) and Whole Life Appraisal (WLA) mechanisms. Both studies offer a range of examples and case studies into how these can be employed. However, there are no suggestions for a holistic organisational system to address the issue and implement change.

There are several other studies addressing the concept of tools (or objectives) for integration. Butter and Hofkes (2001) suggested that such integration can take place through the integration of environmental requirements into the conventional economic models employed in the industry. They use the 'Endogenous Growth' theory to incorporate aspects of environmental impact to the economic frameworks employed in the corporation. In this model, growth is unintentional and arises as a '*side-product*' of investment. However, it was noticed that the suggested model accounts for such sustainability aspects as social welfare functions. Environmental requirements are not included as part of the crucial functions associated with value and profit within company's operations (Butter and Hofkes, 2001). Moreover, environmental measures (which accounts for a collection of impacts and measures) were represented by a single variable.

However, there are other studies that look at integration measures in more detail. One example is found in a study carried out to use the *materials-product chain* concept, a concept that more or less coincides with LCA, as a mean to understand and allocate different complex environmental interventions associated with different unit processes. Some unit processes (similar to those in Figures 4.2 and 9.2) are described within a framework of micro-economic production functions (Kandelaars, 1998). The study mainly targets environmental impacts allocation, however it can easily be used to integrate environmental and economic parameters. Moreover, the fact that the study is targeting a small number of processes (no more than 20) makes it a perfect choice for precast flooring. Unfortunately, it was not possible to obtain a copy of the study (a PhD thesis), but many of the study findings are covered by Guineé (2002). Another modelling option that might be similar to the Kandelaars (1998) approach is through the use of Leontief's[80] conventional Input-Output economic models. There are several research schemes, studies, and software packages in the United States (McMichael and Mellon, 1999), and Europe (Suh, 2004) that employ Input-Output models to integrate environmental and economic measures. There are also integration tools to assess the technological and functional consequences; a UN report on LCA (UNEP, 1996) refers to technological models allowing for such integration; the Technology Assessment (TA) and Substance Flow Analysis (SFA) concepts were developed to work with LCA on assessing the viability of new systems and machinery.

[80] Wassily Leontief is the creator of the open Input-Output model. In this model, an economy with a number of industries (as in supply chains) consists of models. Each of these industries uses input from itself and other industries to produce products (output). Leontief was awarded the Nobel prize for his work in 1973.

In spite of these many studies and tools enabling integration, studies covering the actual and physical application of integration tools (and resulting change in organisation structure and management) are still limited (Avadikyan *et al*, 2004). Moreover, the applicability of such sophisticated models on a low technology, medium delivery industry (precast flooring production) will always be subject to question. Many of the integration tools addressed require organisations to apply economic and efficiency tools that they might not be familiar with. The most appropriate solution should be based on the main characteristics of the conventional decision-making frameworks existing in the industry. It appears that the most appropriate means of integration are those addressed in Chapter Five (such as Environmental or Sustainability Accounting). As noted earlier, accounting functions (such as the Cost of Sales, Net Profits, and Expenses) represent the main language in which different economic objectives are expressed in monetary terms. In sustainability accounting, the direct accounts show the costs and benefits of sustainability related features of the business. The indirect accounts show the indirect sustainability impacts that accrue in the future or to third party stakeholders (Casella Stanger, 2003; Howes, 2002). Much of the account information in a sustainability accounting statement is available in normal accounting systems. However, the way in which the information is presented helps manufacturers identify the hidden costs and benefits associated with environmental and sustainability impacts.

The main limitation to route (C) is associated with the manufacturers' preference to address and protect their economic objectives; negative perceptions on some radical solutions (such as renewal of specific systems) can be looked at in more detail, but this does not necessarily mean that manufacturers will agree to abandon their views. Manufacturers will always have reservations on what and how environmental improvement is addressed; this is a fact that should at present be taken as a given.

	Route A: **Simplistic less-complicated Route**	**Route B:** **Two advanced systems Route (Economic and Environmental)**	**Route C:** **Fully integrated system Route**
Main Business objectives	Always Economic (Environmental: when possible)	Always Economic (Environmental: when profitable)	Economic + Environmental (priority always to economic objectives)
Decision making framework	Economic framework + available and accessible environmental information Managers seek integration whenever possible	Two advanced decision-oriented economic and environmental frameworks, managers do integration by themselves	Fully integrated systems identifying economic and environmental effects
Environmental decision-support tool	Based mainly on Energy and waste breakdowns (LCA is also possible)	Based mainly on LCA info. Other tools can also be used.	Customised LCA tools integrated with decision-making (sustainability accounting, TA, SFA, etc.)
Info: positive, parallel relationships	Available – decision makers need to be alert.	Available – decision makers need to be alert.	Immediately available.
Info: negative, inverse relationships	Available – decision makers need to be alert.	Available – decision makers need to be alert.	Immediately available.
Info: More complex relationships	Not Available	Available – decision makers need to be alert.	Immediately available.
Red-line areas	Should not be challenged	Many could be tackled	Many could be tackled efficiently

Table 9.2 Routes of environmental inclusion in conventional decision-support systems

9.7 Routes to environmental inclusion and stakeholder engagement

It should be noted that the three routes of environmental inclusion identified within the conventional decision making process need to be maintained and improved through continuous feedback and consultation. In order to do this, it is important to recognise the main drivers behind the implementation of sustainability and environmental improvement – these, as identified in Section 1.2.1, are different stakeholders within the wider society. In order to involve those stakeholders, BS 8900 (BSI, 2006) identifies two main steps:

Stakeholder identification

The organization should define and identify stakeholders and their representative organizations. This process should firstly identify the different stakeholders and secondly clarify their interest and relationship with the organization.

Some stakeholders are essential for an organisation to perform its activities (e.g. managers identified in this thesis). Other stakeholders have a relationship with the organization that is more strategic in nature, e.g. special interest groups and government agencies. BS 8900 suggests that all these should be involved, however the nature and level of engagement will necessarily differ. Figure 9.5 offers an example of a stakeholder map.

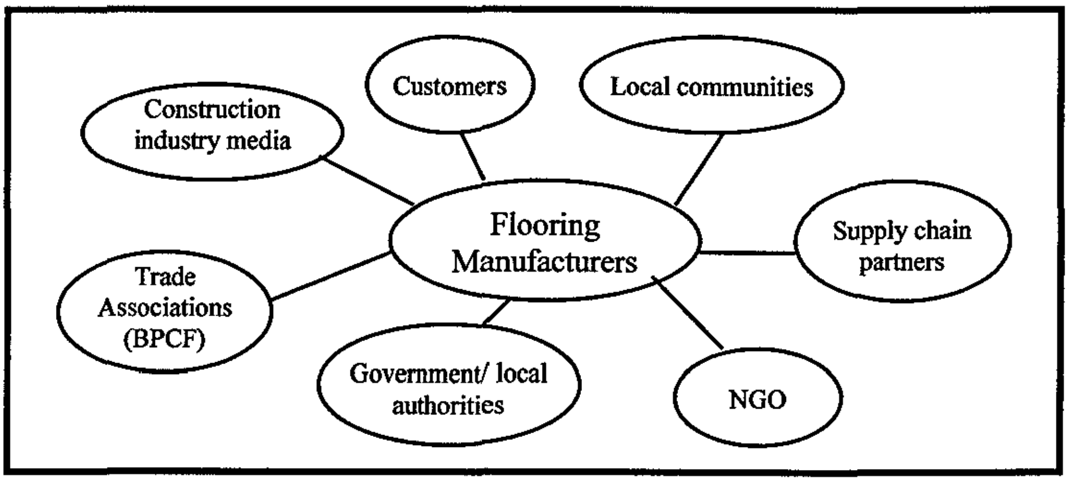


Figure 9.5 Precast concrete flooring manufacturers and their stakeholders.

Stakeholder engagement

As noted above, the method of engagement should be commensurate with the importance of the stakeholder and the issues identified to the organization. The different decision-makers within the organisation will be directly involved in developing routes A, B, and C. However, for some other stakeholders (like local communities and supply chain partners) the engagement mechanism will be different. Manufacturers can do this through provision of annual reports explaining their activities and allowing for feedback from the public. It is even possible to adopt more radical methods such as engaging stakeholders in brainstorming sessions and workshops.

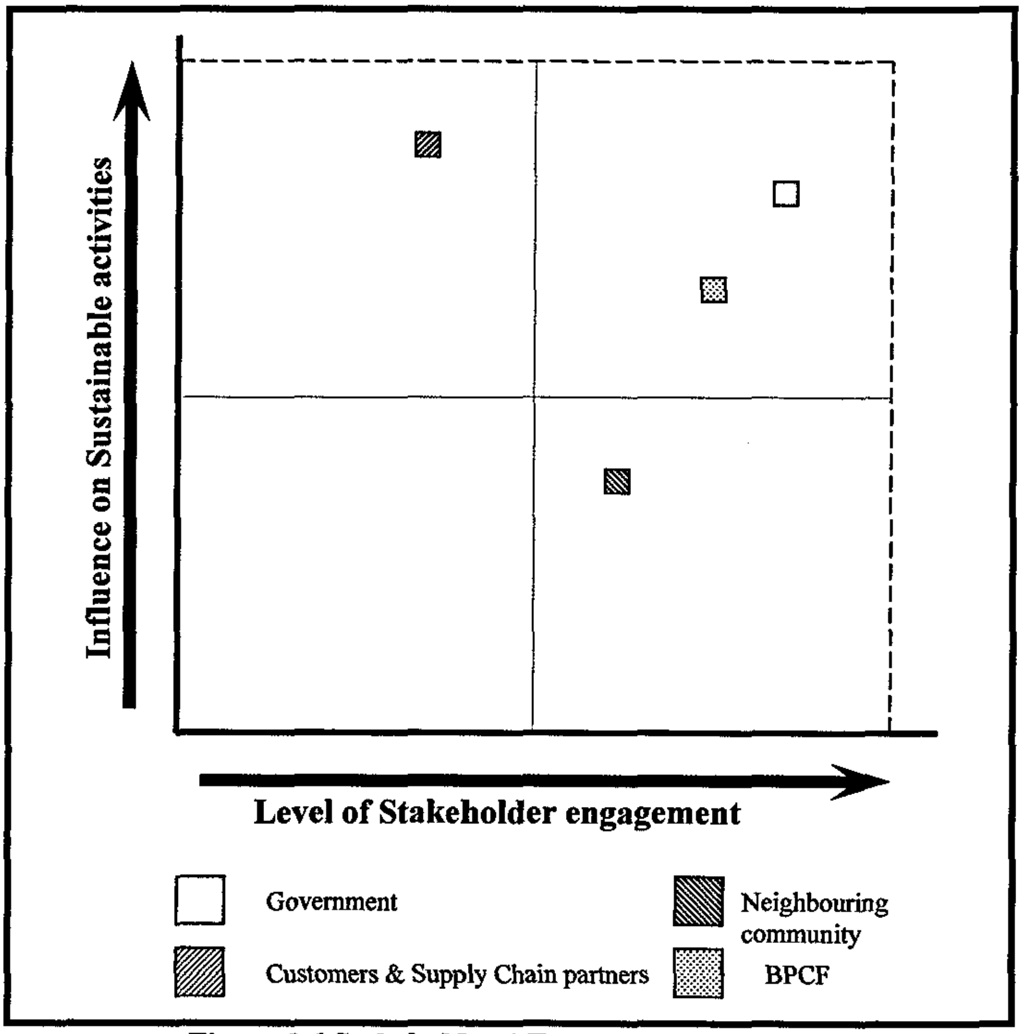


Figure 9.6 Stakeholders' Engagement diagram.

In order to understand the level of stakeholders' engagement, a stakeholder engagement diagram was developed (see Figure 9.6). Four main stakeholder groups were identified; these included government/ local authorities, industry associations (mainly BPCF), customers and supply chain partners, and neighbouring communities:

- **Government/ local authorities:** As explained in Chapter Seven, regulations have a considerable effect on different sustainability and environmental activities implemented by manufacturers. As explained in Section 8.4, local authorities are the main stakeholder in terms of engagement in shaping a company's policy.

- **Customers and supply chain partners:** As explained in the customisation example in Section 9.4.2, customers have a considerable influence in all manufacturers' policies. However, their level of actual engagement remains to be very limited.
- **Neighbouring communities:** Neighbouring communities' involvement is moderate. But their influence on the chosen environmental improvement routes is limited. This is mainly because any strong influence from neighbouring communities will mainly take place via their local authorities. An effective engagement by neighbouring communities can only take place through a more active Corporate Social Responsibility mechanism employed by the organisation.
- **BPCF and other industry associations:** Trade associations are responsible for formulating sector strategies, and leading manufacturers through a structured approach to sustainable development. However, their influence cannot exceed local authorities.

It is difficult to identify how stakeholders will take the three routes identified in this study. The objectives being looked at by each stakeholder group are different, the merits used by some of those stakeholders might be totally different to the ones explored in this study (e.g. ten problematic decision areas). However, this does not necessarily mean that stakeholder engagement will only cause an unnecessary rift between the industry sector and its stakeholders (especially local communities); any feedback from stakeholders can help considerably in improving the routes identified (e.g. prioritising on specific actions to be taken by a local factory) and this should definitely help in making the routes identified more responsive and related to the needs of wider society.

9.8 Conclusions

The discussion in this chapter demonstrates how conventional environmental and economic variables can be looked at in different contexts to include environmental improvement measures within the conventional business framework. The chapter also explains why some of the negative perceptions cannot be tackled unless conventional economic gains are considered as main objectives behind the decisions within the organisation. However, through looking at the various relationships between environmental impacts and economic gains/ losses, it was possible to identify how important it is to apply different contexts to the inclusion of environmental information and requirements within the conventional decision-making process. Of the three routes identified for environmental inclusion, the second and third routes might be the most appropriate and successful in building the case for environmental improvement and enabling manufacturers to improve their businesses through an approach that recognises sustainable development. Engaging different stakeholders in assessing these routes is necessary.

There is a possible fourth route (one of this thesis's recommendations) for the inclusion of environmental measures through the introduction of additional regulative frameworks (or voluntary agreements) and simply wait for the industry to react and adapt to the imposed measures. Such an approach has been used already through the implementation of the Integrated Pollution Prevention Control (IPPC). However, this approach would probably be imposed on the industry, thus producing the same negative perceptions and views generated by previous controversial regulations (such as the Aggregate Levy)[81].

[81] See Chapter Seven.

CHAPTER TEN: CONCLUSIONS

Chapter Ten: Conclusions

The approach employed in this research is quite different to that used in many other studies exploring business and sustainability measures within the industry. There are very few studies that have tried to take the debate a stage further by understanding and quantifying the link between environmental impacts, physical shop-floor measures causing these impacts, and business objectives triggering the implementation of these measures. The research also discusses a range of organisational and human factors affecting the introduction of sustainable development to the industry. A combination of quantitative and qualitative research tools was an appropriate approach. However, the study could have benefited from more positivist approach (despite the fact that this paradigm was more preferred by the author). This chapter offers the conclusions from the research. A summary of the research is presented. The research limitations, recommendations, and future prospects are also explored.

10.1 Summary of the research

This research evaluated the effect of sustainability and environmental improvement efforts on the business case of precast flooring manufacturers (hollowcore and pre-stressed beams). Precast flooring organisations employ conventional decision-making frameworks designed mainly to achieve maximum profitability; precast concrete production systems tend not to account for the various environmental impacts arising from operations. Therefore, in order to achieve the aim and objectives of this research, an 'action research' problem-solving approach, employing a variety of data collection and analysis tools, was chosen (Chapter Two).

Using Life Cycle Assessment (LCA), nine environmental profiles were developed for five UK-based factories belonging to members of the Precast Flooring Federation (PFF). Analysis of these profiles resulted in the recognition and interpretation of a range of environmental impacts associated with precast flooring production. The main environmental impacts arising from hollowcore and pre-stressed beam production were identified (these are upstream impacts associated with cement content in concrete, energy consumption, material use and waste generation during manufacture, and impacts arising from transportation). Ten major decision-areas were found to be linked with these main environmental impacts (Chapter Six), and a group of 29 different environmental solutions were identified for these decision-areas.

In order to tackle these ten problematic decision-areas, and in order to explore if the suggested environmental solutions can be implemented, it was necessary to explore the views of the major decision makers in the PFF organisations and assess if change for environmental improvement is viable in the industry:

Three focus group sessions were conducted with the main categories of decision-makers in the industry (strategic, technical, and marketing), through which it was possible to investigate the social dimension of the problem and identify the main perceptual drivers and obstacles associated with the introduction of sustainability to the industry. It was found that some of the negative views held by manufacturers were affected by many factors including (but not limited to) negative impact on profitability, pressure from the government through regulations, lack of demand from clients, and bias (or denial) by some of the managers (Chapter Seven). Following that, a number of semi-structured interviews were carried out with four decision-maker categories (strategic, technical, marketing, and operational). The interviews were intended to further investigate the previous results/ findings and assess the applicability of the environmental solutions identified in the research (Chapter Eight).

The wealth of findings established in the research was analysed and three routes were identified for the inclusion and integration of environmental requirements within the organisational economic decision-making framework:

a) **Simplistic, less-complicated route:** This route would not challenge the identified red-line areas. It should enable manufacturers to recognise and implement solutions associated with parallel, positive relationships and quantified links between environmental and economic gains.
b) **Two advanced systems route:** Two advanced, but separated, systems of identification of environmental and economic information are available in this case. The level of integration is limited in this route, manufacturers will have to make the links by themselves. The environmental information should be based on sufficient LCA information to enable manufacturers to recognise and implement environmental

solutions associated with linear, as well as complex, relationships between environmental and economic gains. Manufacturers should be able to recognise the potential in solutions tackling some of the areas considered as red-line for manufacturers.

c) **Fully integrated system route:** This route is based on having sufficient LCA information, fully integrated into the organisation's decision-making framework. Decisions are made after looking at different economic, as well as environmental, consequences. More red-line areas can be tackled and a greater number of positive relationships can be identified through the integration system used in this route.

The development of these proposed routes was based on the consistency in the justifications offered by decision-makers on their choice of environmental solutions. It was found that manufacturers had a preference for solutions with the least effect on the organisational structure (and process), and with a track record of applicability (See Chapter Nine). The manufacturers' concerns over cost objectives apparently meant that proven direct (or indirect) positive relationships, between environmental and economic variables, will always be more acceptable and valuable to manufacturers. The Table(s) shown in Appendix P can work as a blueprint for a 'Wish List' for manufacturers to consider sustainability when circumstances change. Manufacturers should also engage different stakeholders in their decisions on what routes to choose and what priorities to consider.

10.2 Research conclusions

The aim of this research has been to "*Evaluate the effect of sustainability and environmental improvement measures on the business case of precast concrete flooring production*". It was clear from the early stages of research that there is a potential conflict (problem) between the business case objectives and environmental improvement objectives in the industry. It was possible to identify at least ten major decision-making areas with a direct, negative influence on the environmental profiles of hollowcore and pre-stressed beams. 29 different environmental solutions were identified to tackle the problem(s).

The aim of the study also implied further research investigating many perceptual, functional, organisational, and business factors associated with the implementation of the environmental solutions identified[82]. The potential conflict between economic, social, and environmental interests has been referred to in numerous studies (DETR, 1999; Nixon *et al*, 2005). Manufacturers will always have to compromise. However, the mode of compromise has always been left widely open to interpretation and personal judgement, leading manufacturers to discard sustainability objectives for the benefit of economic objectives. However, as noted in section 5.1.2, there are four main steps in any problem solving process. The first step, which is to define and understand the nature of the problem(s), is usually the most important. With the wealth of qualitative and quantitative information gathered through the different stages in this research, it was possible to understand the operational, human, and organisational factors causing such conflict.

With the proper understanding of the effect of sustainability measures on the business case, the first three research objectives were fulfilled. This allowed successfully for the identification the most appropriate routes to introduce environmental improvement measures without negatively affecting the manufacturers' business case. Due to the reluctance of managers to embrace the concept of sustainability, it was clear that the most appropriate approach was to avoid challenging the conventional decision-making framework employed in the industry and find ways to take advantage of that framework to introduce sustainability measures (see Chapter Nine).

The notion of 'selling' the concept of sustainability to businesses, developers, and consumers has been used before in many studies (Heerwagen, 1994; Crossley, 2002). However, the suggested approach requires a commitment from the industry on a number of measures. Looking at the three routes identified to undertake such approach in the industry, these routes might seem acceptable to manufacturers because they use the language of decision-makers in the industry and address fears about their business case (Chapter Nine). However, it challenges them to put more effort into understanding the relationship between environmental and economic variables. It also stresses the need to eradicate the social obstacles (influenced by bias and lack of awareness) through proper knowledge and quantified data. The routes do not suggest any organisational change (in terms of structure and process). This clearly means that Avadikyan *et al*'s (2001) approach of reengineering is not recommended. However, with time, it is possible that organisational structures could

[82] It should be noted, however, that the research's emphasis on environmental protection measures does not necessarily mean that other triple bottom line issues (social and economic sustainability) were neglected. Achieving economic growth has been addressed as an objective throughout the study. Moreover, the perceptual and organisational factors addressed through the use of focus groups, and semi-structured interviews, were shown to affect the social as well as environmental measures of sustainable development.

'mutate' and adapt more effectively to the identified sustainability requirements. There is already information, received from PFF2 Marketing manager, that some precast organisations employ cross-departmental, multi-functional teams and task-forces to address some of their new challenges. This may apply in the case of incorporating sustainability needs. Moreover, many of the organisational changes taking place to account for different problem-solving tools, such as lean production or value engineering (see Chapter Five), can work effectively with the routes and mechanisms identified above.

It is not clear which route would be preferable to manufacturers. However, given the immense challenges associated with manufacturers' perceptions and the tendency of the manufacturers to only take tangible and well-calculated risks, it is probable that the manufacturers will (at least initially) undertake the relatively easier to implement Route (A). Nevertheless, the history of the implementation of the Aggregates Levy proves that manufacturers are capable of adapting to the other two routes (Routes B and C), but only under pressure and obligation. Early engagement of stakeholders might help in this regard.

One main question arising is the possible pace and extent of applicability for such solution routes. Such pace (and extent) will always depend on the conventional characteristics associated with the industry itself, including aspects such as energy prices, the current condition of sustainability as a marketing tool for precast flooring compared with other competitors, and any possible change in clients' attitudes and preferences. Moreover, the identified solutions (and routes to these solutions) still need to be developed through additional investigation and research, this is described in the recommendations section (section 10.5).

Despite the variable influences of environmental improvement measures on the business case of precast flooring manufacturers, it is possible to state that the improvement of businesses through a structured approach to sustainability and environmental improvement is plausible. The level of implementation for that structured approach will be affected by a variety of elements, which could be functional, economic, social, or organisational. Engaging stakeholders could have substantial impacts as other objectives (apart from the organisational or environmental objectives identified by organisations) will be considered. The level of success will depend mainly on the quality of information collected, the possibility of shifts in the stakeholders' influence (see Figure 9.5), and the manufacturers' willingness to change.

As explained in Section 10.4, this study has set the road map for the industry to reduce its environmental impacts and adopt sustainable solutions. Looking at the objectives identified in Chapter One:

1. **Understand and evaluate the environmental impacts resulting from production of precast flooring products:** This objective was fulfilled (see Chapter Six).
2. **Determine how managerial, strategic, and technical solutions, measures and decisions affect environmental impacts:** This objective was fulfilled (See Chapter Six).
3. **Understand the priorities of an organisation and how sustainability can be supported by business decisions:** This objective was met (See Chapters Seven and Eight).
4. **Identify the possibility of success and evaluate the most appropriate means of business improvement through the use of sustainability:** This objective was met (See Chapters Eight and Nine). However, it should be noted that further work should still take place to support precast flooring manufacturers and help them to adopt sustainability.

In general, this study covered a number of aspects associated with the sustainability performance of precast flooring production. However, it is important to state that there were several lessons learned throughout the work; given the chance, there were several aspects in research that could have handled differently;

The combinations of qualitative/ qualitative research worked effectively in many areas in the research. Some of the links between outputs from a research stage and inputs to its successive research stage worked well (e.g. between LCA results and the main decision areas where major environmental impacts occurred). However, in some areas where some qualitative tools were used (e.g. Focus Groups), the used tools did not yield the cut-edge results required. Given the chance, the Focus Groups should have been conducted differently to allow for more interpretations and more concrete results (see section 10.5.3). A more detailed stakeholder analysis (see Section 9.7) at an early stage of research could have helped in customising the range of research tools used and target different stakeholder categories successfully. The interpretative approach employed in parts of the research (as in Focus Groups) yielded results affected by a number of variables, it was not always possible to easily isolate some of these variables. A more positivist approach could have been taken to enable the identification and isolation of some of the social variables affecting results. However, it should be noted that this did not affect the overall quality of research as some of the data collection efforts were duplicated during the semi-structured interviews; the objectives targeted in Chapter One were therefore satisfied fully.

10.3 Research Decisions

Throughout the thesis, it is possible to identify a number of decisions taken by the researcher to achieve the main objectives of the study and concentrate on the main factors affecting the organisation's economic or environmental decisions. Table 10.1 shows the chronological order of six main research decisions in the study:

Research Challenge	Research decision	Objective targeted
Lack of environmental impact information in the industry	Use Life Cycle Assessment as a data collection tool.	Objective 1
Variety of environmental impacts affecting the environmental profiles	Concentrate on the four main environmental impact categories	Objectives 1, 2, 3, and 4
	Concentrate on the ten decision-areas associated with the main environmental impact categories	Objectives 2, 3, and 4
Lack of information on the industry's level of commitment to environmental improvement	Use qualitative tools (focus groups and interviews) to investigate the industry's perceptions and commitment	Objectives 3, and 4
Industry's reluctance to compromise on its economic objectives and conventional decision-making framework	Avoid direct conflicts with the conventional decision-making framework employed	Objective 4 and aim of study
	Find ways to take advantage of that framework to introduce sustainability measures.	Objective 4 and aim of study
	Identify different routes of including environmental improvement principles within the conventional decision-making framework	Objective 4 and aim of study

Table 10.1 Main research decisions considered throughout the thesis.

10.4 Original contribution to knowledge

The originality of this research is based mainly on the problem-solving approach undertaken. However, it should be noted that the level of contribution to knowledge throughout the study has exceeded casual problem-solving, this contribution include the following:

- **Establishment of national generic environmental profiles:** A generic gate-to-gate (and cradle-to-gate) environmental profiles for UK-based hollowcore and prestressed beams was developed. The developed profiles were recognised by the Building Research Establishment (BRE) and used as part of a new edition of the '*Green Guide to specification*' (Anderson *et al*, 2001).
- **Findings associated with production measures:** Using LCA, it was possible to establish a number of findings associated with environmental impacts and products' characteristics (concrete mix, product shape and depth, etc.), or production characteristics (length of beds, curing systems, transport devices, shop-floor operations, etc.). An industrial report was already submitted to the PFF council in 2005. Many of these findings and links were not made in key previous studies (Asunmaa, 1999; Addtek, 2000; Alexander *et al* 2003), and are notably for UK-based precast flooring producers.
- **Findings associated with manufacturers' perceptions:** Although much of the information provided by manufacturers (in the focus groups and semi-structured interviews) can be found in other studies exploring sustainability or CSR, linking these effects to human perceptual factors within the precast industry (including Gestalts, Structuration Theory, etc.) should be considered as an original contribution to knowledge. These findings will be included in the final industrial report and further recommendations will be made.

However, it should be noted that the main contribution to this study is the quantification of the contribution of decisions, associated with different levels of management within precast flooring organisations, to environmental impacts. This was possible mainly due to the wealth of information collected in the various stages of the research.

10.5 Research Limitations

In spite of the extensive measures used to obtain up-to-date primary information from the manufacturers, there were some limitations to the data collection and analysis throughout the different stages in the research; these are described below.

10.5.1 Limitations in Life Cycle Inventory (LCI) information

Although LCA accounts for environmental impacts from its widest perspective (Glavind, 2002), LCI data collection still has specific limitations. It should be noted that all these fall within the boundaries allowed under the ISO-14040's standard series (see Appendix C, Sections 2.2, 2.5, 2.7, and 2.9), and include the following:

- **Environmental impact categories considered:** It should be noted that one generic environmental impact category was excluded from the study. This category is Ozone Depletion (measured in kg. of CFC_{11}). Due to the almost negligible impacts associated with this category, and due to the abolition of CFC_{11} use in the industry in 2000, it was not possible to include this category. Indeed, most of the recent LCA studies carried out by the BRE do not account for this category.
- **Other LCA screening limitations:** As noted in Chapter Four, the LCA methodology used was simplified – Screened LCA methodology is valid and complies fully with ISO 14041 requirements. It should be noted that all these fall within the boundaries allowed under the ISO-14040's standard series (see Appendix C, Sections 2.2, 2.5, 2.7, and 2.9)
- **Use of secondary information:** In building the LCI, secondary information taken from other studies (or other factories) was used for some specific LCI items. One example is the amount of waste water from factories (taken from PFF3 records), another example is the levels of pollutants and minerals in extracted water (taken from the dangerous substances directive safety-margin records[83]).

10.5.2 Limitations on samples and data representation

Although the LCA data is taken from most members of the PFF, there are a few limitations to the sample considering that the main producer of hollowcore and pre-stressed precast

[83] See the Dangerous Substances Directive Tables at: http://www.environment-agency.gov.uk/yourenv/eff/water/213902/290690/290939/?version=1&lang=_e

concrete beams in the UK, the producer of nearly 40% of the national production of pre-stressed precast flooring, was reluctant to participate in the study (Due to reasons that cannot be addressed in this thesis). The population considered in the three data collection tools was restricted to member companies in the PFF; these companies produce nearly 30 to 40% of the UK's national production. However, it should be noted that the sample studied and environmental profiles developed from the sample have been approved by the Building Research Establishment (BRE) and are to be incorporated in the new version of the national '*Green Guide to specification*' (Anderson *et al*, 2001).

10.5.3 Limitations to the focus group data

There were several limitations to the focus groups organised for the manufacturers, these included the following:

- **Nature of sample:** The members of the Federation committees (used as focus groups) have been working with each other for a number of years. Given the size of the precast flooring manufacturers' population, it was very difficult to assemble focus groups where members did not know, or had not worked with each other.
- **Duration of the session:** Unfortunately, it was not possible to extend the time taken for each of the three focus groups to more than 30 minutes. However, other means (such as ranking and attitude measurement) were used to obtain more descriptive data.
- **Attitude measurement errors:** By misunderstanding some of the questions, the participants in the focus groups could have made mistakes in rankings and replies. This may have lead to systematic errors in information collected. Oppenheim (1992) notes that systematic errors can be much more significant and can turn the final result into an indistinguishable mixture of true and biased results. Therefore, it was necessary to explain each question extensively prior to any ranking by the respondents and depend more on the qualitative content of the sessions (See Chapter Seven).
- **Data representation obstacles (in Focus Groups):** It was noticed that some of the votes were influenced considerably by the views and personalities of some of the interviewees (especially in the strategic managers' session). However, due to the sufficient feedback received from the other focus groups, in addition to the semi-structured interviews, this negative influence on data representation was minimised.

Other limitations were also detected during the three focus groups. It should be noted that all these limitations are insignificant and should not affect the quality of the study, these are detailed throughout the analysis and discussion chapters.

10.5.4 Other limitations

One of the main limitations in the study is the lack of extensive information covering the two other subjects associated with the three bottom lines of sustainable development. Although the aim of the study mainly targets *business improvement through a structured approach to sustainability*, the study concentrates on environmental and (to some extent) economic measures. Information on social measures was covered only by few inquiries questioning manufacturers' motives toward some Corporate Social Responsibility (CSR) issues such as moral obligation or endorsement of some regulations and measures (see sections 7.1.7 and 7.2.4). However this does not mean that the study fails to address sustainability, Glass (2003) confirms that the level of contribution of each of the three pillars of sustainability remains an aspect that organisations and academics need to specify.

Importantly, the conclusions for Chapters Five, Seven, and Eight set out a clear approach for the PFF manufacturers to improve performance by addressing environmental issues via economic means. It would be beyond the scope of research to cover broader social or economic sustainability in greater depth.

Another limitation is the fact that the study deals with organisations operating in precast concrete flooring factories. The study rarely addresses the top strategic level policies of the entire parent organisations. Considering the strategic level within these organisations will require a substantial amount of work and will take the study far from the scope identified in Chapters One and Two.

10.6 Recommendations and future prospects

Given the scale of the research, and the extent of issues covered, it is possible to make several recommendations for the industry to build on the information and findings established in the study. The following research recommendations can be made from the findings and results of this study.

10.6.1 Recommendations for manufacturers

This study established the basis for precast flooring manufacturers to improve their environmental performance through a structured and informed manner. At the time when this thesis was written, the industry was still at the stage of exploring the findings and assessing the possibilities – Presentations were made to the PFF council and the International Prestressed Hollowcore Association (IPHA) in Delft [84]. Moreover a summarised report is being developed. However, in order to build on the advantages of the study, the manufacturers have to carry out more effort to incorporate sustainability requirements within their conventional decision-making frameworks. This can include the following:

- **More advanced environmental data collection mechanism:** The interview with PFF1 environmental manager (see section 8.4) clearly shows a lack of an organisational mechanism to collect environmental information. Manufacturers can incorporate more data collection mechanisms within their management levels to identify more environmental impacts and sources of negative environmental performance. This suggestion was made by Butter and Hofkes (2001). The availability of any basic form of energy and waste data recording (can help substantially in identifying the main sources of environmental impact.

  Tucker *et al* (1982) identify a sufficient operational data collection tool known as the Foreman Delay Survey (FDS). The purpose of this tool is to measure construction sites performance and to improve productivity on the shop-floor level. Although the tool was mainly designed to breakdown and quantify the causes of delay, it can be

[84] This is in addition to seminar and conference presentations to the Nordic Concrete Network in Oslo in 2003 (www.byggforsk.no/visVedlegg.aspx?vedleggID=231&dokumentID=1132) and at the Business Strategy and the Environment Conference, Leeds University. September, 2005. (http://www.bseconference.org/plaintext/bse2005/proceedings/elhaghafizkglassjacquelineandgibbalist.html).

easily used to breakdown and quantify the different variables affecting levels of energy consumption or waste generation in each production shift. This can be carried out by the manufacturers themselves.

- **Employment of problem solving tools to improve environmental performance:** As noted in Chapter Five, there are several studies exploring the use of tools such as lean production and value engineering in improving sustainability and environmental performance in different businesses and industries. However, there are very few studies clearly quantifying the positive and negative environmental contributions of these management and efficiency problem-solving tools. LCA technology can be useful in the quantification process.
- **Identifying the economic cost of environmental improvement:** One factor which was not covered in this thesis is the actual (direct or hidden) cost of environmental improvement. There are several efforts that do not require substantial costs. On the other hand, some efforts such as the elimination of waste-by-design could be costly. Having a clear idea about the short and long term economic costs and savings of green solutions could lead to more informed decisions. Moreover, and as mentioned in Chapter Nine, the use of the environmental inclusion routes will require such exercise to be carried out.

10.6.2 Recommendations for local authorities and government

The government has already introduced several measures and mechanisms to minimise or control the environmental impacts associated with different production sectors in the industry. However, an industry-wide voluntary agreement framework might help in persuading many of the reluctant medium-delivery manufacturers

This recommendation is largely influenced by a suggestion made in section 9.7. In spite of the negative perceptions of the effects of the Aggregate Levy, the remarkable ability of manufacturers to respond efficiently to it suggests that the industry can adapt successfully to other similar challenges. There is already a history of voluntary agreements being introduced successfully to various industries in Europe. For example, the 'Netherlands Packaging Covenant' scheme was first introduced in 1991 as a voluntary agreement (Doppelt and Nelson, 2001). Moreover, the Integrated Pollution Prevention Control (IPPC) allows for a similar voluntary agreement introduced to industries with considerable environmental impact (far more severe than precast concrete production). The introduction of a framework, similar to the IPPC, to account for Life Cycle impacts in less environmentally severe and medium-delivery industries is a subject that needs to be looked at and researched in more detail.

10.6.3 Recommendations for further research

The results and findings obtained in this study can also help in additional research and development activities. The following research recommendations are made:

- **A tool for quantification of environmental impact scenarios:** Although this research employed a different mechanism, it was possible to collect adequate information to establish an understanding of the different environmental impact scenarios associated with production. With more information, it will be possible to properly quantify each of these scenarios and enable manufacturers to carry out more informed decisions at all levels of management. The proposal can even be taken further to help in developing a simulation tool to offer manufacturers an early forecast of the implications of their decisions.
- **Incorporation of life-cycle elements within the wider precast concrete industry's decision making process:** This research theme is very similar to the theme used in this study. However, by exploring the same objectives within the wider industry, a new set of environmental impacts could emerge. This is mainly due to the different production processes employed for other precast products. This could also influence the type of decisions to be targeted by research.
- **Stakeholder engagement:** The scope of the study is timely and important. However, additional research benefits can be achieved through studying the industry's stakeholders and identifying the external drivers influencing the underlining reasons to implement sustainable development in the precast concrete industry.

As noted earlier, there are a number of efforts carried out to insure that the findings identified in this thesis are considered and that lessons are learnt. In addition to the presentations carried out, a conference paper and a publication were carried out. An industrial report on the LCA findings was submitted to the PFF Council and Technical Committee (mentioned in 10.4). Moreover, another industrial report is being prepared – this report should include the other qualitative findings of the study. Another publication is planned following the submission of the thesis.

APPENDICES

This section includes the appendices referred in different parts of the thesis. These are as follows:

APPENDIX A:

This appendix shows the standard questionnaire used to collect the Life-Cycle Inventory data for Hollow-Core/ Precast Beams production and transport.

APPENDIX B:

This appendix shows the form used for the weekly survey conducted on Concrete waste.

APPENDIX C:

This appendix shows one of the LCA calculation reports developed for the factories included in the study (the name of the factory is anonymous).

APPENDIX D:

This appendix shows the powerpoint presentations (question forms) used in focus groups.

APPENDIX E:

This appendix shows the main Semi-structured interviews question forms, surveys, and interview prompt sheets.

APPENDIX F:

This appendix shows the developed hollowcore and Prestressed beams environmental Profiles (for the five factories included in the study).

APPENDIX G:

Following the concrete waste survey, a check list of different type and streams of concrete waste (generated during the production process) was developed. This is shown in this appendix.

APPENDIX H:

This appendix shows a brief on the energy breakdown exercise results. This report (along with two detailed reports for PFF1 and PFF2) was submitted to the supervisors in 2004.

APPENDIX J:

In early 2005, an investigation was carried out to identify the different mathematical links associated with findings from LCA. The report in this appendix was submitted in May 2005 to the supervisors – it helped in identifying a number of variables associated with energy consumption and waste generation levels.

APPENDIX K:

In the Focus Group sessions, a prompt sheet was used as a stimulus material to help participants in brain storming. This sheet is shown in this appendix.

APPENDIX L:

This appendix includes the script of one of the focus group sessions (Technical managers' Focus Group session).

APPENDIX M:

This appendix shows the quantitative results and analysis of the survey used during the three focus group sessions.

APPENDIX N:

This appendix shows the results of the survey used in the semi-structured interviews carried out for main decision makers in the sector.

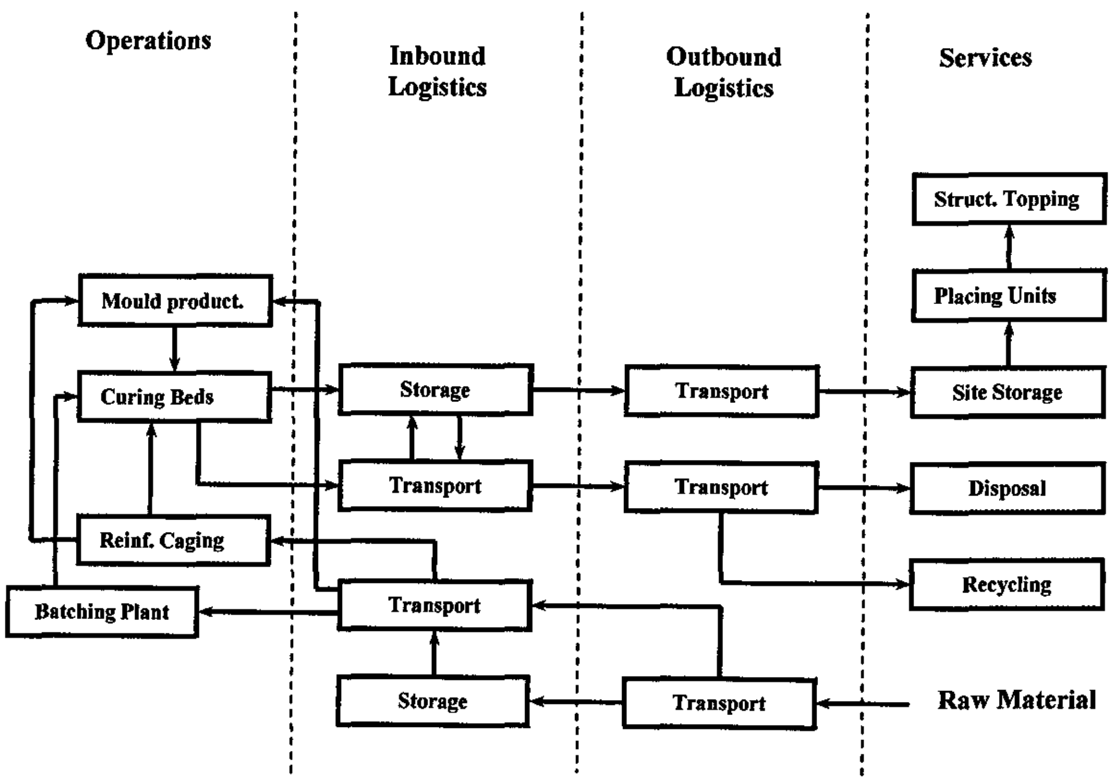
Appendix A: STANDARD QUESTIONNAIRE FOR LIFE_CYCLE INVENTORY DATA COLLECTION

(Hollowcore/ Prestressed Beams)

Construction Materials and the Environment

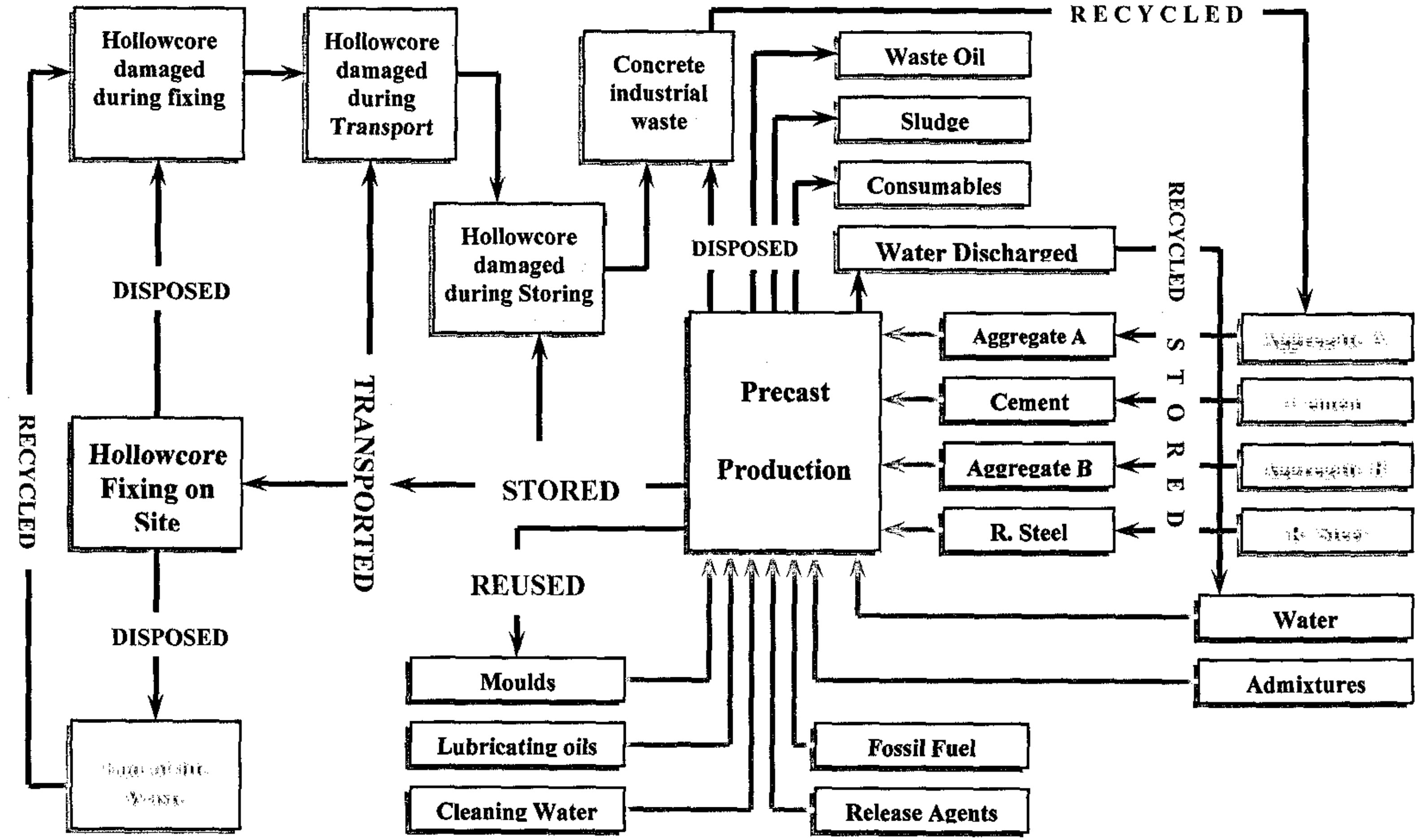
1. Process

The following process tree is intended to give a simplified description of 16 different operational steps that take place during the manufacturing process of a precast concrete product. Please, study the following process tree and carry out any modifications if required:



2. Product flow

This basic process tree demonstrates the resource flows in the manufacturing process of a precast concrete product. Please provide a description for the process and include any BS or CEN numbers, end use, thickness, density, weight etc. in your description of the finished product.



RECYCLED
Hollowcore damaged during fixing
Hollowcore damaged during Transport
Concrete industrial waste
Waste Oil
Sludge
Consumables
Hollowcore damaged during Storing
DISPOSED
Water Discharged
RECYCLED
DISPOSED
Aggregate A
Cement
Aggregate B
R. Steel
STORED
Precast Production
RECYCLED
Hollowcore Fixing on Site
TRANSPORTED
STORED
REUSED
Water
Admixtures
DISPOSED
Moulds
Lubricating oils
Cleaning Water
Fossil Fuel
Release Agents

3. Plant Information

Company name/ Code number: ....
Company address:...
Telephone:.............................., Fax:..
Name of Respondent: ....

4. Quality of Data

Age

Please indicate below the starting and end months in which data in this questionnaire was collected

Start Month: ....

End Month: ....

5. Works Output

Please enter all the main outputs i.e. main product (hollowcore/ precast beam) and any co-products of the production site (without including material sent to waste disposal) and the annual production of each. This information allows the burdens of production to be allocated to co-products using physical relationships.

Output description	Production

6. Works input

6. A) Materials

Please, list all the material involved in the production:

- *Raw Material*: Please list and describe the raw material being used. It would also be useful to list the source and exact type of the material (**quantities are required**):
  1. Coarse Aggregate
  2. Fine Aggregate
  3. Reinforcement Steel
  4. Cement, Lime
  5. Concrete mix

- *Recycled Content*: If recycled material is being used, please specify the source of the material and whether the recycling process is taking place within the same site. Moreover, add any transportation arrangement required to process the recycled content.

- *Processed Material*: Please, list and describe the processed material being used to enable production (quantities of release agents, lubricants are required). Moreover, specify the exact type and (if possible) chemical content as any volatile content need to be included.

It should be noted that the inventory usually account for all material with mass greater than 2% of total product.

6. B) Transport of materials to the factory

This would take place using more than a single mode of transport. Please list the transportation details for each material (detail the mileage of each transport mode separately).

Type of Material	Quantity	Vehicle used	No. of deliveries	Average distance	Return journey (Give %)

Please provide any further information regarding nature of transportation of different material, risks and precautions taken during such trips.

6. C) Direct consumption of fuel

Please provide the amount of fuel purchased by your plant for the **agreed period**. Please separate between types and quantities of fuel for each activity or each machine used in the process (where possible). Heating and lighting should be included. Internal on-site transport should always be carried out with a clear separation between the types of vehicle used for each transport activity.

Fuel Purchased	What are the fuels used for?	Unit of fuel purchased	Quantity	Source of Data
Heating Oil				
Diesel				
Kerosene				
Gasoline				
Natural gas				
LPG				
Grid Electricity				
Other (specify)				

6. D) Water use

Please enter the water brought into plant in the year. It is known that some activities (such as curing) might require more water consumption in comparison with others. It would be critical to separate as much as possible between the unit processes in addition to those not mentioned in the product system (such as cleaning the equipments and platforms).

Water use	Units	Quantity used	Quantity per tonne of product	Type of water usage
Water purchased from water company				
Surface water- private supply				
Groundwater- private supply				
Other				

7. Works Emissions/ Discharges

In precast concrete manufacture, emissions may be from more than a single activity. There are two reliable methods to find out emissions. One is based on previous studies, formulas and conversion factors schedules. The other is more accurate as it depends on the installation of gas emissions detecting systems. This can take place in some processes with high level of controlled environment (such as patching, curing beds heating or water treatment plants).

7. A) Emissions to Air

Type of Emission	Quantity	Emission Concentration (include dust)	Units measured	Sampling procedure (include baseline)	Process where emission took place

Wherever possible, please provide any specific data on how and when such emission takes place. Provide any previous study that explores the emissions, specially:

Carbon Dioxide (CO_2)

Sulphur Oxides (SO_x)

Nitrogen Oxides (NO_x)

For the following categories, please list individual compounds wherever possible:

Particles (with percentage composition for each component)

Volatile Organic Compounds

Halogens

Hydrocarbons e.g. methane

Metals e.g. lead

7. B) Discharges to water

Discharges to water	Units	Measured value (average)	Total volume of discharge	Sampling procedure
Total water to sewer				
Total water to surface water				
BOD to sewer				
BOD to surface water				
COD to sewer				
COD to surface water				
Total organic carbon to sewer				
Organic Carbon to surface water				
pH to sewer				
pH to surface water				
Suspended solids to Sewer				
Suspended solids to surface water				
Other				

Moreover, it would be convenient to provide a description on the water treatment methods being used to surface discharged water and whether these are discharged to Local Rivers (possible impact on biodiversity).

....

....

....

7. C) Solid Waste

Please provide a list of the main materials in the description of the wastes produced. Please address **special** hazardous waste individually (qualitative + quantitative information) as this should be dealt with in accordance with the National Waste Classification Code & Hazard Property Code (EPA 1990 Special Waste Regulations September 1996).

It would be appropriate to specify exactly where and how the waste was generated as these should be linked later to a specific manufacturing or processing activity. Waste generated off-site should be separated from other industrial waste.

Waste produced	Description of Waste	Quantity	Mileage	Last Destination
Controlled Commercial				
Controlled Industrial				
Controlled Special				

Any further qualitative or quantitative information on the emissions and discharges

....

....

Please direct any queries to BPCF

Thank you for answering this questionnaire

Appendix B: Weekly Survey conducted on Concrete waste

WEEKLY INFORMATION FORM: Hollowcore/precast beams

Contact information

Your name:...

Job title:...

Company name:..

Company address:...

Phone:..

Fax:...

Week commencing Monday:..

1. Works output this week

In the table below, please enter details of the total output of precast products during the week.

Unit types	Number of castings	Number of shifts	Net production (tonnes)	Gross production (tonnes)
Hollowcore				
Prestressed Beam				

2. Waste transport

Please complete the table below about the means of transport used for waste:

Unit type	Average type of truck used (e.g. 33+ artic, rigid)	Average load of truck (Full load, half load, one-third, etc.)	Frequency per week (No. of batches)
Hollowcore			
Prestressed Beam			

3. Waste types and description

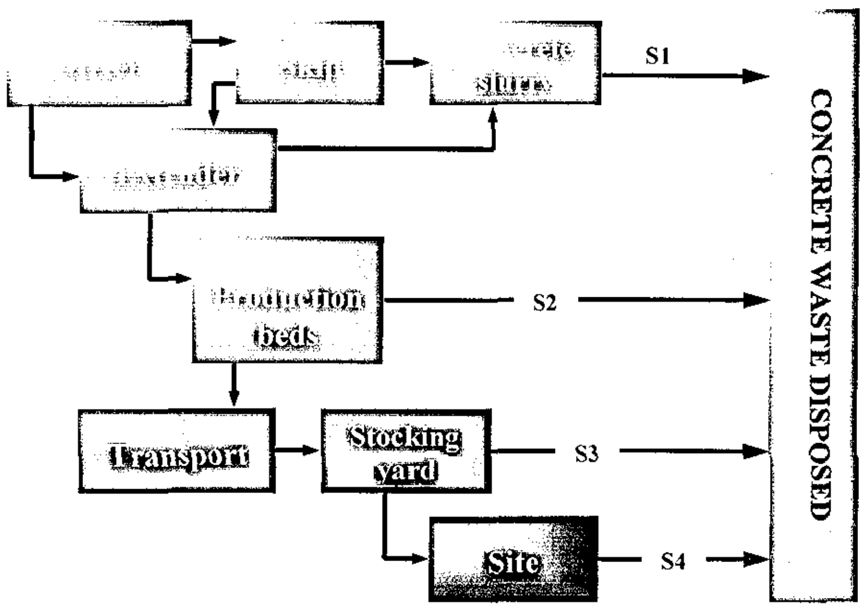
The diagram below shows four typical waste streams that can arise from the hollowcore/beam manufacturing process, i.e.

a. **S1:** Remaining concrete slurry at hoppers/extruders.

b. **S2:** Discarded Cast portions (different reasons).

c. **S3:** Units scrapped at the stock yards (different reasons).

d. **S4:** Site rejects.



In the table below, please enter the amount of concrete waste coming from each of the waste streams and any further comments on the reasons for rejection.

Waste stream		Quantity (%) -tonnes-	Reason for rejection
S1 (Slurry)			
S2 (Cast portions)	Hollowcore		
	Prestressed Beams		
S3 (Units)	Hollowcore		
	Prestressed Beams		
S4 (Site rejects)	Hollowcore		
	Prestressed Beams		
Total			

4. Further information

In the space below, please feel free to make any additional comments or feedback relating to the waste produced during this week's production.

....

....

....

....

....

....

....

....

....

....

....

If you have any queries, please contact Hafiz Elhag at the address below.

Please return this survey to:

Hafiz K. Elhag
British Precast Concrete Federation (BPCF),
60 Charles Street
Leicester
LE1 1FB
Tel. 0116 253 6161
Fax. 0116 251 4568

Thank you for answering this survey

We appreciate your time and effort.

Appendix C: LCA calculation report for [anonymised][1] factory

Introduction

This Life Cycle Assessment (LCA) study explores the different environmental impacts generated during the manufacture and procurement of prestressed precast Hollowcore and beams. The study was prepared for the members of the Precast Flooring Federation (PFF) as part of their intention to give more consideration to different environmental aspects in their factories and successfully adopt a sustainable approach in precast production. The study accounts for the manufacturing activities at five production sites in different regions around England.

This study was carried out in accordance with the Building Research Establishment (BRE) Methodology for Environmental Profiles of construction products which is mainly adapted from the CML Methodology for conducting Life Cycle Assessment studies. This report was also arranged in accordance with ISO-14041 guides on Life-Cycle Assessment (LCA) reporting[2].

> It should be noted that the terminology used is in accordance with conventional LCA requirements as stated in ISO-14041. Some of these are not commonly used. For definitions, please see the Glossary section or see ISO-14041.

[1] The name (and used code) for this company was made anonymous. This is due to the sensitivity of the information used.
[2] Few modifications were carried out to the ISO 14001 methodology, however; the main framework and structure is still the same.

1. Introduction: Information on [anonymised] factory

This report calculates the environmental impacts of Hollowcore and prestressed beam manufactured by [anonymised]. In 2002, The factory produced the following products:

- Hollowcore flooring (around 73% of tonnage production).
- Prestressed precast beams (around 27% of tonnage production).

1.1 Factory Layout

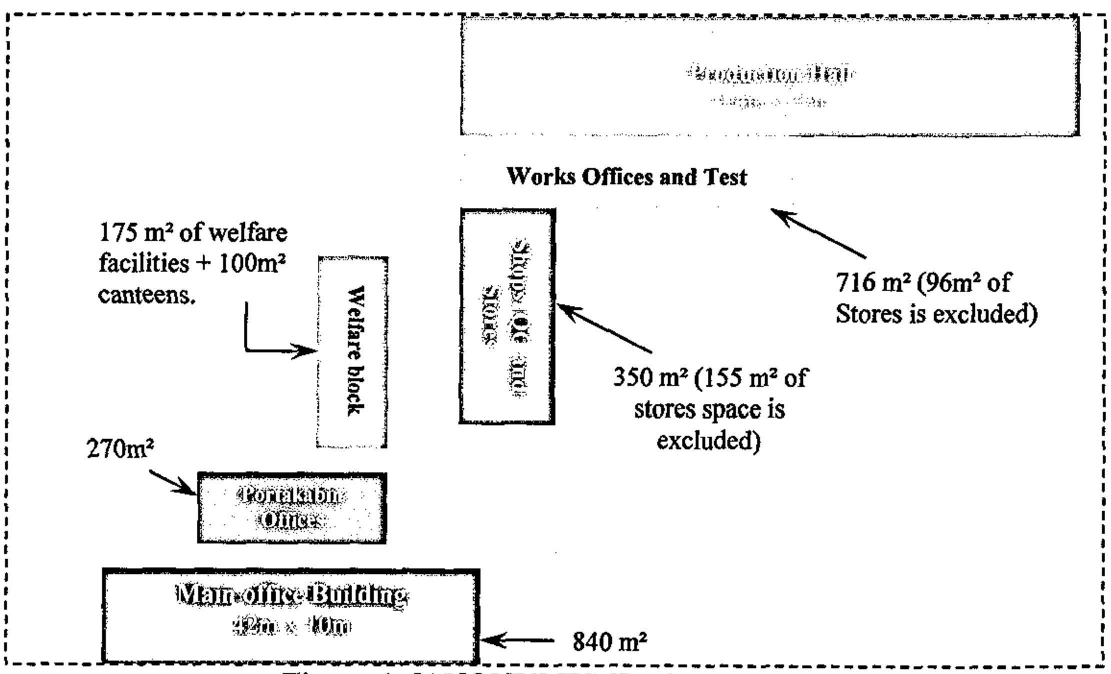


Figure 1. [ANONYMISED] factory site plan.

The factory includes the main offices of the company in addition to the other industrial facilities shown below. Any impacts not directly associated with production should not be added to the environmental profiles. Information on environmental impact breakdown (for different site facilities) is vital as the given inventory will need to be analysed and broken down to account for impacts solely associated with hollowcore and prestressed beams consumption.

1.2 Process description (Machinery, production method, etc.)

The production system at the factory has been through several changes and modifications during the last four decades. Due to the wide variety of precast elements produced at the factory, there are many differences in systems employed in various shops; this would have a considerable effect on the environmental impacts associated with each shop. The study focuses on the following activities:

- **Raw material transport systems:** The factory is supplied with a batching/ mixing plant; therefore, all raw materials are imported from suppliers without a need for advanced processing operations (such as preparation of ready mix concrete, etc.).
- **Concrete mixing/ casting:** It is not vital to identify the exact type of mixer as the vital environmental impacts can be calculated through energy consumption records.
- **Concrete Accelerated curing system:** Products are cast and cured in 107 and 100 metre long beds. The curing/ heating process is operated by fuel oil boilers that heat water, the heated water runs through pipes located under the curing beds.
- **Internal Transport system**: The site has two goliath cranes for different products handling. Fork-lifts (front-loaders) and side-loaders are also used in finished product transport and handling operations.

2. Goal and Scope

The first vital step in any Life-Cycle Assessment (LCA) project is the determination of goals, scope, functional units and the initial boundaries of the study.

2.1 Goal Definition

The goal of the study is to understand the different environmental impacts associated with the precast flooring product (Hollowcore, prestressed Beams) systems throughout their entire life-cycle.

The *PFF* members (target audience) want to explore the effects of changes in their processes (in terms of technology, input and product composition) on the total environmental profile of a hollowcore/ prestressed beam product system. This information, in turn, can be used to prioritise specific options that can be taken to improve the environmental performance.

This study is conducted under the support and supervision of Loughborough University's IMCRC centre. The commissioner is the Precast Flooring Federation (PFF) Technical Committee. Interested parties are mainly the concrete industry and competitors in other flooring industries.

2.2 Scope Definition

The LCA study identifies the environmental impact of concrete floor production as part of the total environmental impacts within the United Kingdom. Therefore, data should be up to date and representative of the present state of technology in the UK. The study uses the most recent data available, mainly from 2002. The proposed period of the study was six months. Most of this period was devoted to the collection of representative data for the most important production and handling processes. Data collection covered the following aspects:

- **Temporal Coverage:** The study covered the period between 1st January and 31st December 2002. Any unavailability of information from that period was dealt with in accordance with the BRE methodology for Environmental Profiles where data from other previous periods or current /similar practices was used.
- **Geographical Coverage:** The study covered product systems with supply chains that might possibly expand to Spain or Italy. However, given that all PFF members are UK-based with competitive markets that do not expand beyond the boundaries of Britain and Northern Ireland, it would be sufficient to limit the geographical criteria to the United Kingdom. However, exceptions would be dealt with in accordance with the BRE Environmental Profile Methodology.
- **Technological Coverage:** Technology coverage would mainly be qualitative in this study. This is due to the difficulty and lack of information and time required to establish a recommended Technology Assessment (TA) study; this aspect would be omitted from any analysis based on comparison.
- **System Boundaries:** The study boundary is only limited to the *gate-to-gate* phase of the products' life as this is the period mostly associated with the manufacturer and his positive or negative contribution to the product's life-cycle.

- **Consideration of primary energy:** This study accounts for primary energy consumed in a separate category. The conversion factors employed to calculate primary energy are the same used for the Climate Change Levy.

2.3 Function Definition

Like any other manufactured material, precast concrete is geared to improving an aspect of life by providing the appropriate material for a particular function (Concrete Society, 2001). However, a precast concrete product can successfully achieve more than a single function:

- **Structural Function.**
- **Thermal insulation Function.**
- **Fire Resistance Function.**
- **Sound insulation Function.**

To simplify the study and avoid any additional factors that might add to the complexity, it was decided to carry out the study considering the main structural function.

2.4 Functional Unit

There are two main functional units that can be considered in this study. These functional units are:

- 1 Square Metre (m^2) of flooring with a thermal resistance of 1.43 m^2 K/W and a 60 years service life.
- 1 tonne, or kilogram, of precast concrete used for hollowcore/ prestressed beam flooring with a thermal resistance of 1.43 m^2 K/W and a 60 years service life.

Due to the difference in thicknesses of hollowcore and prestressed beams manufactured. It was decided to take the second functional unit for this study. However the manufacturers (target audience) should use their nominal mass (kg/m²) information to convert tonne-based environmental impact information to square meter based environmental impact information.

2.5 Initial System Boundaries

As noted above, it was agreed that the study should cover the ***gate-to-gate*** stage of the products' life cycle, this only includes some processes mainly undertaken by precast manufacturers. This would include the following unit processes:

- Transport of raw material to production site.
- Storage of raw material.
- Mixers and batching facilities.
- Accelerated curing facilities (Production beds).
- Product internal transport (using fossil fuel energy).
- Product internal transport (using electricity).

On the other hand, it should be noted that the BRE methodology does not include manufacturing, maintenance and decommissioning of capital equipment. Moreover, the methodology allows for omissions of any insignificant inputs and outputs with marginal impact on the product's environmental profile (Cut-offs).

2.6 Description of Data Categories

The BRE methodology usually includes 13 different categories, these are:

- **Climate Change:** measured using GWP principles (tonnes of CO_2 equivalent).
- **Fossil Fuel depletion:** This unit accounts for the total quantity of fossil fuel (energy) depleted through consumption (measurement unit: TOE).
- **Acid deposition:** Fossil Fuel and transport emissions were the main source of acidification. The used measurement unit is kg SO_2 equivalent.
- **Ozone Depletion:** Ozone depleting gases cause damage to stratospheric ozone. The used measurement unit is ODP, which is one kg of CFC_{11}. However, it should be noted that since 2000 the use of Chlorofluorocarbons was banned in all industries. Therefore, the levels of ozone depletion potential are insignificant and cannot be calculated[3].
- **Human toxic air pollution:** This category was first developed by CML at Leiden University in 1992. The measurement unit used is kg. tox. For human toxicity, the unit is subject to further characterisation and classification.

[3] Many recent BRE environmental profiles for concrete-based products do not account for Ozone Depletion.

- **Human toxic water pollution:** This category was also developed by CML in 1992. The used measurement unit (kg. tox). For human toxicity, the unit is subject to further characterisation and classification.
- **Eco-toxic water pollution:** This category was developed by CML. Although it considered many of the impacts and aspects considered in Human Toxic Water Pollution, it measures pollution in terms of impact on water life systems. The used measurement unit is m^3 of Tox.
- **Low level ozone creation (POCP):** Ozone creation occurs under the influence of radiation from the sun. The method to estimate the ozone creation potential comes also from CML and compares the Photochemical Ozone Creation Potential of Volatile Organic Compounds (VOC) with that of ethane. The used measurement unit is kg of ethane equivalent.
- **Eutrophication:** The maintenance of a low level of nutrient concentration in natural water is essential to biodiversity in water. The amount of total nitrogen and phosphorous play a major part in determining the level of Eutrophication (nutrient enrichment) and this was considered in the characterisation factors derived from the CML work (kg. PO_4).
- **Minerals extraction:** This is the unit that measures the minerals and material depletion in the UK. Recycling would have a considerable effect on this category[4]. The measurement unit used for this category is Tonnes.
- **Water extraction:** The precast concrete manufacturing process requires a considerable amount of water during concrete mixing, curing, cleaning and sawing. The unit used by the BRE to reflect the depletion in water is litres.
- **Waste disposal:** This category measures waste per tonne as a proxy for the other impacts arising from waste disposal (odour, leaching, etc).
- **Transport pollution and congestion:** This unit was chosen to reflect the impacts arising from the transport of freight worldwide. The category measurement unit is tonne.km. However, a new addendum to the methodology allowed for transportation impacts to be included as part of six environmental impact categories – including energy-associated impacts (Anderson and Edwards, 2000).

[4] Other than partial impact on all other categories as the environmental impact of the recycled content is usually related to its extraction.

2.7 Criteria for Initial inclusion of inputs and outputs

The detail of calculation in LCA might reach a very advanced stage. However, it is not practical to study all the relationships between all the unit processes within a product system, or all the relationships between a product system and the system environment (ISO, 1998). Therefore, some specific cut-offs and limitations should be considered:

- The methodology would ignore any insignificant content with less than 2% of the total product. Accordingly, some concrete ingredients, such as admixtures, would be omitted.
- Any environmental impact associated with plant capital equipment or the used production system and infrastructure should not be included.
- Use of qualitative as well as quantitative data (especially for wastes).
- Use of reliable secondary information if necessary[5].

2.8 Data Quality

It should be noted that the primary data used to form the Life-cycle Inventory and Environmental Profile do not have a consistent level of quality. Most of the information was directly supplied by manufacturers. However, in many cases, manufacturers had to make estimations based on standards for concrete manufacturing and production batch quantities in order to calculate the figures required for the environmental profile. It should be noted that any inconsistencies or information defects still fall within the simplification and cut-off framework already considered by the BRE methodology.

2.9 Data reliability requirements

Data quality and robustness is essential in LCA studies. However, approved LCA studies still vary in terms of reliability and fulfilment to some specific data quality requirements. This LCA study would consider the following data quality requirements:

- **Time-related Coverage:** In case the 2002 data is not available, the 2001 or 2000 data would be used. However, if some specific months are unavailable then it would be estimated using general energy and production correlations. If not possible, then it

[5] This would mainly depend on the reliability and representability of the secondary information used (Data quality requirements).

would be covered by either the previous/ following month information or by information from the same month in a previous year.

- **Geographical Coverage:** All data collected, standards or conversion factors used would be that of England and Wales (or the United Kingdom). However, the UK figures might be used if no information on imported goods (such as reinforcement steel transport) is available. In some cases, information would be supplied from studies of similar nature (product, production system, etc.) from Europe and North America.
- **Technology coverage:** It should be noted that the BRE methodology only considers basic weighted average technology coverage of the actual process mix. However, the availability of information for some activities allows for sufficient information to be provided and therefore avoid any defects concerning technology coverage.
- **Reproducibility:** The data in this report is presented in a way that enables an independent practitioner to reproduce the results reported in the study.
- **Consistency:** A qualitative assessment of how uniformly the study methodology is applied to the various components of the analysis would be considered.
- **Representativeness:** The final study covers at least five different precast floor manufacturing facilities in England. It is believed that each of the factories involved in this study reflect the true population of interest.

3. Life Cycle Inventory

In order to build a sufficient environmental profile, A Life-Cycle Inventory (LCI) will need to be made. This is carried out in the following two subheadings (3.1 and 3.2), the following two sections handle the calculation and categorisation of the environmental impacts resulting from hollowcore and prestressed beams product system.

3.1 Work Output

The production and output figures taken from the [ANONYMISED] factory were provided by their management. In 2002, the net production of hollowcore and prestressed beams in the factory was:

Prestressed beam production = 30,915.5 tonnes

Hollowcore production = 83,795 tonnes

However, although these figures are correct (in terms of proportion), the figures are not 100% accurate. Moreover, not all concrete waste streams are accounted for in this study;

Therefore, the figures to be used are the modified ones (modified in accordance with raw material information provided by the company in addition to the waste ratio calculated for the study in section 4), these are:

Prestressed beams production = 34,629 (36,360) tonnes

Hollowcore production = 92,131 (98,148) tonnes

Along with concrete production, the factory emits a substantial amount of waste (Concrete, waste water, timber, metal, ancillary materials, etc.):

Non- Hazardous Waste	1949 tonnes
Concrete waste	24,275.98 tonnes[6]
Hazardous waste to recycling	4.8 tonnes
Waste metal to recycling	276.1 tonnes

Table 1. Waste generated from [ANONYMISED] factory in 2002.

[6] This figure includes Concrete waste-by-design (Autoscrap), this category was not considered in the environmental profiles, as noted in section 4.

3.2 Work Input

The following information on work input was partially provided by the company's accounts department, and their environmental manager:

Ingredients:	
Light Aggregate	51,072 tonnes
Coarse Aggregate	61,222 tonnes
Cement	20,312 tonnes
Reinforcement Steel	1,108 tonnes
Pulverised Fly Ash (PFA)	1,091 tonnes
Ancillary & processing materials:	
Water	25,396 m^3
Hydraulic- Lubricant Oil	4,395 litres
Energy and Fossil Fuels:	
Gas Oil	114,747 litres
Heavy Fuel Oil	441,478 litres
Light Fuel Oil	342,076 litres
Liquefied Petroleum Gas	63,720 litres
Electricity consumption	1,778,523 kWh

Table 2. Input material for [ANONYMISED] factory in 2002

The list containing work output and input (above) is known as Life-cycle inventory (LCI); the following stage in Life Cycle Assessments is Impact Assessment.

4. Allocation and Breakdown of the Life Cycle Inventory

The study is handling two precast products. Therefore it is necessary to break down the LCI information (above) into two inventories for hollowcore and prestressed beams. Due to the lack of sufficient information enabling the breakdown of inventory information, several BRE certified methods of allocation were employed:

4.1 Ingredients

Unfortunately, no detailed information was provided on the exact amount of ingredients used for each product (hollowcore/ beams). Moreover, it was not possible to identify the total number of jobs or batches (for each hollowcore or prestressed beam product-range) and then use the available nominal weight standards to provide an informed breakdown for the total amount of ingredients for each product. Therefore, the most appropriate method of allocation was to use the quantities and proportions of production for the two products to break down ingredients (allocation by mass):

	Hollowcore	**Prestressed beams**
Fine Aggregates	37,184 tonnes	13,888 tonnes
Coarse Aggregates	44,574 tonnes	16,648 tonnes
Cement	14,492.3 tonnes	5,523 tonnes
Reinforcement Wire	806.7 tonnes	301.3 tonnes
PFA	1091 tonnes	-

Table 3. Allocation for raw material used in production.

4.2 Ancillary processing material

Unfortunately, the information provided (on amounts of ingredients used for hollowcore and beam) was insufficient. Moreover, it was not possible to identify the total number of jobs and batches for each hollowcore or prestressed beam type and then to use available nominal weight standards to provide informed breakdowns for the total amount of ancillary processing materials. Therefore, the most appropriate method of allocation is to use allocation by mass:

	Hollowcore	**Prestressed beams**
Water	18,490,100 litres	6,905,900 litres
Hyd-Lubricant Oil	3,200 litres	1,195.13 litres

Table 4. Allocation of ancillary materials in production.

4.3 Energy and Fossil Fuels

When exploring the different fuels consumed in the factory site, it was found that not all fuels are directly consumed to support the same production operations there:

- **Gas Oil:** Is used for internal transport operations, all these are associated with production at the plant.
- **Fuel Oil:** Is used to operate the boilers for the curing process. This is associated with production at the plant.
- **Liquefied Petroleum Gas (LPG):** This is associated with the heating system of some of the buildings not immediately associated with the production process.
- **Electrical Consumption:** Electricity is used in the factory to provide energy for different activities associated (or not associated) with hollowcore and prestressed beam production.

The LPG consumption was not be included. Moreover, an electrical energy breakdown was carried out to calculate the exact amount of energy associated with hollowcore and prestressed beam production.

	Hollowcore	**Prestressed beams**
Gas Oil	83,544 litres	31,203 litres
Heavy Fuel Oil	321,427 litres	120,051 litres
Light Fuel Oil	249,055 litres	93,020 litres
Electricity Consumption	1,109,099 kWh	417,170 kWh

Table 5. Allocation of fossil fuels for production.

5. Impact Assessment

The LCI above is used to calculate the following impacts:

5.1 Transportation impacts

The company maintains a stable supply chain; with suppliers mainly located at the [anonymised] area. The transportation impact methodology of the BRE considers six main impact categories, the level of environmental impact depends on the distances covered, type of trucks used, and loads carried:

5.1.1 Hollowcore Truck and land deliveries

According to the factory staff, all the input raw material deliveries are carried out with articulated trucks (20 to 25 tonnes load). This would ideally match loads usually carried out by *+33 tonne* artic trucks (covered in the BRE addendum) that carry between 23.7 - 23.8 as maximum loads.

	Quantity (tonnes)	Lorries used	Maximum Net Load [7]	Average Distance (km)
Fine Aggregate	37,184	+33 Artic	23.7	4.67
Coarse aggregate	44,574	+33 Artic	23.7	16.1
Cement	14,492.3	+33 Artic	23.6	23
R. Steel	806.7	+33 Artic	19.5	255.9
PFA	1091	+33 Artic	23.6	30

Table 6. Transportation criteria for [ANONYMISED] (Hollowcore).

In order to calculate the environmental impact for each of these journeys, the following issues were considered:

- The distances were provided in miles, these deliveries were adjusted to kilometres.
- It was confirmed that the return journey is always 100% empty.

Based on these considerations, a basic transportation calculation was carried out. The calculations were mainly based on the 2000 modification of the BRE transport impact calculation methodology:

$$\textbf{Impact} = \mathbf{I \times FD \times M / (L \times 1000)}$$

As:

I = Environmental Profile for 1000km of transport by 33 tonne articulated lorry

M = Mass of material being transported.

D = Transport distance.

F = return journey factor (which is 2)

[7] Taken from DETR transport statistics of 1996

L = Net load of the Lorries type used.

Total fine Aggregate impact = I x 2 x 4.67 x 37,184/ 23700 = 14.654 x I

Total coarse Aggregate impact = I x 2 x 16.1 x 44,574/ 23700 = 60.56 x I

Total cement impact = I x 2 x 14,492.3 x 23/ 23600 = 28.25 x I

Total reinforcement impact = I x 2 x 806.7 x 256/ 19500 = 21.173 x I

Total PFA impacts = I x 2 x 1091 x 30/ 23600 = 2.8 x I

Accordingly, the total hollowcore transport impact = **127.44 x I**

Issue	Unit
Climate Change	165,672 kg CO_2 eq (100 yrs)
Acid Deposition	1529.28 kg SO_2 eq.
Pollution to Air: Human Toxicity	1784.16 kg tox.
Pollution to Air: Photochemical Ozone Creation Potential	229.4 kg ethane eq.
Pollution to Water: Eutrophication	254.88 kg PO_4 eq
Fossil Fuel Depletion	50.976 TOE
Transport Pollution and Congestion	127, 440 tonne.km

Table 7. The Environmental profile of transporting 1 tonne of prestressed beam

Linking the impacts above to the functional unit used (1 tonne of hollowcore) requires the division of the impacts above over the total net production of hollowcore (92,131.53 tonnes).

Issue	Unit
Climate Change	1.798 kg CO2 eq (100 yrs)
Acid Deposition	0.0166 kg SO2 eq.
Pollution to Air: Human Toxicity	0.0194 kg tox.
Pollution to Air: Photochemical Ozone Creation Potential	0.00249 kg ethane eq.
Pollution to Water: Eutrophication	0.002766 kg PO4 eq
Fossil Fuel Depletion	0.00055 TOE
Transport Pollution and Congestion	1.383 tonne.km

Table 8. The Environmental profile of transporting 1 tonne of hollowcore

5.1.2 Prestressed beams transportation impacts.

According to the factory staff, all the input raw material deliveries are carried out with articulated trucks (over 20 to 25 tonnes load). This would ideally match loads usually carried out by *+33 tonne* artic trucks (covered in the BRE addendum) that carry between 23.7 to 23.8 as maximum loads.

	Quantity (tonnes)	Lorries used	Maximum Net Load[8]	Average Distance (km)
Fine Aggregate	13,888	+33 Artic	23.7	4.67
Coarse aggregate	16,648	+33 Artic	23.7	16.1
Cement	5,523	+33 Artic	23.6	23
R. Steel	301.3	+33 Artic	19.5	255.9

Table 9. Transport criteria for prestressed beams

A basic transportation calculation was carried out. As noted above, the calculations were mainly based on the 2000 modification of the BRE transport impact calculation methodology:

Impact = I x FD x M / (L x 1000)

As:

I = Environmental Profile for 1000km of transport by 33 tonne articulated lorry

M = Mass of material being transported.

D = Transport distance.

F = return journey factor (which is 2)

L = Net load of the type of Lorries used.

Total fine Aggregate impact = I x 2 x 4.67 x 13,888/ 23700 = 5.473 x I

Total coarse Aggregate impact = I x 2 x 16.1 x 16,648/ 23700 = 22.619 x I

Total cement impact = I x 2 x 5,523 x 23/ 23600 = 10.765 x I

Total reinforcement impact = I x 2 x 301.3 x 256/ 19500 = 7.911 x I

Accordingly, the total prestressed beam transport impact = **46.77 x I**

[8] Taken from DETR transport statistics of 1996

Issue	Unit
Climate Change	60,801 kg CO_2 eq (100 yrs)
Acid Deposition	561.24 kg SO_2 eq.
Pollution to Air: Human Toxicity	654.78 kg tox.
Pollution to Air: Photochemical Ozone Creation Potential	84.186 kg ethane eq.
Pollution to Water: Eutrophication	93.54 kg PO_4 eq
Fossil Fuel Depletion	18.708 TOE
Transport Pollution and Congestion	46,770 tonne.km

Table 10. The total Environmental impact of prestressed beam transportation

Linking the impacts above to the functional unit (1 tonne of prestressed beam) requires the division of the impacts above over the total net production of prestressed beams (34,629.55 tonnes).

Issue	Unit
Climate Change	1.756 kg CO_2 eq (100 yrs)
Acid Deposition	0.0162 kg SO_2 eq.
Pollution to Air: Human Toxicity	0.0189 kg tox.
Pollution to Air: Photochemical Ozone Creation Potential	0.00243 kg ethane eq.
Pollution to Water: Eutrophication	0.002701 kg PO_4 eq
Fossil Fuel Depletion	0.00054 TOE
Transport Pollution and Congestion	1.383 tonne.km

Table 11. The Environmental profile of hollowcore transportation

The slight difference between the profiles is due to the fact that PFA is used in hollowcore production, PFA is brought from a supplier located much further anyway than the cement supplier. However, it should be noted that the advantages of using PFA should appear in a complete cradle-to-grave (or cradle-to-gate) environmental profile.

5.2 Fuel Consumption

The BRE methodology accounts for primary energy consumption and fossil fuel depletion. The primary energy factors used in this report are the ones introduced at the Climate

Change Levy Scheme[9] (2.60 for electrical consumption and 1.00 for other forms of fossil fuel):

	Hollowcore Amount	Amounts in TOE	Amounts in TOE (primary energy)	Per functional unit	Per functional unit (primary)
Gas Oil	83,544 litres	76.8171	76.8171	8.3×10^{-4}	8.3×10^{-4}
H. Fuel Oil	321,427 litres	314.9048	314.9048	3.42×10^{-4}	3.42×10^{-4}
L. Fuel Oil	249,055 litres	218.5816	218.5816	23.7×10^{-4}	23.7×10^{-4}
Electricity	1,109,099 kWh	95.4268	248.11	10.4×10^{-4}	26.9×10^{-4}
			Total	76.6×10^{-4}	93.1×10^{-4}

Table 12. Fossil fuel consumption factors for hollowcore

	Prestressed beams	Amount in TOE	Amount in TOE (primary energy)	Per functional unit	Per functional unit (primary)
Gas Oil	31,203 litres	28.6906	28.6906	8.3×10^{-4}	8.3×10^{-4}
H. Fuel Oil	120,051 litres	117.615	117.615	3.39×10^{-4}	3.39×10^{-4}
L. Fuel Oil	93,020 litres	81.6351	81.6351	23.6×10^{-4}	23.6×10^{-4}
Electricity	417,170 kWh	35.8933	93.3226	10.4×10^{-4}	26.9×10^{-4}
		Total	227.6282	76.2×10^{-4}	92.8×10^{-4}

Table 13. Fossil fuel consumption factors for prestressed beams

As mentioned above, the fuel consumption have a separate impact category, however, fossil fuel consumption also have a major influence on carbon dioxide, sulphur dioxide, VOC and other emissions. These are demonstrated in section 5.4

5.3 Water Use

Water has a separate environmental impact category; this is calculated by dividing the amount of water at the LCI by the company's net production, this produces the total amount of water consumed per functional unit.

[9] Refer the Climate Change Levy Discount Scheme. Info sheet No. 3

However, the site still has several facilities consuming water, estimations show that the building is used by around 175 people on a daily basis (either at the offices, factory, or stockyard). For employee water consumption, the average annual figure of 8,110 litres per employee can be used. This figure was taken from a study by DEFRA to explore levels of office water consumption[10]:

Water consumption per 1 *tonne* of hollowcore =

18,490,100 - (8110 x 127) /92,131.53 = 189.51 litres

Water consumption per 1 tonne of Prestressed beams =

6905900 – (8110 x 48)/ 34629.55 = 188.18 litres

The slight difference in water consumption for hollowcore and prestressed beam is mainly due to:

- The different concrete waste levels for hollowcore and prestressed beams affecting total environmental impact categories (including water consumption).
- The allocation of daily factory employees (127 and 48 employees) and their levels of water consumption.

This difference could have been more pronounced if the number of annual castings for hollowcore and prestressed beams was considered. However, this difference was not considered due to unavailability of sufficient 2002 record information.

5.4 Emissions to Air

Due to the unavailability of sufficient equipment to detect the emissions, conversion factors will be used to estimate the amount of emissions generating due to fuel consumption. The conversion factors employed are collected from several sources:

- Carbon dioxide conversion factor: This was used from the DETR guidelines for company reporting (2001).
- Sulphur dioxide, carbon monoxide, methane, N_2O, Nitrogen Oxides, and VOC conversion factors: These were taken from the BRE Environmental Profile handbook

[10] http://www.defra.gov.uk/corporate/sdstrategy/operations/partc.htm

(1999); the conversion factors are originally taken from National Atmospheric Emissions Inventory[11].

The following table reveals the conversion factors used. For more accurate details on the amount of emissions and characterisation of emissions to specific impact categories, more accurate means of calculation (such as spreadsheets) can be used.

kg/ GJ	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Fuel Oil	72.22	0.021	6×10^{-4}	0.076	99×10^{-4}	702×10^{-4}	59×10^{-3}
Gas Oil	69.44	0.021	5.9×10^{-4}	0.091	117×10^{-4}	702×10^{-4}	107×10^{-3}
Electricity	119.44	0.4043	55.77×10^{-4}	0.4218	1665×10^{-4}	175.2×10^{-4}	1.234

Table 14. Employed emissions conversion factors.

These conversion factors where used to produce the total amount of emissions (per functional unit):

Total emission (kg)	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Electricity	476912.5	1614.27	22.29	1684.14	664.7	285.56	4927
Heavy Fuel Oil	1068395	303	7.9	2530	240	938.1	13848
Light Fuel Oil	660500	210	5.487	1756	166.45	651.17	9612.1
Gas Oil	223187	67.5	1.896	292.5	37.6	225.63	343.91

Table 15. Converted emission figures (hollowcore).

Total emission (kg)	CO_2	CH_4	SO_2	N_2O	CO	NO_x	NMVOC
Electricity	179383	607.2	1853	8.4	250.05	633	107.4
Heavy Fuel Oil	399005.3	113.2	5172.1	2.95	89.56	944.86	350.38
Light Fuel Oil	246691.5	78.56	3590	2.049	62.17	655.84	243.2
Gas Oil	83358.68	25.21	128.45	0.7	14.05	109.24	84.27

Table 16. Converted emission figures (prestressed beams).

Following the conversion of energy values, the calculated emissions will need to be characterised and located in specific impact categories, the characterisation factors used can be found in the BRE Environental Profiling Handbook[12]. These include the following:

[11] See the National Atmospheric Emissions Inventory website: http://www.naei.org.uk

- **Characterisation of Climate Change impacts**

These include CO_2 (1), CH_4 (21), and N_2O (310) emissions.

- **Characterisation of Acid Deposition impacts**

These include NO_x (0.7)& SO_2 (1) emissions.

- **Characterisation of Human Air Toxicity impacts**

These include CO (0.012), NMVOC (0.022), SO_2, NO_X (0.78) emissions.

- **Characterisation of Photochemical Ozone Creation Potential (POCP)**

These include CH_4 (0.007), NMVOC (0.416).

	Climate Change kg CO_2 eq.	**Acid Deposition kg. SO_2 eq.**	**Human Tox (Air) kg. Tox**	**POCP kg. Ethene Eq.**
CO_2	2428994.5	-	-	-
CH_4	46090.17	-	-	15.3634
N_2O	11647.63	-	-	-
NO_X	-	4383.85	4884.86	-
CO	-	-	13.305	-
NMVOC	-	-	46.21012	873.8
SO_2	-	28731.01	34477.21	-
Total	2486732.3	33114.86	39421.59	889.155
Per functional unit	26.99	0.359	0.4278	0.009651

Table 17. Hollowcore emissions characterisation.

	Climate Change kg CO_2 eq.	**Acid Deposition kg SO_2 eq.**	**Human Tox (Air) kg Tox**	**POCP kg Ethene Eq.**
CO_2	908,437.7	-	-	-
CH_4	17,307.57	-	-	15.3634
N_2O	4370.69	-	-	-
NO_X	-	1,640.06	1,827.49	-
CO	-	-	4.9899	-
NMVOC	-	-	17.27	326.66
SO_2	-	10,743.55	12,892.26	-
Total	930,115.96	12,383.61	14,742.01	342.023
Per functional unit	26.859	0.359	0.4278	0.001115

Table 18. Prestressed beams emissions characterisation

[12] These were also the ones used by CML; refer Guinee (2002).

If primary energy is considered, these figures will rise dramatically: reaching nearly 35 kg of CO_2 eq.

5.5 Discharge to Water

A great amount of water used in the production system usually hydrates and integrates with the concrete product during curing, or evaporates; Levitt (1982) described conditions at precast factories where water spillages occur in several activities and where considerable amounts of water can be found at the shopfloor's surface. Therefore, the amount of water not being discharged can be significant. The amount of water discharged was not recorded due to the unavailability of any measuring devices at the site. Therefore, secondary information from another study, handling the same products, was used. The PFF3 factory has a water recycling facility that enables the calculation of water discharged through the system. This was around 40% of the total water supplied in the first place:

Water discharged from hollowcore manufacture = 0.4 x 18,490,100
= 7,396,040 litres (80.277 litres per 1 tonne)
Water discharged from prestressed beams manufacture = 0.4 x 6,905,900
= 2,762,360 litres (79.769 litres per 1 tonne)

Waste water will have an impact on several impact categories[13], these include Human Toxicity (water), Eutrophication, and Eco-toxicity.

5.6 Impacts to water

It was found that the discharged water from the factory complies with the requirements of Severn Trent Co. The Severn Trent Co. minimum requirements for toxicity and water composition were used to calculate potential impacts from the discharged water at the factory. It should be noted that these requirements also match minimum requirements under the Dangerous Substances Directive.

[13] The BRE tables (taken from CML methodology) are fully employed in this function.

Using hazardous Substances tables found at the Environment Agency website[14] (also simplified in a Severn Trent PDF publication), the details of satisfactory water levels were derived from these tables and then used to estimate the chemical content of discharged water. Within **1 litre** of water, there is:

Substance	Quantity (kg)	Substance	Quantity (kg)	Substance	Quantity (kg)
Ammonia	5×10^{-7}	Cd	500×10^{-7}	Ni	0.5×10^{-7}
Nitrite	1×10^{-7}	Cr	0.5×10^{-7}	Tetrachloroethene	0.1×10^{-7}
Nitrate	500×10^{-7}	Cu	30×10^{-7}	Trichloroethene	0.3×10^{-7}
Bromate	0.1×10^{-7}	Hg	100×10^{-7}	Zn	50×10^{-7}
Barium	10×10^{-7}	Ag	10×10^{-7}	Pb	0.5×10^{-7}

Table 19. minimum requirements within 1 litre of water.

5.6.1 Human Water Toxicity

As mentioned above, the quantities given above will be used to calculate the level of toxicity within water emissions:

Substance	characterisation	Total Tox. (kg/l)	Substance	Characterisation into Tox.	Total Tox. (kg/l)
Barium	$10 \times 10^{-7} \times 0.14$	1.4×10^{-7}	Cr	$0.5 \times 10^{-7} \times 0.57$	0.285×10^{-7}
Nitrite	1×10^{-7}	0.022×10^{-7}	Cu	$30 \times 10^{-7} \times 0.02$	0.6×10^{-7}
Nitrate	500×10^{-7}	0.39×10^{-7}	Hg	$0.01 \times 10^{-7} \times 4.7$	0.047×10^{-7}
Cd	$0.05 \times 10^{-7} \times 2.9$	0.145×10^{-7}	Ni	$0.5 \times 10^{-7} \times 0.057$	0.0285×10^{-7}
Pb	$0.5 \times 10^{-7} \times 0.79$	0.395×10^{-7}	Tetrachloroethene	$0.1 \times 10^{-7} \times 0.18$	0.018×10^{-7}
Zn	$50 \times 10^{-7} \times 0.0029$	0.145×10^{-7}	Trichloroethene	$0.3 \times 10^{-7} \times 0.2$	0.06×10^{-7}

Table 20. Human toxicity impacts

Accordingly, total toxicity = **35.355×10^{-8} kg. tox/l.** Linking this to the functional unit used, the Human Water Toxicity should reach:

252.4×10^{-8} kg Tox. Per 1 tonne of hollowcore production

250.8×10^{-8} kg Tox. Per 1 tonne of prestressed beams production

5.6.2 Eutrophication (emission to water)

Within the available water content provided above, the main factors of eutrophication are Ammoniacal N and Nitrate:

$$\textbf{Amount of Ammoniacal N} = \frac{\textbf{Amount of } NH_3 \textbf{ x Atomic weight of N}}{\textbf{Molecular mass of Ammonia}}$$

[14] See to the Dangerous Sudstances directive: http://www.environment-agency.gov.uk/yourenv/eff/water/213902/290690/290939/?version=1&lang=_e

$= 50 \times 10^{-8} \times 14.01/17.03 = 41.133 \times 10^{-8}$ kg

Impact of Ammoniacal N (conversion factor 0.33) = 1357×10^{-6} kg PO_4 eq.per 1 litre of discharged water

Impact of Nitrate (in kg PO_4) = $0.1 \times 5 \times 10^{-5} = 5 \times 10^{-6}$ kg PO_4 eq. per 1 litre of discharged water

Total Eurtrophication per 1 litre of water = 0.5136×10^{-6} kg PO_4 eq.
Eutrophication impact per 1 tonne of Hollowcore = 412.2×10^{-6} kg PO_4 eq.
Eutrophication impact per 1 tonne of prestressed beam= 409.6×10^{-6} kg PO_4 eq.

The difference between the figures at this report and the spreadsheet originally used in the study is apparently due to the differences in calculation accuracy; the figures at spreadsheets are more accurate.

5.7 Solid Waste

Sufficient information on waste was provided by the company. However, the amount of concrete waste provided had to be adjusted to delete the concrete waste-by-design (also known as Auto-scrap) category. This category was found to be around 5 – 8% of gross production.

5.7.1 Hazardous Waste

Waste is hazardous when it contains substances or has properties that make it harmful to human health or the environment. Hazardous waste includes all materials and elements that have the potential of contaminating land, air or water. This would probably include waste oil, obsolete agents, paint, etc. [15]. It might also include solid materials with a high probability of leaching and therefore contaminating the environment. In a low-technology industry, such as precast concrete manufacturing, hazardous waste is not common. Figures from the company confirm that no more than 4.8 tonnes of hazardous waste was produced during last year's activities. This included around 1,300 litres of waste oil.

15 http://www.environment-agency.gov.uk/subjects/waste/232021/799638/799655/?lang=_e

5.7.2 Non-Hazardous Waste

Non-hazardous waste may include many items such as steel cut-offs, work gloves, timber, non-contaminated aggregate, paper, etc. This waste is usually taken to landfill.

5.7.3 Concrete Waste

Concrete industrial waste is usually the largest portion of waste at precast concrete plant; concrete waste is usually recycled, crushed, taken from site, and handled by specialist haulage contractors.

The figure provided on concrete waste was 24,276 tonnes of concrete; this is approximately 18.05%. The figure was found to be high compared with studies carried out with other PFF members. Moreover, comparing these figures to other studies in Europe reveal that the given figure must have been defective:

A study carried out in Holland by CREM (Fluitman & deLange, 1996) where an extensive investigation was carried out (comparing prestressed hollowcore flooring with a shuttering '*Omnia*' slab) estimated that 263.72 kg of hollowcore produced will include and amount for a possible solid waste quantity of 36.3 kg. This is around 13.76%. Considering that this amount accounts for all waste (hazardous, non hazardous, metal, etc.) it is obvious that the company's figure needs further investigation.

Accordingly, a waste survey was organised to calculate the total amount of waste usually generating during production activities. Due to the unavailability and difficulty of calculating the amount of waste coming from customisation and sawing to meet design requirements, it was decided to isolate this stream of concrete waste.

According to the survey, the amount of hollowcore waste per casting is:

S1 + S2+ S3+ S4= 0.265 +0.886+ 0.326+ 0.023 = 1.5 tonne

The ratio of waste is 4.61%,

The total amount of hollowcore waste = 6017 tonne

The amount of prestressed beams waste per casting is:

S1 + S2+ S3+ S4= 0.282 +0.953+ 0.278 = 1.513 tonne

The ratio of waste is 4.76%

The total amount of prestressed beams waste = 1730.75 tonne

6. Environmental Profile

All the values from the impact categories presented at section 5 are gathered together to produce the final environmental profile for hollowcore and prestressed beams. Each of the characterised impact categories, at the tables below, is associated with the production of one tonne of Hollowcore (Table 21), and prestressed beams (Table 22):

Environmental Profile	
Climate Change (kg CO_2 eq.)	28.788
Acid Deposition (kg SO_2 eq.)	0.376
Ozone Depletion (kg CFC_{11} eq.)	-
Human Air Toxicity (kg TOX)	0.447
POCP (kg ethene eq.)	0.012
Human water Toxicity (kg TOX)	2.524×10^{-5}
Eco-toxicity (m^3 tox)	584.31
Eutrophication (kg. PO_4 eq.)	0.01207
Fossil Fuel Depletion (TOE)	0.00821
Mineral Extraction (Tonnes)	1.0653
Water Extraction (Litres)	189.426
Waste Disposal (Tonnes)	0.0829
Transport (Tonne.km)	1.383

Table 21. Hollowcore Environmental Profile

Environmental Profile	
Climate Change (kg CO_2 eq.)	28.615
Acid Deposition (kg SO_2 eq.)	0.374
Ozone Depletion (kg CFC_{11} eq.)	-
Human Air Toxicity (kg TOX)	0.445
POCP (kg ethene eq.)	0.012
Human water Toxicity (kg TOX)	2.508×10^{-5}
Eco-toxicity (m^3 tox)	580.62
Eutrophication (kg. PO_4 eq.)	0.01196
Fossil Fuel Depletion (TOE)	0.00816
Mineral Extraction (tonnes)	1.05
Water Extraction (litres)	188.184
Waste Disposal (tonnes)	0.0675
Transport (tonne.km)	1.35

Table 22. Prestressed beams Environmental Profile.

6.1 Data Normalisation

Normalisation involves comparing the impacts arising from any activity with those from a common unit of activity- usually the environmental impacts for an average citizen for a year. This step reduces each impact to a dimensionless ratio and eliminates the problem of units being widely variant between issues – normalisation conversion factors can be found the BRE Methodology for Environmental Profiles of Construction materials, components and buildings (Howard *et al*, 1999).

For example, total CO_2 emission in the UK was 574,750,000 kg in 1996. In order to link this to a UK citizen, the figure is divided by the population of UK at the time (this is 58,801,500). This offers a normalised CO_2 emission figure of 9,774.411 kg/ person.

Issues	One UK citizen impact	Normalised Data
Climate Change (kg CO_2 eq.)	12270 kg CO2	2.35×10^{-3}
Acid Deposition (kg SO_2 eq.)	58.88 kg SO2	6.386×10^{-3}
Ozone Depletion (kg. CFC11 eq.)	0.28595 kg CFC 11 eq.	-
Human Air Toxicity (kg TOX)	90.7 kg. TOX	4.93×10^{-3}
POCP (kg ethene eq.)	32.23 kg Ethene eq.	0.1323×10^{-3}
Human water Toxicity (kg TOX)	0.02746 kg TOX	0.9192×10^{-3}
Eco-toxicity (m^3 tox)	837600 M^3 tox	0.698×10^{-3}
Eutrophication (kg. PO_4 eq.)	8.006 kg PO_4 eq.	1.51×10^{-3}
Fossil Fuel Depletion (TOE)	4.085 TOE	0.201×10^{-3}
Mineral Extraction (Tonnes)	5.04 tonnes	0.21137
Water Extraction (Litres)	417600 litres	0.454×10^{-3}
Waste Disposal (Tonnes)	7.194 tonnes	11.52×10^{-3}
Transport (Tonne.km)	4140.84 tonne.km	0.334×10^{-3}

Table 23. Normalised Hollowcore Environmental Profile

Issues	One UK citizen impact	Normalised Data
Climate Change (kg CO2 eq.)	12270 kg CO_2	2.33 x 10^{-3}
Acid Deposition (kg SO2 eq.)	58.88 kg SO_2	6.352 x 10^{-3}
Ozone Depletion (kg CFC11 eq.)	0.28595 kg CFC_{11} eq.	-
Human Air Toxicity (kg TOX)	90.7 kg. TOX	4.91 x 10^{-3}
POCP (kg ethene eq.)	32.23 kg Ethene eq.	0.372 x 10^{-3}
Human water Toxicity (Kg TOX)	0.02746 kg TOX	0.935 x 10^{-3}
Eco-toxicity (M^3 tox)	837600 M^3 tox	0.6976 x 10^{-3}
Eutrophication (kg PO_4 eq.)	8.006 kg PO_4 eq.	1.494 x 10^{-3}
Fossil Fuel Depletion (TOE)	4.085 TOE	1.998 x 10^{-3}
Mineral Extraction (Tonnes)	5.04 tonnes	0.2083
Water Extraction (Litres)	417600 litres	0.451 x 10^{-3}
Waste Disposal (Tonnes)	7.194 tonnes	9.38 x 10^{-3}
Transport (Tonne.km)	4140.84 tonne.km	0.321 x 10^{-3}

Table 24. Normalised prestressed beam Environmental Profile

An additional step used by the BRE is the weighting of all these different environmental impacts in one scale known as Eco-point. This can be found in the main thesis text at Chapter Six.

7. Conclusion

This report accounts for all the necessary aspects that would usually be considered for the development of Environmental Profiles for [ANONYMISED] hollowcore and prestressed beams. This includes goal and scope definition, Life Cycle Inventory (LCI) development, impact assessment, characterisation and normalisation of information. The environmental profile produced was assembled using a collection of information from different sources; these included:

- Primary information taken directly from company records. These account for most of the information including production proportions, raw materials, site electricity consumption, fossil fuel consumption, water consumption, etc.
- Primary information collected using surveys and other data collection methods. These include information covering concrete waste, observations used to analyse crane movements and energy, etc.
- Secondary information taken from records from previous /following years. These were mostly used for analysis (which is not part of this report), these include energy and detailed production for 2001, castings for 2001, etc.
- Secondary information collected from similar studies. These included information on water discharged, some COD and BOD emissions, workshops and offices energy and lighting.
- Secondary information gathered from standards and directives; these include the level of toxic substances content within water, emissions, conversion and characterisation factors, crane movement information and some lighting and electricity consumption figures.
- Secondary information gathered from company's and site's own standards; such as the breakdown for criteria for hollowcore and prestressed beam concrete waste at the beginning and end of the casting beds.
- Information estimated based on observation, empirical evidence, and experience; these include estimations for some waste streams (such as wet concrete waste and slurry).

The study has also attempted to tackle several complexities such as breaking down electrical consumption and allocating some specific environmental burdens based on castings rather than mass.

The produced Environmental profile can give [ANONYMISED] a clear view into what the main environmental impacts are. The company can now identify the major contributors to energy consumption or waste. Moreover, it can environmentally assess the impacts of its transport systems and its supply chain.

By using the Eco-point system, developed by the BRE, the company can get a good appreciation of the profile outcome and is able to assess how important these different environmental impact areas are. Environmental Profiles can also help in developing Environmental Product Declarations (EPD); a new aspect which is expected to gain more importance in the industry's markets.

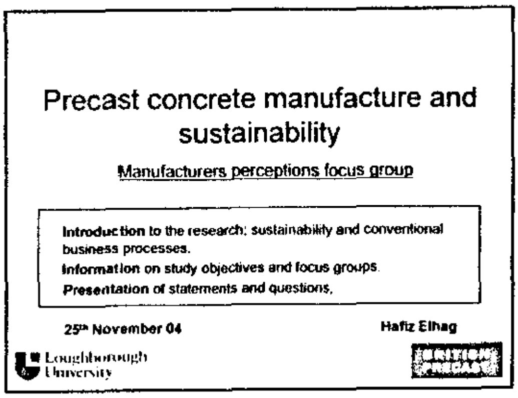
However, the study still has specific limitations, these include the following:

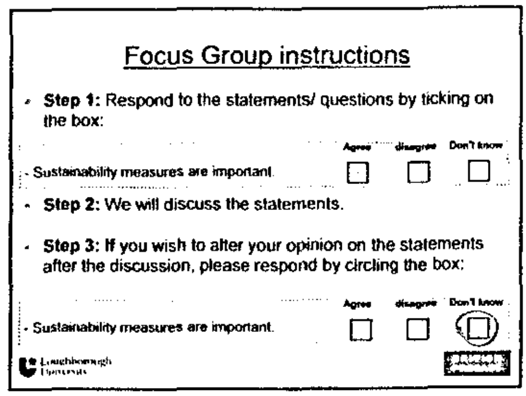
- The fact that only one electricity meter is available at site might affect the reliability of the energy breakdown.
- The additional main office activities overlapping (in terms of energy and impact allocation) with the basic hollowcore or prestressed beams based activities.
- The unavailability of any records for sufficient and detailed production figures in tonnes, this has created a difficulty in applying proper allocations (even though this is already a consideration under the BRE methodology).
- The inability to include waste-by-design as the profile will be extremely disproportionate compared with profiles of other members.

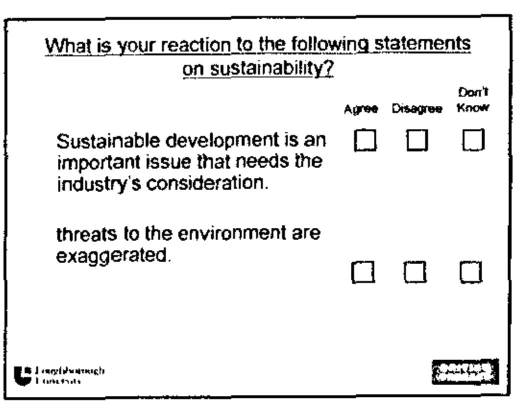
More credibility could have been added to the study if more accurate figures were available from the manufacturer. However, the figures used are still viable given that all the limitations and cut-offs are within the requirements and specifications of the Building Research Establishment (BRE) methodology.

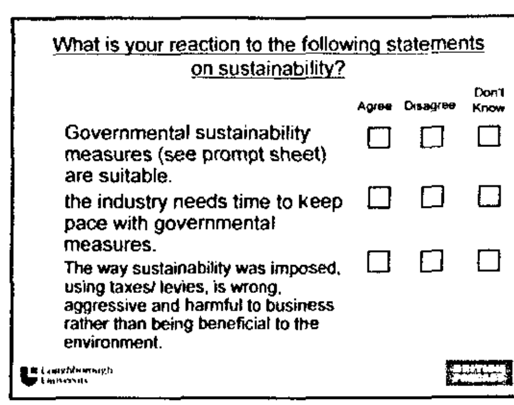
Appendix D: Question forms (powerpoint) used in Focus Groups

Questions from first and second Focus Groups (Technical and Strategic managers).









What are the main pull/ push factors for your organisation to seek sustainability?

	Low	Medium	High
Regulations and associated levies.	☐	☐	☐
Doing the right thing!	☐	☐	☐
Marketing, corporate image, Customer focus	☐	☐	☐
Potential competitive advantage.	☐	☐	☐
No strong and convincing motivators to seek sustainability.	☐	☐	☐

Main Obstacles affecting implementation of sustainability

	Low	Medium	High
Lack of environmental policies and strategies.	☐	☐	☐
Lack of expertise and investment on cement alternatives and use of recycled Aggregate in precast elements.	☐	☐	☐
Difficulties in selling sustainability compared to other flooring sectors (steel, timber, etc.).	☐	☐	☐

Main Obstacles affecting implementation of sustainability

	Low	Medium	High
Poorly monitored/ controlled internal/ external transport systems.	☐	☐	☐
Increased orders and work intensity mean no time for proper planning to reduce energy impacts.	☐	☐	☐
Customisation and increased waste levels from cutting to specifications.	☐	☐	☐

If you have any observations or queries about this focus group, please contact me at:

HKE@britishprecast.org

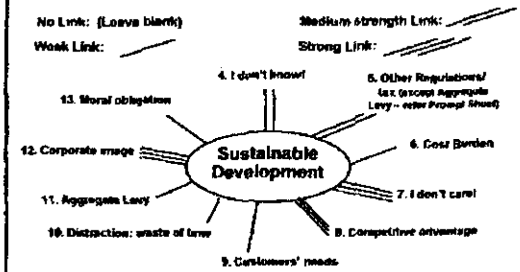
Questions from the third Focus Group (Marketing managers)

What is your reaction to the following statements on sustainability?

		Agree	Disagree	Don't Know
1.	Sustainable development is an important issue that needs the industry's consideration.	☐	☐	☐
2.	Threats to the environment are exaggerated.	☐	☐	☐
3.	Governmental sustainability measures (see prompt sheet) are suitable.	☐	☐	☐

- 9 -

How do you rate the following terms/ words in describing sustainable development and its impact on the industry?



- 10 -

Do you take these as obstacles affecting implementation of sustainability?

		NO	Yes (Low)	Yes (Medium)	Yes (High)
14.	The flow of production orders and the way jobs are organised may affect curing energy and climate change impacts.	☐	☐	☐	☐
15.	A concrete mix change might affect the suppliers' choice and upset the principles on which supply chains are established.	☐	☐	☐	☐

- 11 -

Do you take these as obstacles affecting implementation of sustainability?

		NO	Yes (Low)	Yes (Medium)	Yes (High)
16.	Difficulties in selling sustainability compared to other flooring sectors (steel, timber, etc).	☐	☐	☐	☐
17.	Customisation and increased concrete waste levels from cutting to specifications.	☐	☐	☐	☐
18.	Strategies on markets targeted affect transportation impacts and CO_2 emissions (up to 20%).	☐	☐	☐	☐

- 12 -

Appendix E: Main Semi-structured interviews question forms, surveys, and interview prompt sheets

It should be noted that the questions were standardised (demonstrated in the marketing managers' decision-maker category below). Most of the differences were associated with decision-area categories considered (Question 3). These are detailed blow.

Marketing Managers category Questions

1. Explore process decisions /nature

(Use prompt sheet with probes for managerial roles and decisions: PS-1/ Q1).

1.1 Describe your role and levels of responsibility within your organisation

1.2 Who is also involved in decision making with you?

1.3 What are the main economic and workability objectives (business justification) that you look for in the decision areas (mentioned in the prompt sheet provided)?

1.4 If change was necessary to improve environmental performance, what are the specific objectives that you would be worried about? *(red line areas)*

2. Decisions and Environmental impacts

(Use prompt sheet with probes for environmental impacts: PS-1/ Q2).

2.1 Have you thought about this before?

2.2 How do you think these impacts occur? How do you think these should be tackled?

3. What are your opinions on specific tactical solutions?

(Use prompt sheet with probes for environmental impacts: PS-1/ Q3).

What is your first impression on the following options for each of the environmental impact areas explored?

3.1 **DA-1:** Choice of raw material suppliers, and customer locations
- a) Maintain supply chain choice impacts and concentrate on means of transport (more efficient vehicles, use of rail, etc.).
- b) Consider sourcing distance as a factor in choosing suppliers and jobs to be taken.
- c) Use more energy efficient raw materials' transport trucks.
- d) Ignore impacts from transportation and concentrate efforts on something else.

3.2 **DA-2/ DA-3:** Dealing with bespoke design impacts, product shapes and depths:
- a) Replace the used concrete cast system.
- b) Tackle customisation impacts through reuse and recycling of sawed/ discarded portions.
- c) Maintain customised waste. Instead work on increasing production per energy consumed.
- d) Work with designers to eliminate concrete waste.
- e) Ignore problem and invest in other energy saving activities.

3.3 **DA-4:** Choice of jobs/ orders size and flow

a) Consider production per stock to maintain stable flow in production.
b) Additional tasks for managers to work with shop-floor in reorganising orders to enable productive flow.
c) Allowing for more planning and production flow through the increase of procurement lead times.
d) Ignore the problem and consider it to be associated with shop-floor personnel.

4. Any further notes, comments?

4.1 Do you have any further suggestions on general organisation/ managerial work, or your colleagues' (in other departments) work?

Technical Managers category Questions

What is your first impression on the following options for each of the environmental impact areas explored?

DA-5(/DA-6): Cement content within the product's mix (and Accelerating hardening and curing through change in product content):

a) Reduce cement content and use a partial replacement material (PFA, GGBS, other).
b) Reduce cement content and increase levels of fined lime in the mix.
c) Reduce cement content and use plasticizers.
d) Reduce cement and let the cast product take more curing time.

DA-7: Dealing with material reuse and recycling problems

a) Use of discharged water and concrete residue internal recycling and reprocessing systems.
b) Reuse of local crushed concrete in production.

DA-4: Choice of jobs/ orders size and flow (optional for tech. managers):

a) Consider production per stock to maintain stable flow in production.
b) Additional tasks for managers to work with shop-floor in reorganising orders to enable productive flow.
c) Allowing for more planning and production flow through the increase of procurement lead times.
d) Ignore the problem and consider it to be associated with shop-floor personnel.

Operational Managers category Questions

What is your first impression on the following options for each of the environmental impact areas explored?

DA-8: Production systems employed

a) Change the major production systems employed to more environmentally acceptable ones (casting system, curing fuel, internal transport machinery, etc).
b) Carry out few changes to some of the employed systems (such as changing the numbers or length of the curing beds, or installation of a power control and beds' heating control facilities for the curing).
c) Maintain the major production systems and invest in operational and maintenance systems.

DA-3: Bespoke design impacts

a) Replace the used concrete cast system.
b) Tackle customisation impacts through reuse and recycling of sawed/ discarded portions.
c) Maintain customised waste. Instead work on increasing production per energy consumed.
d) Ignore problem and invest in other energy saving activities.

DA-9: Operation of curing beds, concrete bullets, gantry systems, and internal transport plants

a) Abandoning accelerated curing and leaving products to cure naturally.
b) Reduce timing for accelerated curing and use other means of curing (such as accelerators) – to be checked with technical managers' replies.
c) Development of a standardised curing energy control system rather than using an ON/ OFF system.
d) Only heat beds with casts. Keep beds unheated when not used.
e) Use advanced heat insulation (covering blankets system, etc.).

DA-4: Organisation of flows of jobs/ orders

a) Modify the way jobs are set and organised (such as: never to cast products with less than the full length of the bed).
b) Consider production per stock to maintain stable flow in production.
c) Additional tasks for managers to work with shop-floor in reorganising orders to enable productive flow.
d) Allowing for more planning and production flow through the increase of procurement lead times.

Strategic Managers category Questions

What is your first impression on the following options for each of the environmental impact areas explored?

DA-10: Factory layout:

a) Modify the layout of the factory to bring stockyards and production halls much closer.
b) Use of more energy efficient and flexible internal transport systems (a combination of cranes and forklifts).

DA-8: Production systems employed:

a) Change the major production systems employed to more environmentally acceptable ones (casting system, curing fuel, internal transport machinery, etc).
b) Carry out few changes to some of the employed systems (such as changing the length of the curing beds, or installation of a power control and beds' heating control facilities for the curing).
c) Maintain the major production systems and invest in operational and maintenance systems.

DA-1: Choice of raw material suppliers, and customer locations

a) Maintain supply chain choice impacts and concentrate on means of transport (more efficient vehicles, use of rail, etc.).
b) Consider sourcing distance as a factor in choosing suppliers and jobs to be taken.
c) Ignore impacts from transportation and concentrate efforts on something else.

DA-2/ DA-3: Bespoke design impacts + Dealing with products' shapes and depths

a) Replace the used concrete cast system.
b) Tackle customisation impacts through reuse and recycling of sawed/ discarded portions.
c) Maintain customised waste. Instead work on increasing production per energy consumed.
d) Ignore problem and invest in other energy saving activities.

Appendix E (Continued):

This section shows the forms used for question:

DA-1: Supply chain structure and suppliers choice for manufacturers.

Economic and workability objectives	Very important	Important	Not important	IEP
Quality, Clients' satisfaction	☐	☐	☐	☐
Profits, pursueing larger market volumes	☐	☐	☐	☐
Lead time, and logistical requirements	☐	☐	☐	☐
savings, Production volumes	☐	☐	☐	☐

DA-2: Product depths produced by the factory.

Economic and workability objectives	Very important	Important	Not important	IEP
Market breakdown (serving larger markets)	☐	☐	☐	☐
Demand from region(s)	☐	☐	☐	☐
Costs, predetermined strategy	☐	☐	☐	☐

DA-3: Levels of customisation of products.

Economic and workability objectives	Very important	Important	Not important	IEP
Client's satisfaction	☐	☐	☐	☐
Market volume served	☐	☐	☐	☐
Profitability, competition, and innovation	☐	☐	☐	☐

DA-4: Size and flow of jobs/ orders coming to the shop-floor.

Economic and workability objectives	Very important	Important	Not important	IEP
Lead-times, nature of delivery	☐	☐	☐	☐
Factory production volume	☐	☐	☐	☐
Jobs/ orders circulation and production control	☐	☐	☐	☐

DA-5: Cement content within products' concrete mix.

Economic and workability objectives	Very important	Important	Not important	IEP
Improving products' quality and strength	☐	☐	☐	☐
Faster production (curing) times	☐	☐	☐	☐
Economic factors (cost of cement	☐	☐	☐	☐

DA-6: Accelerating hardening and curing through changes to product's content.

Economic and workability objectives	Very important	Important	Not important	IEP
Control over production time	☐	☐	☐	☐
Increasing production volume	☐	☐	☐	☐

DA-7: Reuse and recycling of materials and products.

Economic and workability objectives	Very important	Important	Not important	IEP
Financial savings (cost of sales)	☐	☐	☐	☐
Marketing prospects	☐	☐	☐	☐
Overcoming material shortages	☐	☐	☐	☐
Machinery used	☐	☐	☐	☐

DA-8: Type of production systems employed.

Economic and workability objectives	Very important	Important	Not important	IEP
Market volume – demand.	☐	☐	☐	☐
Productivity – Functional requirements	☐	☐	☐	☐
Cost reduction.	☐	☐	☐	☐

DA-9: Operation of curing beds, concrete bullets, gantry systems, and internal transport plants.

Economic and workability objectives	Very important	Important	Not important	IEP
Size, nature of jobs carried out	☐	☐	☐	☐
Production volume (maintain mass production principles)	☐	☐	☐	☐
Workability and quality requirements	☐	☐	☐	☐
Meeting deadlines and project lead times.	☐	☐	☐	☐

DA-10: The layout of the factory.

Economic and workability objectives	Very important	Important	Not important	IEP
Productivity and functionality requirements	☐	☐	☐	☐
Regulation on land-use	☐	☐	☐	☐
Site purchased (cost)	☐	☐	☐	☐
Machinery used	☐	☐	☐	☐

Appendix E (Continued):

This section shows the prompt sheets given to address Question 2 in the interviews:

DA-1: Decisions associated with raw material supplies, clients' location, etc.

Type of Environmental impacts	Affects distances and therefore transportation impacts: energy, CO_2 and SO_2 emissions.
Scale of impact	**See Figure 1.** showing the transportation emissions as percentages (%) of total CO_2 emissions of precast manufacturers (located near/ or far from quarries and cement plants.

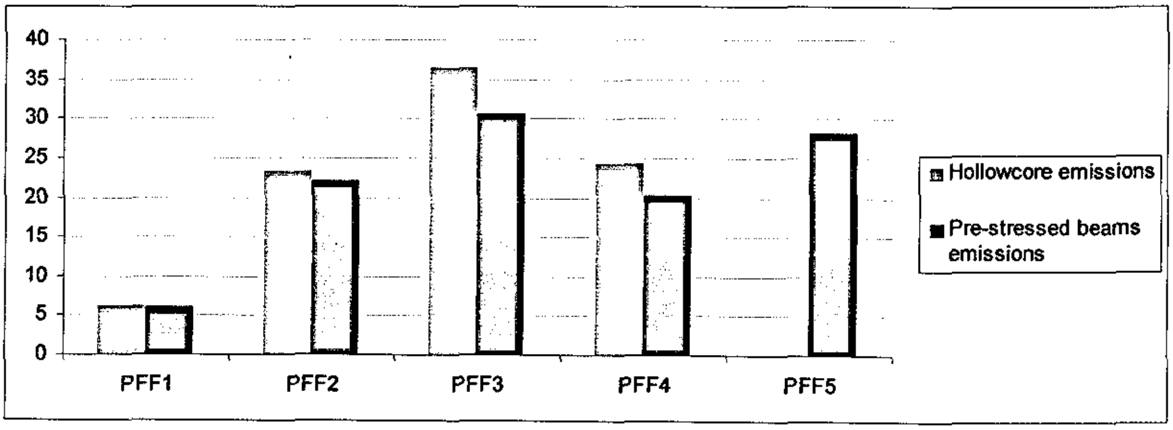


Figure 1. Transportation emissions as percentages (%) of total CO_2 emissions

DA-2: Decisions associated with product depth

Type of Environmental impacts	Affects average curing energy, concrete waste, and possibly internal transport energy levels
Scale of impact	**Curing energy:** can increase by 2.41 times when a shallower depth is produced. **Concrete waste:** can be increase by up to 1.22 t/ casting when a deeper product is manufactured (for a 100 metre long bed).

DA-3: Decisions associated with levels of products' customisation.

Type of Environmental impacts	Affects concrete waste levels and possibly levels of energy consumption.
Scale of impact	**Concrete waste:** can increase/ decrease by an average of 2.5 tonnes per casting (**see Figure 2.** for concrete waste).

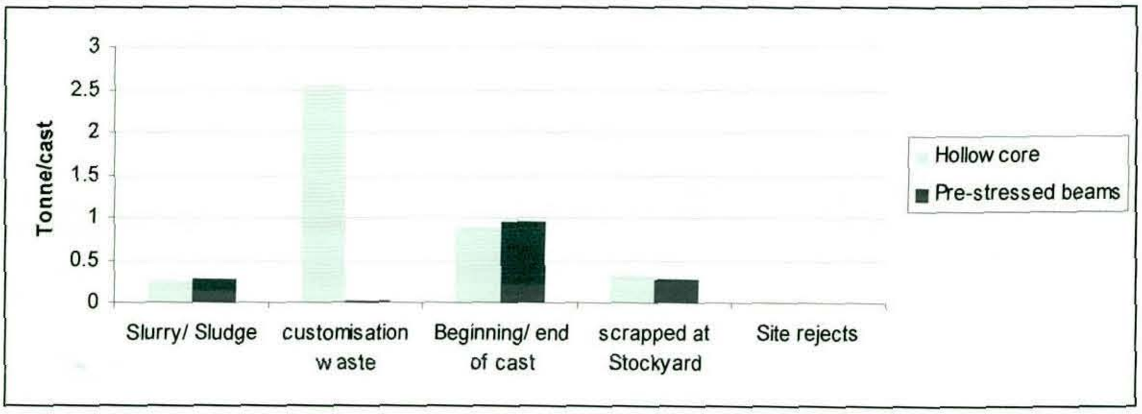


Figure 2. Concrete waste generation (tonnes) per casting for precast products.

DA-4: Decisions associated with size and flow of jobs/ orders coming to the shop-floor.

Type of Environmental impacts	Affects ability of shop-floor to cope with employment of full capacity of production affecting levels of curing energy, and levels of waste.
Scale of impact	**Curing energy:** up to 40% can be wasted (refer graph). **Concrete waste:** can increase by 0.025 to 0.03% for every one linear metre not employed in the bed

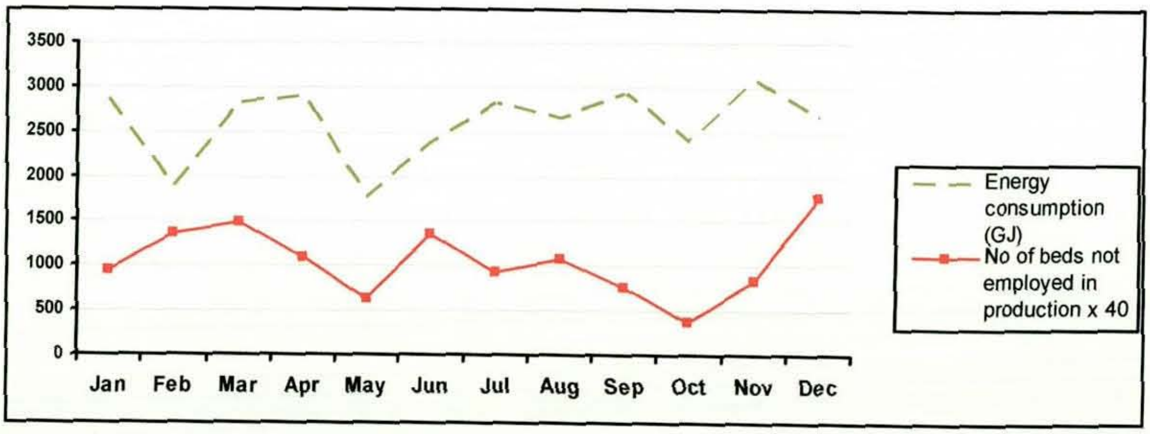


Figure 3. Number of beds not used compared to levels of curing energy consumed in 2002.

DA-5: Decisions associated with cement content in products' concrete mix.

Type of Environmental impacts: Affects upstream CO_2, Eutrohpication, and Human water toxicity. (Mainly CO_2).

Scale of impact: **Upstream CO_2 emissions:** Increases by 0.88 tonnes for every additional tonne of cement used in production, reaching 158 kg of CO_2 per 1 tonne of concrete produced (considering 18% cement content), this is compared to 23 kg CO_2 from concrete gate-to-gate operations.

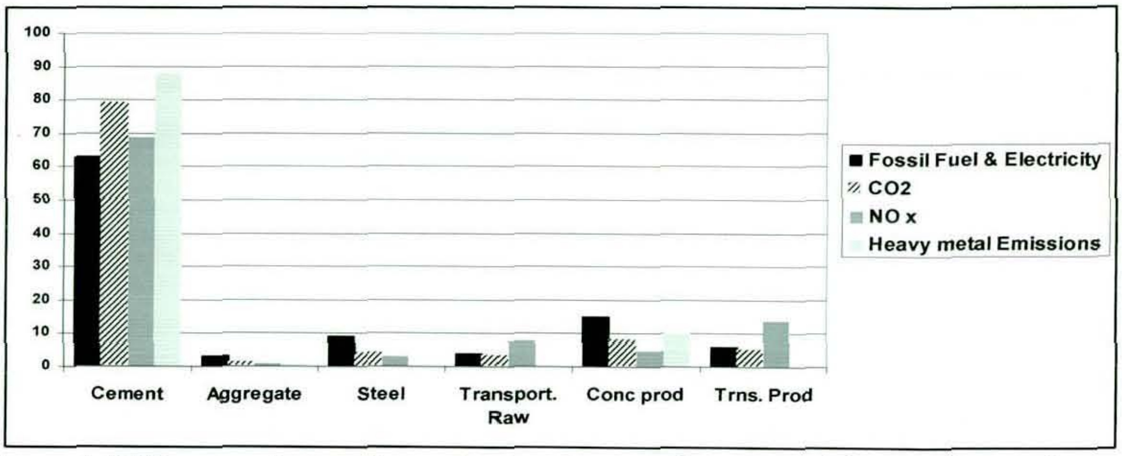


Figure 4. Different emissions for production stages and raw materials manufacture for hollowcore (Vares and Hakkinen, 1999).

DA-6: Decisions affecting product content, aimed at accelerating hardening.

Type of Environmental impacts: Affects upstream CO_2 emissions.

Scale of impact: **Upstream CO_2 emissions:** Only 0.38 CO_2 kg per 1 kilogram of a normal plasticizer to 0.69CO_2 kg per 1 kilogram of super-plasticizer (other studies estimate it to be 3.64 kg per 1 tonne of Hollowcore).

Transportation impact: around 0.54 CO_2 kg per 1 tonne of Hollowcore.

DA-7: Decisions associated with recycling and reuse of concrete residue.	
Type of Environmental impacts	Affects entire environmental impact.
Scale of impact	**Scale of impact** depends on the amount of recycled material and the price (per tonne) of recycled material versus finalised product. **Reduction will be based on the following ratio (%):** {(100 x amount of concrete recycled x price of 1 tonne of concrete recycled)/ [(amount of production x price of 1 tonne of production) + (amount of concrete recycled x price of 1 tonne of concrete recycled)]}.

DA-8: Decisions on product systems employed	
Type of Environmental impacts	Affects energy, concrete waste, water levels, etc.
Scale of impact	**Curing energy:** around 60% of the accelerated curing energy can be affected by such decisions. **Electrical energy:** Around 80% can be affected by such decisions **Concrete waste:** nearly 3.5 (hollowcore) to 1 tonne (beams) per casting can be slashed.

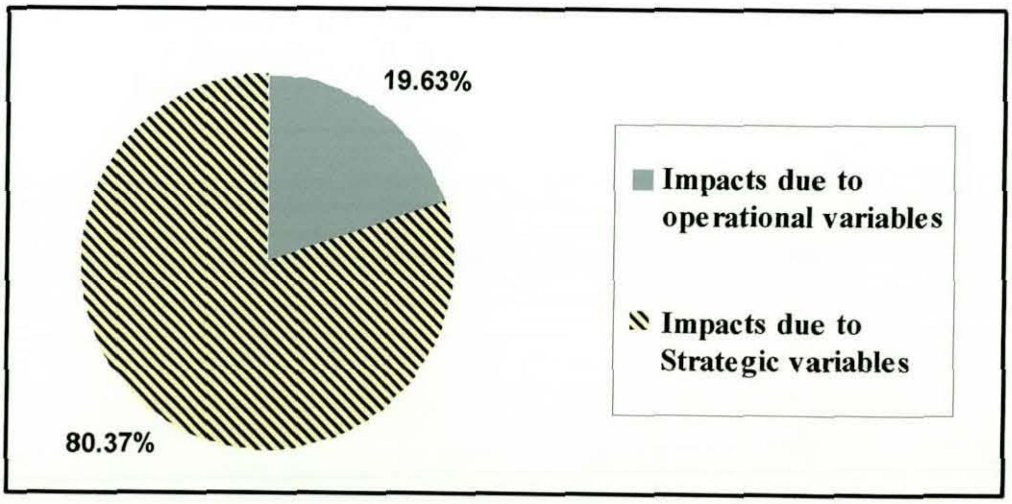


Figure 5. Curing energy consumption levels breakdown between operational and strategic variables.

DA-9: Decisions associated with the way different production systems are being operated.	
Type of Environmental impacts	Include all production associated impacts, including curing energy, concrete waste, different toxicity levels and possibly internal transport energy levels.
Scale of impact	**Curing energy:** can be affected by up to 40% (refer graph above). **Concrete waste:** can increase by 0.025 to 0.03% for every one linear metre not employed in the bed.

DA-10: Decisions associated with Factory layout.	
Type of Environmental impacts	Affects internal transport impact levels.
Scale of impact	Possible impact by ± 86.3 to 47.4 Mega-Joules per tonne of net production, around 0.0031-0.0056 eco-points per tonne (no figures on possible increase/ decrease).

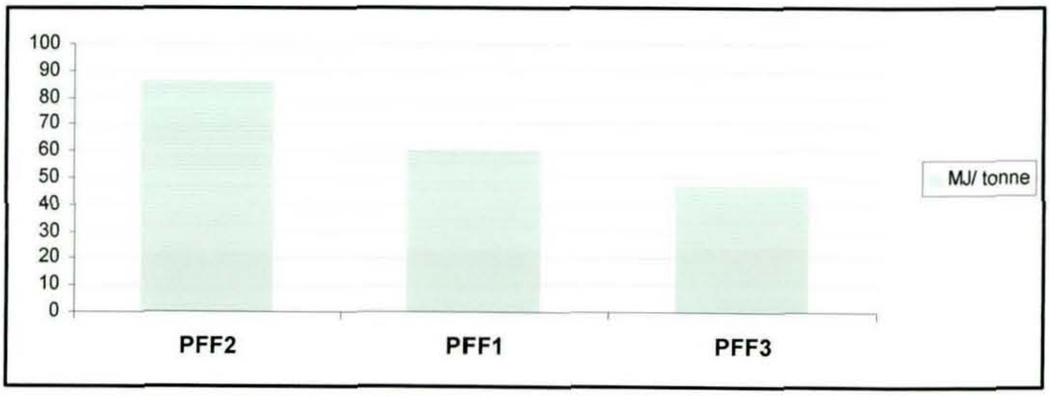


Figure 6. Impact of factory layout on internal transport energy.

Appendix E (Continued):

This section shows the survey forms and prompts given to address Question 3 in the interviews (the environmental solutions):

DA-1: Choice of raw material supplier, and customer location.

Options	Doable	Likely	Never
Option I. Maintain supply chain choice impacts and concentrate on means of transport (more efficient vehicles, use of rail, etc.)	☐	☐	☐
Option II. Consider sourcing distance as a factor in choosing suppliers and jobs to be taken.	☐	☐	☐
Option III. Use more energy efficient raw materials' transport trucks.	☐	☐	☐
Option IV. Ignore impacts from transportation and concentrate efforts on something else.	☐	☐	☐

DA-2/ DA-3: Dealing with bespoke design impacts + products' shapes and depths.

Options	Doable	Likely	Never
Option I. Replace the used concrete cast system.	☐	☐	☐
Option II. Tackle customisation impacts through reuse and recycling of sawed/ discarded portions.	☐	☐	☐
Option III. Maintain customised waste. Instead work on increasing production per energy consumed.	☐	☐	☐
Option IV. Ignore problem and invest in other energy saving activities.	☐	☐	☐

DA-4: Choice of jobs/ orders size and flow.

Options	Doable	Likely	Never
Option I. Consider production per stock to maintain stable flow in production.	☐	☐	☐
Option II. Additional tasks for managers to work with shop-floor in reorganising orders to enable productive flow.	☐	☐	☐
Option III. Allowing for more production control through increase of orders' lead-times.	☐	☐	☐
Option IV. Ignore the problem and pass it on to the shop-floor personnel.	☐	☐	☐

DA-5 (/DA-6): Cement content within products' mix.

Options	Doable	Likely	Never
Option I. Reduce cement content and use a partial replacement by-product (PFA, GGBS, other).	☐	☐	☐
Option II. Reduce cement content and increase fined-lime levels in the mix.	☐	☐	☐
Option III. Reduce cement content and use plasticizers/ accelerators.	☐	☐	☐
Option IV. Reduce cement and let cast products take more curing time.	☐	☐	☐

DA-7: Dealing with material reuse and recycling problems.

Options	Doable	Likely	Never
Option I. Use of discharged water and concrete residue internal recycling and reprocessing systems.	☐	☐	☐
Option II. Reuse of local crushed concrete in production.	☐	☐	☐

DA-8: Dealing with production systems employed.

Options	Doable	likely	Never
Option I. Change the major production systems employed to more environmentally acceptable ones (casting system, curing fuel, internal transport machinery, etc.)	☐	☐	☐
Option II. *Carry out few changes to some of the* employed systems (such as changing the length of the curing beds, or installation of a power control and beds' heating control facilities for curing).	☐	☐	☐
Option III. Maintain the major production systems and invest in operational and maintenance systems.	☐	☐	☐

DA-9: Operation of curing beds, concrete bullets, gantry systems, and internal transport plants.

Options	Doable	Likely	Never
Option I. Abandoning accelerated curing and leaving products to cure naturally.	☐	☐	☐
Option II. Reduce timing for accelerated curing and use other means of curing (such as accelerators) – to be checked with technical managers' replies	☐	☐	☐
Option III. Development of a standardised curing energy control system rather than using an ON/ OFF system.	☐	☐	☐
Option IV. Only heat beds with casts. Keep beds unheated when not used.	☐	☐	☐
Option V. *Use advanced heat insulation (covering* blankets system, etc.).	☐	☐	☐

DA-10: Dealing with environmental impacts caused by factory layout.

Options	Doable	Likely	Never
Option I. Modify the layout of the factory to bring stockyards and production halls much closer.	☐	☐	☐
Option II. Use of more energy efficient and flexible internal transport systems (combination of cranes and forklifts).	☐	☐	☐

Appendix F: Hollowcore and prestressed beams environmental profiles (for the five factories included in the study)

Environmental Profiles for Hollowcore produced in the five factories included in research (figures are per one tonne of production) at the factory in question:

	PFF1	PFF2	PFF3	PFF4	PFF5
Climate Change (kg CO_2 eq.)	28.79	22.57	16.97	18.14	Not Applicable
Acid Deposition (kg SO_2 eq.)	0.376	0.189	0.147	0.235	Not Applicable
Human Air Toxicity (kg TOX)	0.447	0.225	0.174	0.282	Not Applicable
POCP (kg Ethene eq.)	0.01214	0.01298	0.01119	0.00991	Not Applicable
Human water Toxicity (kg TOX)	2.52×10^{-5}	1.65×10^{-5}	1.172×10^{-5}	6.97×10^{-6}	Not Applicable
Eco-Toxicity (m^3 tox)	584.31	381.26	271.44	161.25	Not Applicable
Eutrophication (kg. PO_4 eq.)	0.01207	0.01415	0.01251	0.00876	Not Applicable
Fossil Fuel Depletion (TOE)	0.00821	0.00587	0.00443	0.0057	Not Applicable
Mineral Extraction (tonnes)	1.0653	1.0174	1.0418	1.0025	Not Applicable
Water Extraction (litres)	189.43	130.95	93.23	55.38	Not Applicable
Waste Disposal (tonnes)	0.083	0.087	0.045	0.0027	Not Applicable
Transport (tonne.km)	1.383	4.064	4.247	2.007	Not Applicable

Environmental Profiles for prestressed beams produced in the five factories included in research (figures are per one tonne of production):

	PFF1	PFF2	PFF3	PFF4	PFF5
Climate Change (kg CO_2 eq.)	28.61	23.59	14.97	15.6	15.81
Acid Deposition (kg SO_2 eq.)	0.374	0.202	0.134	0.188	0.107
Human Air Toxicity (kg TOX)	0.445	0.2397	0.158	0.225	0.126
POCP (kg ethene eq.)	0.01203	0.01322	0.0095	0.0075	0.0102
Human water Toxicity (kg TOX)	2.508×10^{-5}	1.647×10^{-5}	1.157×10^{-5}	$6.97\ 10^{-6}$	$1.05\ 10^{-5}$
Eco-toxicity (m^3 tox)	580.6	381.3	267.8	161.25	243.1
Eutrophication (kg PO_4 eq.)	0.01998	0.01452	0.01084	0.00621	0.01
Fossil Fuel Depletion (TOE)	0.00816	0.00605	0.00385	0.00489	0.0046
Mineral Extraction (tonnes)	1.05	1.0198	1.0033	1.0025	1.0538
Water Extraction (litres)	188.18	130.97	91.98	55.38	83.49
Waste Disposal (tonnes)	0.0675	0.089	0.0062	0.0026	0.0599
Transport (tonne.km)	1.3502	4.01	3.53	1.26	3.42

Appendix G: A check list of different type of concrete waste generated during the production process

Type of waste	Included in your waste figures	Estimate of typical wastage (%) of total waste				
		0-1%	1-25%	25-50%	50-75%	75-100%
I. **Waste in the casting process**	Y					
• Spillage at Delivery point	Y					
• Waste in the mixing process	Y					
• Waste from clearing equipment in plant	Y					
• Beginning and end of the bed.	Y					
• Concrete left in the mixer, hopper, etc.	Y					
• Other waste	Y					
II. **Waste-By-Design**	Y					
• Testing cubes and other Cut-outs	N					
• "Auto-scrap"- extra width sawn off to provide '600' and '900' widths.	Y					
• Special cured/ splayed ends	Y					
• Other.	Y					
III. **Waste Damaged during process**	Y					
• Breakage/ damage in factory	Y					
• Breakage/ damage during internal transportation.	Y					
• Breakage/ damage in stockyard.	Y					
• Other	N					
IV. **Waste damaged due to workmanship**	Y					
• Casting defects	Y					
• Bond Slip	Y					
• Setting out errors	Y					
• Other	Y					
V. **Misc. (miss batching, breakdowns, etc.**	Y/N					

Notes.

1. **All the waste washed from the beds in the production process is assumed to drain into the slurry pit, which is emptied twice a week. So all the areas under heading I (Waste in the casting process) are included in this category. Bed ends wastes are exempt, as these are too large to be washed away.**
2. **Waste on the bed ends is emptied into the recycling area with the other scrap, this is taken into account on bed-scrap.**

Form used to ease estimation of concrete waste

Appendix H: Brief of the energy breakdown results

Due to insufficient information provided for the LCA study during the period between September 2003 and April 2004, there was a need to recalculate and assess the energy information supplied by the Precast Flooring Federation (PFF) manufacturers and carry out an analysis; breaking down the electrical energy consumption at these factories. Unfortunately, there is a lack of clear information specifying the exact level of energy consumption. The following figures were taken from a Finnish study. It is known that these studies excluded the amount of energy consumed in site offices (which is similar to the procedure adopted in this LCA study). However, it should be noted that these studies might have been carried out in regions with different climate conditions:

Type of Plant	Average (MJ/m^3)	Approximate range (MJ/m^3)
Precast elements plants	790	400 – 1700
Ready-mixed plants	520	160- 700
Small product plants	350	200- 700 (without the casting process)
Mixed plants	580	300 -1500

Table 1. Primary energy consumption at Finnish Precast Plants (Asumnaa 1999)

The following table offers more information specifically from three studies at Finland and Sweden. It should be noted that, unlike table 1, it was not clear whether the attached offices' impacts were considered (product density was estimated to be 2.3 tonnes/m^3):

Type of product	Average (MJ/m^3)	Study/ source
Hollowcore	1113.2	Finland (Italian company)[1]
Hollowcore	851	EPD from Sweden[2]
Precast plant (General)	742.9	RTT- Finland[3]

Table 2. Energy Consumption at some precast plants; taken from several sources

[1] Punkki, Jouni: Sustainable Prefabrication. fib symposium proceedings, Concrete and Environment. Berlin 2001.

[2] Alexander, S.; Skjelle, A.; Suikka, A.; Vamberski, J. (2003) Environmental Issues in Prefabrication ; State-of-art report prepared by Task Group 3.1 (Ninth Draft), FIB; ISSN 1562-3610, ISBN 2-88394-061-4.

[3] Vares, S.; Hakkinen, T. (1998) Environmental Burden of Concrete and Concrete Products. Technical paper from Technical Research Centre, Finland. VTT building Technology.

The table above shows how figures from various plants can be considerably different. The information collected, so far, reveals the following:

PFF1 energy data:

Information for PFF1 shows a considerably higher average for energy consumption (1074.512 MJ/m^3) than other factories in the study, however, the total energy of the site is consumed by the following:

- **Heavy & Light Fuel oil:** for Curing and Heating: 56.83%
- **Electrical Energy:** for mixing, casting, site and main offices, cranes and other gantry systems: 31.58%
- **Liquefied Petroleum Gas:** for building heating: 3.12%
- **Gas oil:** for internal transport and some mobile machinery: 8.47%

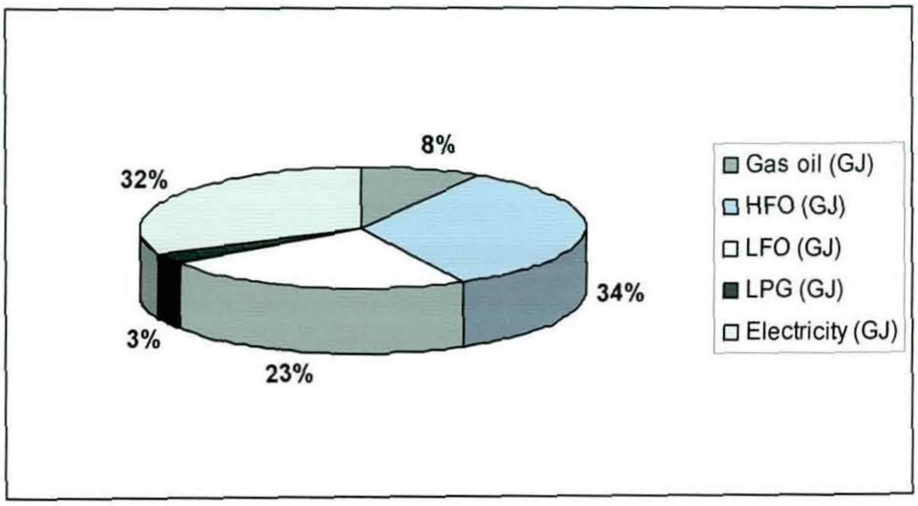


Figure 1. Energy breakdown at the PFF1 site

However, a substantial amount of electrical energy is consumed within the head-office activities (situated at the PFF1 site). Therefore, it was necessary to separate the head office and the factory activities. Energy analysis estimation was carried out for the electrical energy at PFF1 in 2004. However the information was used to break down energy consumption for the period between January to Decmenber 2002. This is revealed the following table:

Building/ structure	Activity	Energy (kWh)	Allocation to Hollowcore	Allocation to Pre-Beams	Level of confidence
Main office	All activities	134,400	None	None	Informed estimation
	Total	**134,400**	**None**	**None**	**Estimation**
Portakabins	Heating	18,597.6	None	none	Estimation
	Lighting	5,589	None	None	Estimation
	Office Equipments	6,561	None	None	Estimation
	Catering	729	None	None	Estimation
	Other Electricity	972	None	None	Estimation
	Total	**32,449**	**None**	**None**	**Estimation**
Canteen & Welfare	Cooking	20,350	None	None	Secondary information
	Lighting	7,550	None	None	Estimation
	Total	**27,900**	**None**	**None**	**Estimation**
QC	Lighting	13,864	None	None	Estimation
	Total	**13,864**	**None**	**None**	**Estimation**
External Lighting	4″ SON (250w)	4,200	none	None	Estimation
	51″ SON (400w)	85,680	46,841	17,325	Estimation
	17″ Crane THL (1000w)	35,700	26,061	9,639	Estimation
	10″ THL (1000w)	42,000	22,960	19,040	Estimation
	12″ THL (500w)	25,200	13,777	5,095	Estimation
	5″ Bollards (50w)	1,050	None	None	Estimation
	Total	**193,830**	**103,872**	**46,316**	**Estimation**
other Energy	Cranes	301,520	220,260	81,260	Estimation
	maintenance Mixers, etc,	1,074,560	784,966	289,594	
	Total	**1,376,080**	**1,005,226**	**370,854**	**Estimation**
Entire Site	**All activities**	**1,778,523**	**1,109,099**	**417,170**	**-**

Table 3. Breakdown of energy consumption throughout the PFF1 site.

This means that the average energy consumed in production at PFF1 is **967.9 MJ/m³**. This figure is relatively higher than the Finnish average; however, it is still within the provided range. This figure is divided as follows:

- Product Accelerated Curing & Heating Activities: account for **595.31 MJ/m³**.
- Operation of cranes, gantry systems, mixers and casting machines: account for **273.59 MJ/m³**.
- Internal Transport and mobile Plant operations: account for **88.76 MJ/m³**.
- Concrete Sawing: Accounts for **10.28 MJ/m³**.

This breakdown shows the huge impact of the accelerated curing technique on the entire energy consumption at the factory. This might be a difficult result to understand as Accelerated curing, along with mixing and casting) are some of the most predictable and standardised steps in Hollowcore and Prestressed beams production. The reason mentioned by their Technical manager (the fact that the beds are kept hot between castings) might be the main reason why curing energy consumption is so high.

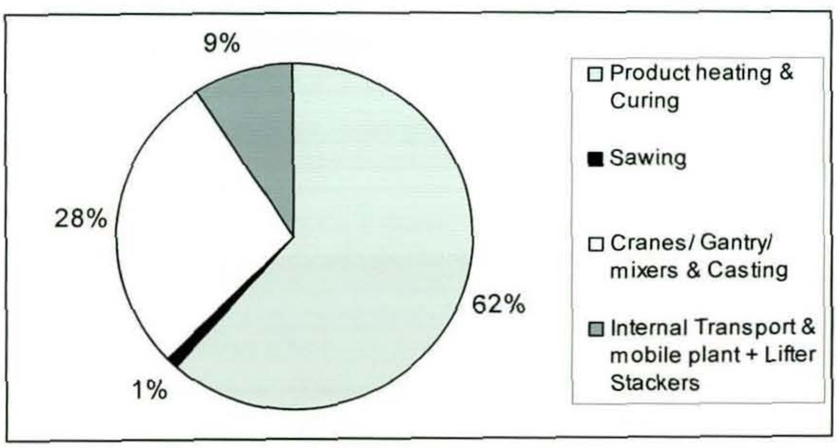


Figure 2. Production energy breakdown

PFF2 energy data:

The PFF2 production energy analysis shows a slightly lower average for energy consumption (800.26 MJ/m³). In addition to Prestressed beams and Hollowcore, the PFF2 factory produces several other products such as precast blocks and precast stairs. The total energy of the site is consumed as following:

- **Fuel and gas oil:** for internal transport and mobile plant: 35.25%

- **Electrical Energy:** for concrete mixing, casting, site offices, cranes and other gantry systems: 64.75%

Energy analysis estimation was carried out for the electrical energy at PFF2, this has revealed the following:

Building/ structure	Activity	Energy (kWh)	Allocation to Hollowcore	Allocation to Pre-Beams	Level of confidence
Main office	Heating	39,500	None	None	Estimation
	Hot water	2,300	none	None	Secondary information
	Cooling	132	None	none	Estimation
	Controls	1,971	none	none	Secondary information
	Lighting	7,556	none	none	Secondary information
	Office Equipments	8,870	none	none	Secondary information
	Catering Equipments	1,643	none	none	Secondary information
	Other Electricity	1,643	none	none	Secondary information
	Total	**63,615**	**None**	**None**	-
Canteen	Cooking	38,500	None	none	Secondary information
	Heating	--	None	None	--
	Lighting	4,120	None	None	Secondary information
	Total	**42,620**	**None**	**None**	--
Attached Office & Test	Heating	56,813	27,471.3 (mass)	20,839.8 (mass)	Estimation
	Lighting	10,868	5,255.1 (mass)	3,986.5 (mass)	Secondary information
	Total	**67,681**	**32,726.4**	**24,826.3**	-
Shop 1 & 4	Block Making	93,400	None	None	Measured /estimated
	Lighting	16,880	None	None	Estimation
	Total	**110,280**	**None**	**None**	--
Shop 2	Lighting	5,073	None	None	Estimation
	Concrete Mixing	2,842.6	None	None	Secondary information
	Total	**7,915.6**	**None**	**None**	--
Shop 3	Curing	1,965,645	1,060,675 (per castings)	904,970 (per castings)	Estimation, secondary information
	Lighting	17,520	9,454 (per castings)	8,066 (per castings)	Estimation
	Concrete Mixing	174,791	99,392 (per mass)	75,399 (per mass)	Secondary information
	Total	**2,157,956**	**1,169,521**	**988,435**	--
Remaining Energy	caging, cranes, external lighting	**183,932.4**	**88,938.4 (mass)**	**67,469 (mass)**	
Entire Site	**All**	**2,634,000**	**1,291,185.8**	**1,080,730**	--

Table 4. Breakdown of energy consumption throughout the PFF2 site.

This means that the average energy consumption at PFF2 is **735 MJ/m³** for prestressed beams and **786.25 MJ/m³** for Hollowcore. Considering the proportions of both flooring products, this offers an average for the two products of **757.12 MJ/m³**. These figures are very close to the Finnish average; however, considering the temperature differences between Finland and [anonamised – East Midlands], these figures still look high for a UK average. The average energy consumption for PFF2 site is broken down as follows:

- Product Accelerated Curing & Heating Activities: account for **429.2 MJ/m³**.
- Operation of gantry systems, mixers and casting machines: account for **88.9 MJ/m³**.
- Internal Transport and mobile plant operations: account for **238.9 MJ/m³**.

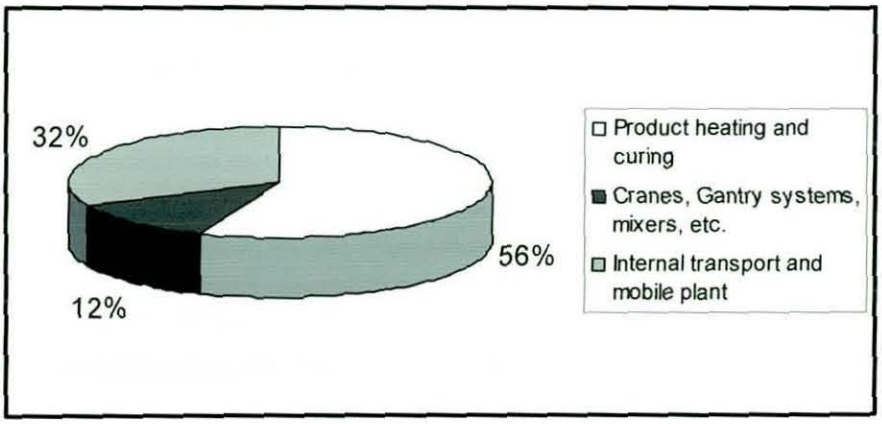


Figure 3. Precast beam production energy breakdown at PFF2

Due to the amount cast per batch, the hollowcore energy consumption average is slightly less than that for prestressed precast beams. The breakdown shows again the substantial share of energy consumed by *Accelerated Curing*. This proportion could have been considerably higher given that the primary energy of electricity is 2.6 times the actual electricity consumption read on the factory meters. The breakdown also shows the differences in energy breakdowns between cranes and means of internal transport fueled by gas oil. There are several possibilities for such differences:

- **The possibility of defects in calculations:** Due to dependency on secondary information to cover some of the aspects considered in the energy estimation, it is possible that the final results are not entirely accurate. However, the difference between the Gas oil consumption figures is so high (3 to 2.6 times compared with PFF1) that no normal secondary data defect could have been the reason. It was possible later to identify the main reason: the internal transportation of wet-cast products requires re-handling.

- **The internal transport system and the factory layout:** The layout of the PFF1 site is different to that at PFF2, the goliath crane system plays a vital role in transporting and stacking elements. Most of the stockyard is already covered by overhead goliath cranes. On the other hand, the stockyard at PFF2 is irregularly shaped and located at a far corner in the site. Fork lifts play a major role in moving, reorganising and stacking the produced elements.

Accurate information will need to be collected in order to find the main factors contributing to these differences.

Comparison with the PFF3 energy information:

The PFF3 factory at [annonamised location] has less complicated facilities. Moreover, the fact that fewer systems are used there and the provision of multiple energy metering systems have made it easier to estimate the energy consumption at the factory; the total energy consumption at PFF3 is **486.36 MJ/m³**. This is nearly equivalent to the amount consumed by PFF2 on curing; it is also considerably less than that for PFF1 curing:

- **Fuel and gas oil:** for internal transport and mobile plant: **120.02 MJ/m³**.
- **Electrical Energy:** for concrete mixing, casting, site facilities: **366.33 MJ/m³**.

Unfortunately, no information was supplied on the main reason why the energy consumption level is so low. It is possible that some energy consuming activities (such as concrete mixing or mobile plant operation) where not accounted for in the supplied information. PFF3 will need to be contacted for more clarification.

Appendix J: Investigation of some mathematical links associated with findings from LCA (May, 2005)

The following report investigates possible mathematical links developed from an earlier LCA analysis study for some of the PFF manufacturers. The report links between different environmental impacts and the factors influencing (or suspected of influencing) these impacts. It contains information collected and analysed during May 2005 concentrating on the following issues:

1. Establishment of a basic mathematical formula explaining the link between energy and different possible factors (independent variables).
2. The relationship between products' depths and energy consumption.
3. Identification of possible other factors affecting curing energy consumption patterns (such as the number and operation of casting/ curing beds in the factory).
4. Quantification of beds used/ unused in PFF1 factories and exploring how these affect energy consumption patterns.
5. Preparation of appropriate equations and links governing concrete waste generation.
6. Identify the effect of concrete mixes used on transport and curing environmental impacts.

1. Energy consumption and possible variables

Energy in a precast factory is evidently consumed by stationary and mobile plant performing different tasks inside and outside the factory. However, the fluctuating monthly energy consumption average clearly shows that there are other factors that affect energy consumption. This section analyses the possible elements contributing to increases and decreases in the average energy consumption. It concentrates mostly on curing energy (as this is around 60% of the total site-to-site energy consumption level). This is carried out using the following assumptions:

- Taking the monthly energy consumed in accelerated curing as the only dependent variable (E).

- Identifying the different independent variables affecting energy consumption (temperature control, economies of scale, operational arrangements, length of cast, depth of products, etc.) as V_1, V_2, V_3, and V_n.
- Taking the minimum monthly energy consumption recorded in the year as the energy consumption level associated with the basic production system (M).

$$E = V_1 + V_2 + V_3 + V_4 + V_5 + \ldots + V_n + M$$

If the variables' equations were identified, it would be possible to set a limit for the optimum value for E and each of the variables.

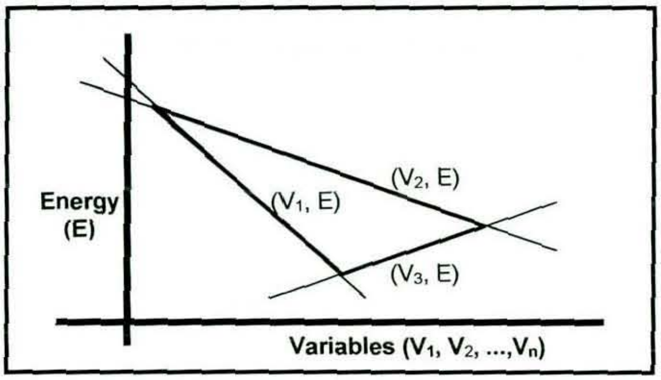


Figure 1. Possible calculation of optimum energy consumption level.

These variables include the following:

1.1 Economies of scale (multipliable variable)

The clearest indication of the influence of economies of scale on curing energy levels is shown in the monthly fluctuation pattern in energy when linked to fluctuation in production. The fluctuations in some months reach 40% of the average energy consumption level. However, due to the many other variables, it is not possible to offer a conclusive specific figure on the environmental impacts' increases and reductions directly associated with economies of scale.

1.2 Cement content in the mix (multipliable and addable variable)

Increasing the proportion of cement within concrete accelerates the curing process. This can be tested, although not convincingly proved, through comparisons between monthly cement usage and levels of curing energy consumption. Due to lack of sufficient information, it is not possible to precisely measure and determine this variable.

However, there are strong indications that cement content is a very important element in cradle-to-site environmental impact information. Figures from manufacturer PFF1 show how cement, in some instances, was replaced by the less polluting PFA. In 2002, PFF1 managed to avoid the use of up to 551.2 tonnes of cement. Considering that 1 tonne of cement is capable of producing around 880 kg of CO_2 (Gilbert, 2005), PFF1 was able to avoid an extra 485 tonnes of CO_2 emissions, this is more than 5.26 kg of CO_2 equivalent for each tonne of Hollowcore produced in 2002.

1.3 Temperature

Unfortunately, basic information on ambient temperature does not show a convincing consistency. The following figure is the only indication so far that ambient temperature can have a foreseeable impact on curing energy consumption. The figure compares monthly average ambient temperatures and energy consumption averages (per production), using a trend-line it is possible to identify a slight resemblance in pattern.

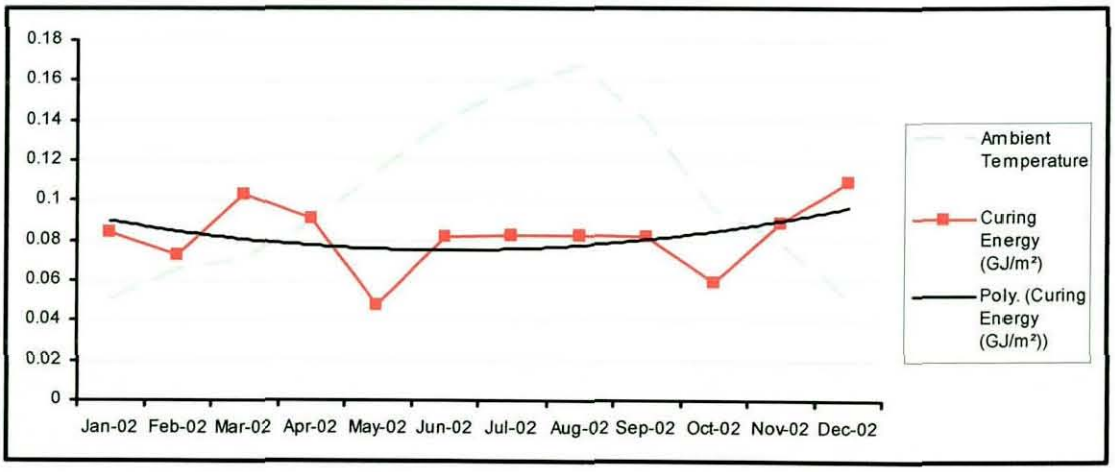


Figure 2. comparing curing energy consumption averages with monthly temperature levels.

Unfortunately, there is no clear information that might help in classifying this variable as addable or multipliable, however, there is evidence from a study carried out in Finland that temperature can have a significant multipliable influence on energy consumption reaching 40% of a factory's total energy consumption in winter in Finnish precast factories. In the UK, night-time temperatures (especially in Autumn and spring when difference between night and day time ambient temperatures can be significant) could have been more relevant.

1.4 Heating cycle

It was assumed in the LCA analysis report that specific heating cycles are used for different products' depths. Although some manufacturers have standardised heating cycles, information from the shop-floor shows that curing is mainly a call of judgement. Some manufacturers prefer to keep the beds heating for a 12-24 hours period where all beds are turned on/ and off simultaneously. This means that all castings receive the same amount of heating (per m^2). However, this does not necessarily mean that all products require the same amount of curing energy per tonne of production. The following table shows how energy per tonne can be significantly different between various Hollowcore product depths. For this purpose, it is assumed that the average curing energy consumed per cast is 65.04 Giga-joules (this average is verified in section 2):

Hollowcore depth	Weight kg/m^2	Tonnes per one cast[1]	Energy consumed per 1 tonne of production
150 mm	238	28.56	2,277
150 mm (H)	301	36.12	1801
200 mm	272	32.64	1993
200 mm (H)	302	36.24	1795
220 mm	313	37.6	1730
260 mm	405	48.6	1338
320 mm	404	48.5	1341
400 mm	493	59.2	1099
450 mm	576	69.12	941

Table 1. Curing energy consumption average for different hollowcore product ranges.

The difference of heating cycles per depth is around 1: 1.5 (between the shallowest and deepest products). Even if such differences were considered, there are still different levels of energy consumed for products. This might highlight the impact of another variable: impact arising from products' depths: the shallower the product the more energy (per tonne) is consumed for it. It should be noted that the same might not apply when considering production per m^2. However, for some of the manufacturers, the influence of

[1] It is assumed that the cast bed is 100 metres long.

beds employment and casts organisation can also have a significant impact. This is explored and discussed in the following section.

2. Relationship between products' depths and energy consumption

This relationship was assumed earlier in the LCA analysis report. However, due to lack of information on products' depths and detailed curing energy consumption it was not possible to offer exact figures and information on this issue. Therefore, the work was rather concentrated on linking between products' depths and internal transport energy consumption. The main assumption was that size (and increased depth) affects internal transport patterns more than tonnage:

The first comparison was carried out for 2001 production information for precast manufacturer PFF1, the aggregated monthly products average depth was compared against monthly gas oil purchases. Although it appears that there are no relationships, apart from the April high energy consumption levels, figure (3) still shows a consistency (using a polynomial trend-line) – Energy levels increases are accompanied by decreases in products' average depths, which means that when products become more dense with lower levels, the amount of energy required for internal transport increases. This also supports the hypothesis that internal transport energy consumption is associated with volume rather than mass. However, there are other factors that need to be verified, such as the link between the number of products manufactured and internal transport energy consumed.

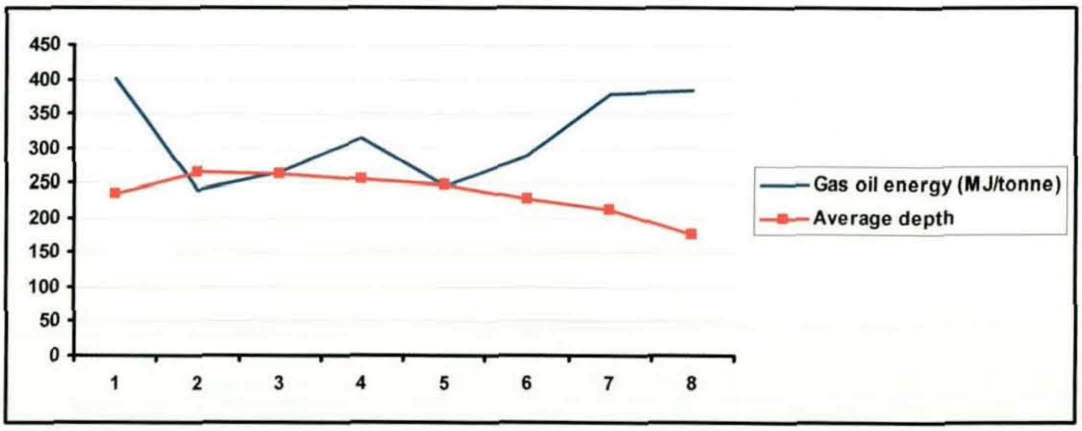


Figure 3. Monthly gas oil compared with the average depth of hollowcore production 2001

It is hard (as seen in figure 4) to tell whether this unmistakably means that internal transport energy is directly linked to the average depths of products or to the production as hollowcore production tonnage shows a pattern identical to that for hollowcore average depth. However, one extra figure (figure 5) can show how these two aspects may work concurrently as the production of the 400mm hollowcore range has dropped sharply in the last three months causing a sudden increase in energy levels and a decrease in tonnage as well as average depths.

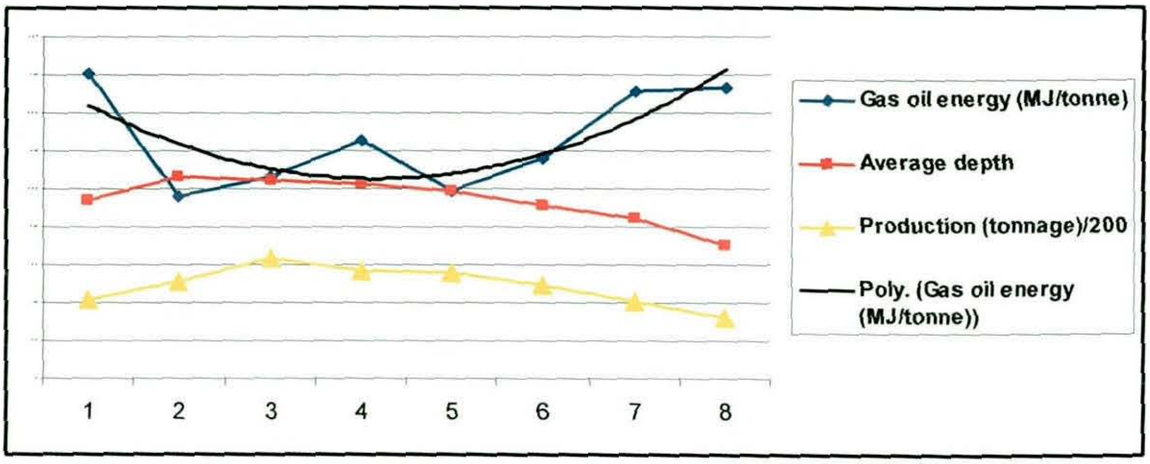


Figure 4. Monthly gas oil (pattern and poly trend-line) compared to monthly production and average depth (2001).

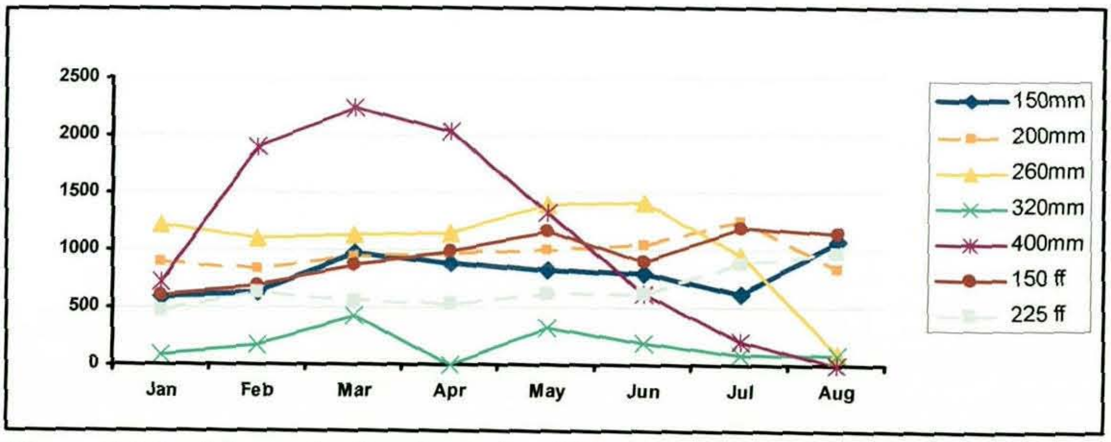


Figure 5. Monthly production levels for different products ranges and depths (2001).

3. The influence of "use of beds" on the curing energy consumption

The process of heating all casting beds (whether with a cast or not) during curing can have a significant influence on energy patterns. Manufacturers may not pay much attention to this, but the "utilisation of beds" factor might surpass the "economies of scale" factor in influencing curing energy consumption patterns:

As noted earlier, signs of an "economies of scale" influence were found in the monthly figures of production (m^2) and levels of energy consumption (MJ/m^2) for PFF1. When comparing production (m^2) to basic energy consumption (MJ or GJ), the graph should show a parallel, consistent relationship (figure 6). This was evident in the graph. However, May and October show a clear anomaly.

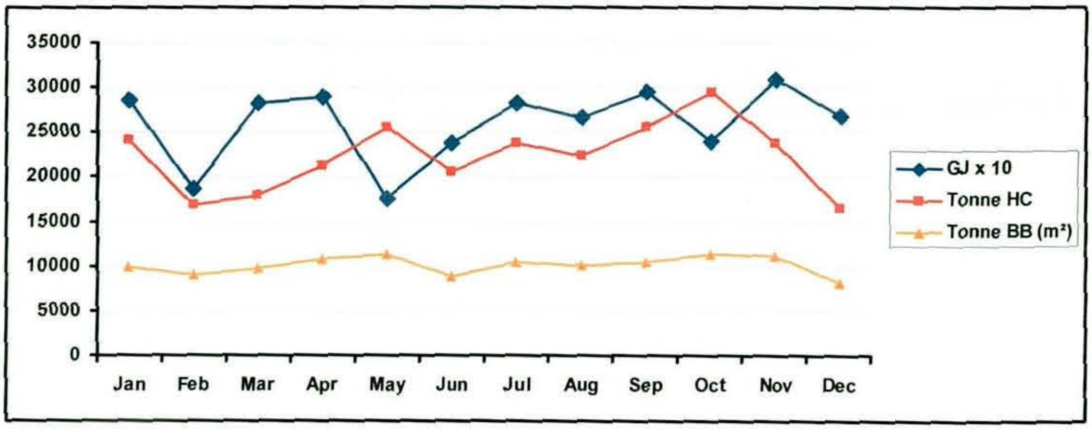


Figure 6. Factory production compared with curing energy use (2002).

Results from two months (May and October 2002) show an inverse relationship. This raises several questions about the extent of economies of scale influence and the possibility of other major factors and variables. The main suspected variable was found to be the level of utilisation of beds in the shop-floor, this level of utilisation can affect curing energy consumption in two main ways:

- Beds not used still consume energy, according to what was found in PFF1.
- Energy consumed by beds is not easy to identify. However, the possibility that energy consumption of empty and occupied beds is different could have a positive or negative influence on total curing energy.

3.1 Identifying numbers of curing beds employed or left empty per month

Using the 2002 production information, an attempt was carried out to identify the average monthly number of beds left employed (or empty) during casting. The production shed in

PFF1 has 19 beds working for an average of 12 hours a day. Seven of the beds are for prestressed beams, while the other 12 are for hollowcore production.

One of the prestressed beams curing beds is not heated, this leaves the shed with a curing energy consumption equivalent to 18 beds a day. Unfortunately, it is not possible to identify exactly how many of these were active in 2002, however, it is assumed that all these were fully working during the year. Knowing that the factory weekly operates for five working days and one half-day (Saturday):

- The maximum number of casts should range between **95** to **114** casts per week. However, taking out the annual maintenance period of 3 weeks, in addition to the Christmas week, the maximum annual number of cast will be **4560** to **5472** casts. These are to be redistributed to the 52 weeks of the year again: making the modified weekly cast production between to **87.7** to **105.2** casts. Due to lack of sufficient week-by-week information, the latter averages will be used to analyse the 2002 figures.

- Using information from the concrete waste survey carried out in 2004, it is possible to identify the average number of casts already carried out in the factory:

Weeks	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**
No. of casts HC	55	54	56	53	50	50
No. of casts beams	33	29	26	27	32	32
	Total average Hollowcore		53 casts	**Total Average (beams)**		29.8 casts

Table 2. Casts information from the 2004 weekly waste survey for PFF1.

This leaves the total number of casts at **82.8** casts, this means that between 95% to 79% of the operational capacity is employed in the factory: this can have several meanings:

1. It might be due to casts avoided (sometimes) on Saturdays, leaving maximum casts at around 87.7 casts (average given above) or less.
2. It might mean that only between 15 and 18 beds are used daily by the workforce.

- Considering that a hollowcore cast on average produces **32.7** tonnes and **120 m^2** (gross production), a prestressed concrete beam cast produces **27.1** tonnes and an average of **970** linear metres[2], the amount of monthly casts for 2002 are as follows:

Month	HC monthly casts	HC weekly casts	Beams monthly casts	Beams weekly casts
January 02	201	50.25	100.25	25
February 02	140.15	35	90	22.47
March 02	150	37.5	97.3	24.3
April 02	178.3	44.6	107.6	26.9
May 02	213.23	53.3	120.3	30
June 02	171.66	42.9	88.14	22
July 02	199	49.7	104	26
August 02	186	46.5	101.6	25.4
September 02	213.12	53.3	105.6	26.4
October 02	245.44	61.4	114.29	28.6
November 02	199	49.7	112.75	28.2
December 02	138.4	34.6	81.63	20.4

Table 3. Casts estimated monthly and weekly information for PFF1 – 2002.

- As noted above, the energy consumed is also affected by empty beds being heated. This will require further deductions to the figures in Table 3 from the total beds' capacity at PFF1. Due to the occasional possibility of shutting some of the segments of production, and due to one prestressed beam bed not being heated during curing, the number of casts with heating will be assumed to be 90 to 108 casts per week (360 to 432 casts per month):

Month	Hollowcore/ beams empty heated beds (month)	Hollowcore/ beams empty heated beds (weekly)
January 02	58.75 to 130.75	14.75 to 32.75
February 02	100 to 172	25 to 43
March 02	112.7 to 184.7	28.2 to 46.2
April 02	74.1 to 146.1	18.5 to 36.53

[2] Results are taken directly from the waste survey results 2004. The linear metre figure was taken from the aggregated average for prestressed beams produced in 2001, these were found to be dominated by two main types of prestressed beams: 150mm and 225mm, the former dominates production by a rate of 5:2.

May 02	26.5 to 98.5	6.6 to 24.63
June 02	100.2 to 172.2	25.1 to 43.1
July 02	57 to 129	14.25 to 32.25
August 02	72.4 to 144.4	18.1 to 36.1

Table 4. Estimated times when curing beds were left heating but not utilised (2002).

Month	Hollowcore/ beams empty heated beds (month)	Hollowcore/ beams empty heated beds (weekly)
September 02	41.3 to 113.3	10.3 to 28.33
October 02	0.3 to 72.3	0.1 to 18.1
November 02	48.25 to 120.25	12.1 to 30.1
December 02	140 to 212	35 to 53

Table 5. Estimated times when curing beds were left heating but not utilised (2002).

As noted earlier these beds consume considerable energy as well, however, energy consumed in these beds cannot be detected in a production or energy per production graph. Therefore, a separate graph is set for this category:

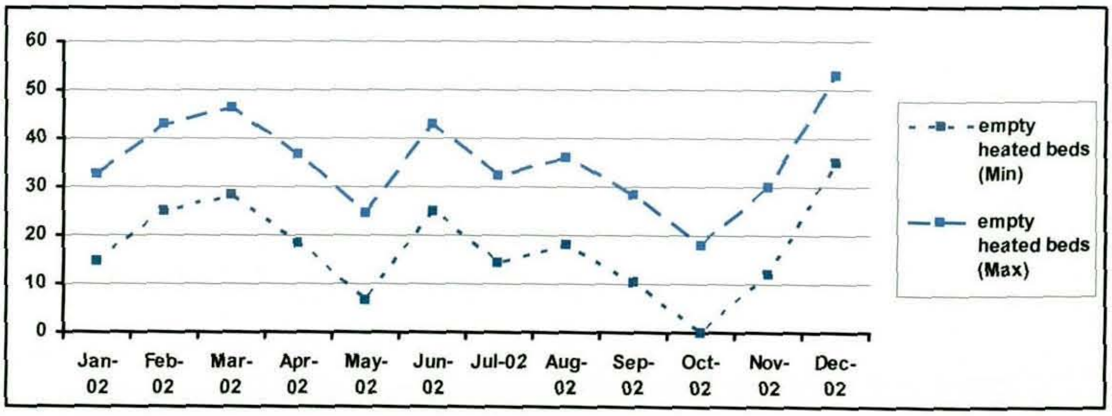


Figure 7. Weekly number of times when beds were heated but not utilised in production (2002).

When compared to the earlier graphs exploring energy versus production, Figure 7 clearly explains some of the mysteries surrounding Figure 6 results (notably those of May and October 2002). When read in conjunction with the previous figures, it explicitly shows the impact coming from the heating of empty beds. However, attempting to quantify the energy going to these beds and finding out whether these consume more or less energy than the utilised beds is another issue.

3.2 Quantifying empty beds' energy consumption

It should be noted that identifying energy consumption in beds is not easy due to many factors and aspects generally affecting curing energy consumption. However, the graph above, when compared with other graphs for curing energy consumption at the year, clearly shows that this amount of wasted energy is not small. The graph (below) might show a strong link and possible justification for May and October 2002 results. However, comparing energy consumption and curing beds use in February, July, and December in the same year show clear inconsistency. This can prove that the number of times when beds were heated but not employed in production is a major issue, but it is not the only significant factor affecting curing energy consumption patterns in the factory.

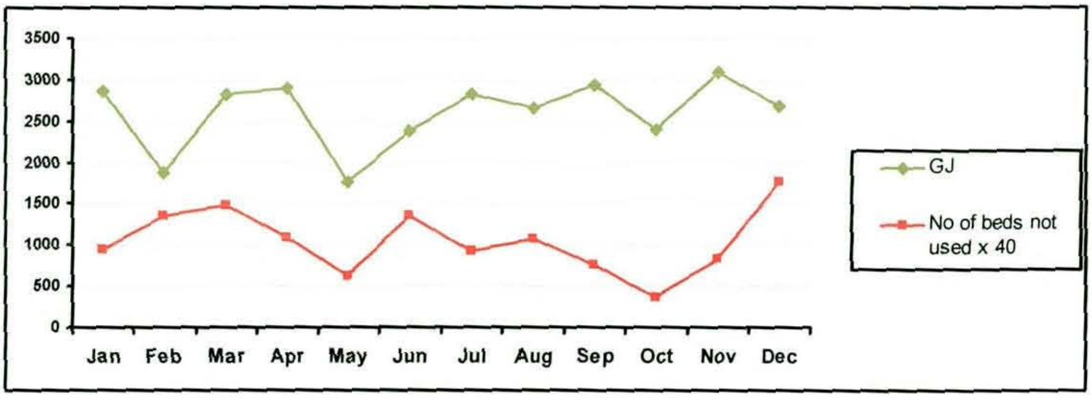


Figure 8. Number of times when heated beds were not utilised compared to curing energy patterns at PFF1 (2002).

In an attempt to quantify (or recognise) the impact coming from empty curing beds, 12 equations, representing energy consumption in the 12 months in 2002, were formed. The following assumptions are made:

The total monthly energy consumption for curing is ($\mathbf{E}_{month}$). It consists of:

1. The amount of energy used per bed employed in production during the month ($\mathbf{E}_U$).
2. The amount of energy used per bed not employed (but heated anyway) in production during the month ($\mathbf{E}_{NU}$).

These will need to be multiplied by the number of monthly casts for used beds ($\mathbf{N}_U$) and the number of beds not used in production ($\mathbf{N}_{NU}$). Accordingly:

$$\mathbf{E}_{month} = \mathbf{N}_U \times \mathbf{E}_U + \mathbf{N}_{NU} \times \mathbf{E}_{NU}$$

3. The average between maximum and minimum bed heating times (found in Table 4/ Figure 7) is used.

These 12 equations (for 2002 information) were formed using the above formula:

Month	Equation
January 02	$95E_{NU} + 301E_U = 28612.25$
February 02	$136E_{NU} + 230E_U = 18711.78$
March 02	$148.8E_{NU} + 247.2E_U = 28298.49$
April 02	$110.1E_{NU} + 285.9E_U = 29002.48$
May 02	$62.5E_{NU} = 333.5E_U = 17648.63$
June 02	$136.4E_{NU} + 259.6E_U = 23861.7$
July 02	$93E_{NU} + 303E_U = 28231$
August 02	$108.4E_{NU} + 287.6E_U = 26621$
September 02	$77.3E_{NU} + 318.7E_U = 29463$
October 02	$36.4E_{NU} + 359.6E_U = 24023$
November 02	$84.4E_{NU} + 311.6E_U = 30907$
December 02	$176E_{NU} + 220E_U = 26794$

Table 5. equations identifying curing energy consumption patterns in utilised/ unutilised beds.

Using the year 2002 information, it is also possible to estimate the average single bed energy consumption for the year (whether used or not) at **65.037 Giga-joules per cast**. The equations above can considerably help in understanding the link between energy consumption and numbers of beds employed. The equations may also be useful in identifying better means in controlling curing energy consumption. From the equations above, a graph (figure 9) and a table (Table 5) were developed.

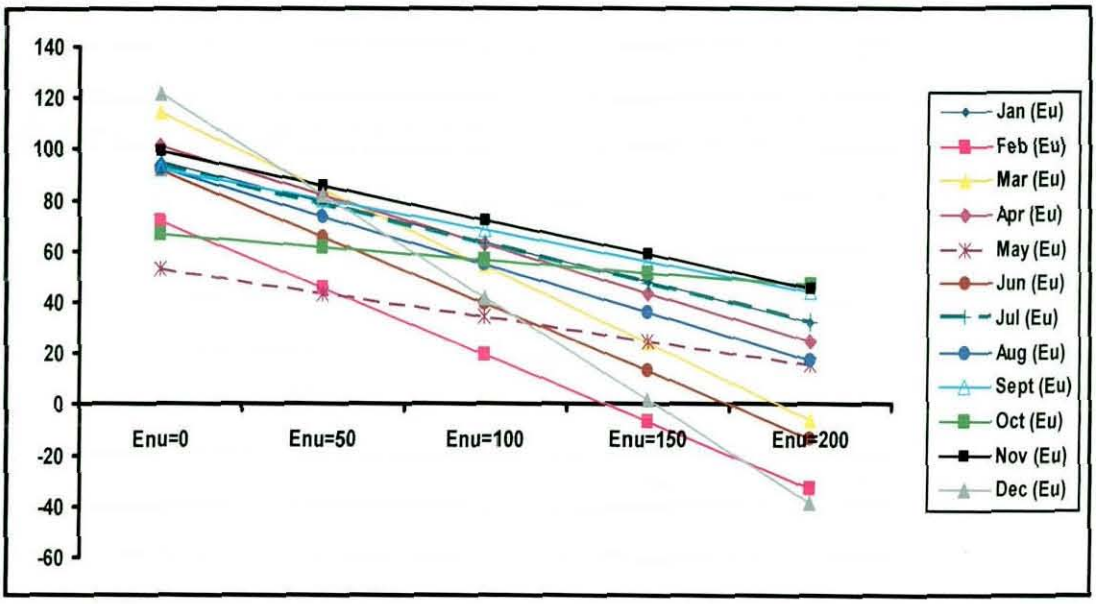


Figure 9. 2002 Monthly curing energy based on numbers of used/ unused beds (in Giga-joules).

The table offers possible estimations for energy consumptions in beds used in casting (E_U) and beds not used in casting (E_{NU}). However, the table cannot be used to estimate which energy consumption category was the least in the month/ year.

	E_{NU}=0	E_{NU}=50	E_{NU}=100	E_{NU}=150	E_{NU}=200
Jan (E_U)	95.06	79.28	63.5	47.71	31.93
Feb (E_U)	71.97	45.82	19.66	unfeasible	unfeasible
Mar (E_U)	114.48	84.39	54.29	24.19	unfeasible
Apr (E_U)	101.44	82.19	62.93	43.68	24.42
May (E_U)	52.92	43.55	34.18	24.81	15.44
Jun (E_U)	91.92	65.65	39.38	13.1	unfeasible
Jul (E_U)	93.17	77.83	62.48	47.13	31.79
Aug (E_U)	92.56	73.72	54.87	36.03	17.18
Sept (E_U)	92.45	80.32	68.19	56.07	43.94
Oct (E_U)	66.8	61.74	56.68	51.62	46.56
Nov (E_U)	99.19	85.65	72.1	58.56	45.02
Dec (E_U)	121.79	81.79	41.79	1.79	unfeasible

Table 5. Different possible values for the amount of curing energy used in utilised or unutilised beds – in Giga Joules per bed (2002).

The different values received from each month (in Table 5) show that there are other significant dependant variables affecting energy consumption levels in the factory. This can be due to any factor (economies of scale, impacts from climate, impacts from management, etc.). The identification of these variables will require additional information (which is not available in the LCA 2002 data).

4. Concrete waste criteria

Waste criteria were quantified and explained thoroughly in several parts during the study. This can be explained in detail below:

4.1 Concrete waste at bed ends

Waste at bed ends is estimated by most participants in the study at around 1.5 metres in each end (for slipforming and extrusion cast products), this would include the actual waste in addition to the areas not cast in the bed. For a 100 metre long bed this amount will obviously reach 3% per cast, for a 150 metres long bed, it will reach 2% per cast. The amount of waste is directly related to the number of casts. The following formula was developed for this concrete waste category:

$$\text{Concrete Waste } (m^2) = 3 \text{ x } [(0.833\text{x}P_1/\text{Bed length}_1) + (0.833\text{x}P_2/\text{Bed length}_2)]$$

$$\text{Concrete waste (tonnes)} = 3 \text{ x } [(0.833\text{x}W_1\text{x}P_1/\text{Bed length}_1) + (0.833\text{x}W_2\text{x}P_2/\text{Bed length}_2)]$$

Where:

- **P_1, P_2** = the production (in m^2) for the product ranges (can be more than two) manufactured at the factory.
- **W_1, W_2** = the average weight (in tonnes/m^2) for the product ranges manufactured.
- **Bed length_1, Bed length_2** = the total length for the casting beds for each of the manufactured products.

4.2 Waste-by-design and other concrete waste

These concrete waste categories are subject to unique and specific conditions that cannot be standardised and generalised for every production facility. Therefore, it is unfeasible to develop generic formulas for these waste categories.

5. Products and concrete mix

The basic ingredients of a concrete mix are cement, fine aggregate, coarse aggregate, water, and some additions (admixtures, limestone dust, and PFA). This can be put in the following basic formula:

1 tonne of gross production = cem_1 + water + Agg_{fine} + Agg_{coarse} + $Add_{1.1}$ + $Add_{1.2}$

- **Cem_1** = the cement content within the concrete mix (per 1 tonne).
- **Agg_{fine}** = fine aggregate content within the concrete mix (per 1 tonne).
- **Agg_{coarse}** = Coarse aggregate content within the concrete mix (per 1 tonne).
- **Additions ($Add_{1.1}$, $Add_{1.2}$)** = different materials/ products added to the mix. These include admixtures and additions such as PFA or GGBS.

Precast concrete mixes can vary considerably, the inclusion of additions can also play a major role in controlling w/c ratios in concrete. The following limitations are not comprehensive, however, table 6 includes some generic concrete mixes taken from Richardson (1991), these can help in understanding possible (and most applicable) ratios:

Ingredient (in tonnes)	Normal wet-cast structural element	prestressed product (with Limestone aggregate)	Extruded floor element production	Wet cast flooring mix with gravel
Cem_1	1 (16.8%)	1 (14.6%)	1 (16%)	1 (15.5%)
Agg_{soft}	1.5 (25.2%)	2 (29.2%)	1.2 (19.2%)	2 (31%)
$Agg_{coarse1}$	3 (50.4%)	2 (29.2%)	3.7 (59.2%)	2 (31%)
$Agg_{coarse2}$	-	1.5 (21.9%)	-	1 (15.5%)
water	0.45 (7.6%)	0.35 (5.1%)	0.35 (5.6%)	0.45 (7%)

Table 6. Precast concrete mixes taken from literature.

Due to the special needs of different product ranges and casting machines, the average cement content rate (per tonne of production) will vary from one month to another. In an ideal situation, this rate should be consistent with the amount of curing energy consumed per tonne of production or per casting (the increase heat of hydration can be employed in curing). However, as casts approximately receive the same rate of curing heat regardless of specific cement contents or depths, it is very hard to quantify the positive impact of cement content on curing energy. However, it is possible to link cement content to other types of impacts such as transportation: the total amount of cement per annum is:

$$\mathbf{cem_1 \times Q_1 + cem_2 \times Q_2 + cem_3 \times Q_3 + cem_4 \times Q_4 + cem_5 \times Q_5 + ... + cem_n \times Q_n}$$

Where cem_1 (and cem_2, etc.) is the content of cement within a tonne of a specific product,

Q_1 (Q_2, etc.) is the amount of production (in tonnes) for that product.

6. External transport

External transport is the only category where calculations are solely based on linear relationships. This makes it much easier to predict and standardise. Transportation impacts are associated with transport modes used, transport distances, and amount of products (and raw materials) transported. Using information available, it is possible to summarise external environmental impact criteria in two main equations:

The first is the major and more general one: The transportation associated environmental impact of a product is to be identified as "**I**", this is the sum of impacts from several raw materials: I_1, I_2, I_3. This means that:

$$\mathbf{I = I_{cement} + I_{Aggregate\text{-}A} + I_{Aggregate\text{-}B} + I_{Admixture} + I_5 + \ldots}$$

For each of these material impacts, the following equation can be used:

$$\mathbf{I = (FxDxM) / (1000xL)}$$

Where:

- **I** = environmental impact, it can be modified (using a schedule of conversion factors) to calculate energy, CO_2, acid deposition, and all other emissions.
- **F** = is the factor for the frequency of return journeys. This is taken as 2 as most return journeys (either for raw materials or final deliveries) will be empty[3].
- **D** = distance travelled by lorry, train, ship, etc.
- **M** = This is the mass of materials to be transported.
- **L** = the net load carried by the trucks used (capacity).

With F and L already recognized, transportation impact will directly depend on two main variables: these are D and M;

[3] According to the BRE LCA methodology, the return trips are always assumed to be 'full' for trains and ships.

6.1 Distances travelled

The distances travelled will depend on the location of the manufacturer (and his suppliers). However, these distances are also associated with the raw materials and the concrete mixes used for production. The following equations apply to some of the manufacturers included in the earlier LCA analysis study:

Manufacturer	Equations (cement)	Equations (coarse Aggregates)
PFF1	$I_{cement} = 1.228 \times D$	$I_{coarse\ agg.} = 3.762 \times D$
PFF2	$I_{cement} = 0.89 \times D$	$I_{coarse\ agg.} = 2.21 \times D$
PFF3	$I_{cement} = 0.864 \times D$	$I_{coarse\ agg.} = 2.52 \times D$
PFF4	$I_{cement} = 0.52 \times D$	$I_{coarse\ agg.} = 1.37 \times D$ (D = 0)

Table 7. Equations for cement and aggregates transportation impacts for precast manufacturers.

The impact equations, above, are largely affected by the volume of production (and the nature of mix design). However, the more interesting issue is the comparison between cement and aggregate impacts for each factory. Although the quantity of coarse aggregates used in concrete is more than cement. It is noticed that environmental impacts from cement transportation can surpass coarse aggregates transportation impacts if the average sourcing distance for cement is 2.7 to 3.1 times longer than that for aggregates.

The following two figures (Figures 10 and 11) show cement and coarse aggregate transportation impacts when sourcing distances increase. The figures are for PFF2 and PFF3:

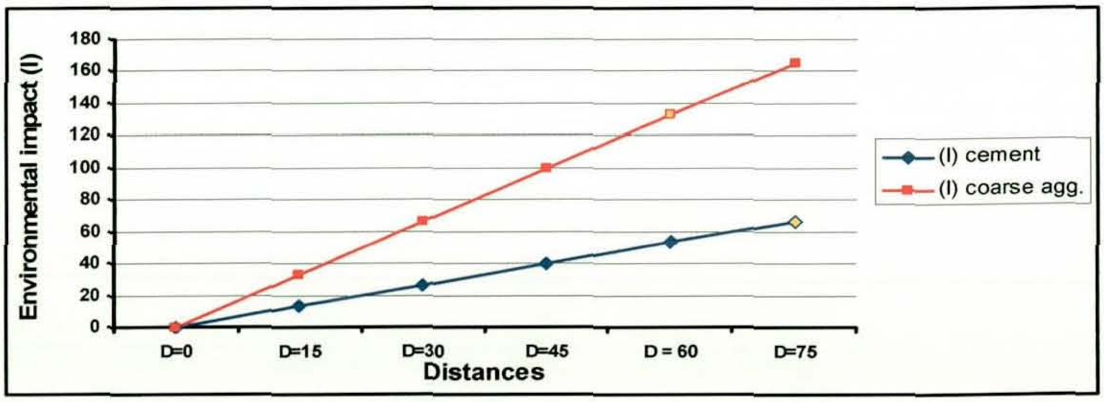


Figure 10. Environmental impacts arising from cement and coarse aggregates transportation based on the sourcing distances taken for PFF2 (2002)

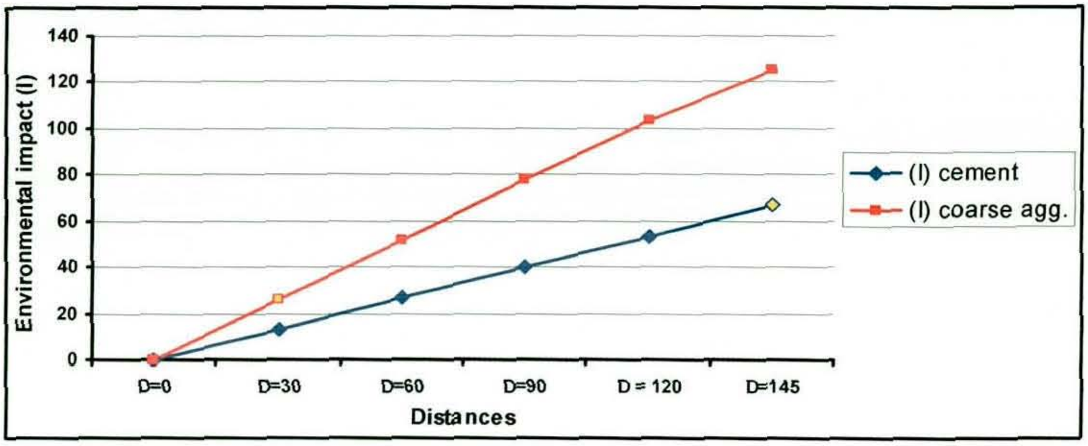


Figure 11. Environmental impacts arising from cement and coarse aggregates transportation based on the sourcing distances taken for PFF3 (2002)

The grey spots in the two figures show the actual sourcing distances. While the difference in sourcing distances for cement and coarse aggregates for PFF2 are small (cement sourcing distance is being longer), the total environmental impact for coarse aggregates transportation is much higher than impact from cement transportation. On the other hand, the cement sourcing distance for PFF3 is 4½ times longer than the coarse aggregate transport distance, and cement transportation impacts are more than twice coarse aggregates' transportation impacts.

6.2 Mass of materials

Cement, coarse, and fine aggregate are the main materials causing most of the impact. These are brought from different locations (depending on many aspects including a factory's location). However, one of the main issues associated with mass of materials is the concrete mixes employed. The following equations apply to some of the manufacturers included in the LCA analysis study:

Manufacturer	Equations (cement)	Equations (coarse aggregate)
PFF1	$I_{cement} = 0.00195 \times M$	$I_{coarse\ agg.} = 0.00136 \times M$
PFF2	$I_{cement} = 0.00613 \times M$	$I_{coarse\ agg.} = 0.00543 \times M$
PFF3	$I_{cement} = 0.0123 \times M$	$I_{coarse\ agg.} = 0.00273 \times M$
PFF4	$I_{cement} = 0.00886 \times M$	$I_{coarse\ agg.} = 0$

Table 8. Equations for coarse aggregate and cement transportation impacts for precast manufacturers.

The two following figures (12 and 13) are also for transportation impacts (I_{cement} and $I_{coarse\ agg}$), the figures are for the same manufacturers (PFF2, and PFF3) showing the impact of mass (and frequency) on transportation environmental impacts:

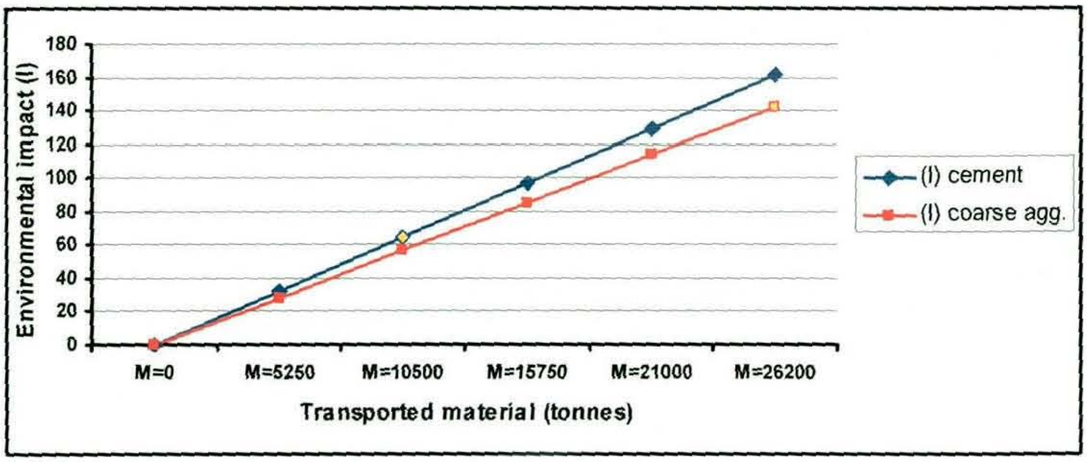


Figure 12. Environmental impacts arising from cement and coarse aggregates transportation based on transported materials (tonnage) for PFF2 (2002)

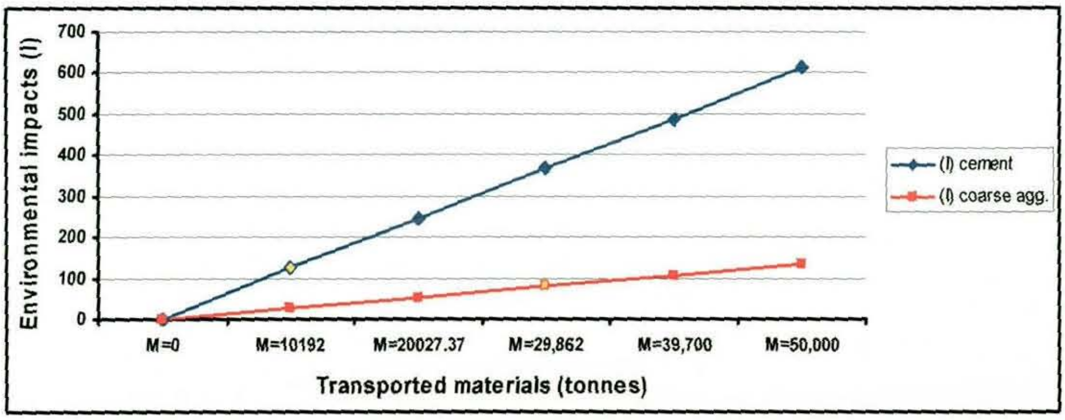


Figure 13. Environmental impacts arising from cement and coarse aggregates transportation based on transported materials (tonnage) for PFF3 (2002)

The grey spots in the two figures show the actual transported mass during 2002 for the two manufacturers. The two figures show the influence of mass over the total transportation environmental impact. However, the influence of sourcing distances (especially cement's sourcing distances) is evident in Figure 13.

Appendix K: Calculation of the suggested environmental solutions

This Appendix includes calculations associated with Section 6.7 and some of the environmental solutions suggested in the study. The decision areas (for which these environmental solutions were made) can be found in Section 6.6:

D1 – Option I. Maintain impacts associated with the supply chain and concentrate on means of transport (more efficient vehicles, use of rail, etc.):

Energy savings can be made in changing to rail use. These savings are around **0.426 - 0.533 MJ/tonne** for every 1 km saved in the sourcing distance. This was calculated as follows:

1. Energy consumed by a truck (per 1 km) = 0.7 to 0.576 MJ/tonne.km (see Option II – D1).
2. Energy consumed by a diesel train (per 1 km) = 0.1466 MJ/ tonne.km
3. Energy consumed by an electric train (per 1 km) = 0.15 MJ/ tonne.km
4. Maximum energy savings due to change from truck transport to train (per 1 km) = 0.7 – 0.1466 = 0.533 MJ/ tonne.km
5. Minimum energy savings due to change from truck transport to train (per 1 km) = 0.576 – 0.15 = 0.426 MJ/ tonne.km

D1 – Option II. Consider sourcing distance as a factor in choosing suppliers and jobs to be taken:

Savings in transport energy, of between **0.576** and **0.7 MJ/tonne per kilometre**, can be made for different materials' sourcing distances (depending on transported goods). This was calculated as follows:

1. Fuel consumed by a truck (per 1 km) = 0.35 litres of diesel = 0.2975 kg of diesel (DETR, 2001).
2. Energy consumed by a truck (per 1 km) = 0.2975 x 45.9 = 13.655 MJ
3. Energy consumed per 1 tonne of steel transported = 0.7 MJ/ tonne per Kilometre.

4. Energy consumed per 1 tonne of aggregate transported = 0.576 MJ/ tonne per kilometre.

D1 – Option III. Use more energy efficient raw material trucks:

Benefits include substantial cuts in sulfur emissions. If LPG fuel is used, savings in CO_2 emissions can reach **35-44%**. This was calculated as follows:

Using DETR Guideline for companies on greenhouse gas emissions

1. CO_2 emissions per km from a petrol fuelled artic truck = 0.81 kg CO_2
2. CO_2 emissions per km from a Diesel fuelled artic truck = 0.94 kg CO_2
3. CO_2 emissions per km from an LPG fuelled artic truck = 0.53 kg CO_2

Savings of using LPG are 44% compared to petrol, and 35% compared to Diesel.

D2/ D3 – Option I. Replace the concrete casting system employed

Basic savings in energy consumption averages would vary between **3 – 11.4%** (depending on types of casting and waste generation). Savings in waste can reach an average of 2.5 tonnes for every cast carried out. These were based on the following:

A wet casting system does not generate concrete waste at the ends of the casting bed (this is around 3% for a 100 metre casting bed). Moreover, an additional 8.4% is associated with wet waste (0.265 tonnes per one cast of 32.5 tonnes), and 2.56 tonnes from waste-by-design. 2.5 tonnes per casting is the average for waste-by-design in the factories where such type of waste was considered.

D2/ D3 – Option III. Maintain customised waste. Instead work on increasing production per unit of energy consumed (also applies to Option IV):

Through improving curing energy consumed per production, savings in curing energy can range from **0.3%** to **31.3%** (depending on energy factors targeted). The 0.3% is based on slight modifications to the product's depth (from 200mm to 225 mm deep), the savings will actually increase production per average curing energy consumed. The 31.3% will account for this possibility in addition to a possible 31% saving in curing energy during summer for one of the manufacturers included in the study [anonymised].

Savings in energy (a maximum of 0.261 eco-points per 100 metre casting) may not offset customisation impacts (reaching up to 2.14 eco-points per 100 metre casting). These were calculated as following:

- As noted in Section 6.4.2.2, average energy consumption per 1 m^2 for a 100 metre bed = 84.719 MJ/m^2.
- Average energy consumption for an entire 100 metre bed = 84.719 x 120 = 10166.28 MJ = 10166.28 x 0.0000239 TOE = 0.243 TOE
- Energy per bed in Eco-points = 0.6536 Eco-points
- It was identified in the study that savings in curing energy could reach 40%. This will be around 0.261 Eco-points.
- Customisation impacts were calculated by multiplying the amount average customised waste (2.5 tonnes) by the eco-point score for 1 tonne of produced Hollowcore (0.856 Eco-points).

D4 – Options I, III, and IV:

Savings in main curing energy levels; these are not specifically identified (depending on the quality of the executed solution). However, these could reach up to **34.54 MJ/ m^2** of production (hollowcore). This figure was directly taken from Section 6.4.2.2

D4 – Option II. Modify the way jobs are set and organised (such as never casting products using less than the full length of the bed):

Savings in curing energy amounting to **0.66%** to **1%** for every metre in the casting bed missed in production (depending on the length of the curing bed). The calculations in this are very basic – based on the usual length of curing beds in factories (100m to 150m).

D5/ D6 – Options I to IV:

Reducing cement content by **2%** can reduce emissions by **17.6** kg of CO_2 per one tonne of product. This is around **0.051** eco-points per tonne of product. This was calculated as follows:

- The production of 1 tonne of cement generates 880 kg of CO_2 – accordingly reducing cement content by 20 kg (this is 2% of 1 tonne of final product) will reduce upstream climate change emissions by 17.6 kg of CO_2, this is multiplied by 0.0029 (conversion factor for CO_2 eq. to Eco-points), producing 0.051 eco-points.

D5/ D6 – Option IV: Reduce cement and allow more curing time for products:

Any additional hour of curing costs around **0.8375 GJ** to **0.47 GJ** per bed – this is around **0.000374** to **0.000667 TOE/ tonne** of production, this is around **0.00101** to **0.00179** eco-points per tonne of product (which is low compared to upstream energy savings). This was calculated as follows:

This was based on the daily average energy consumption levels in two of the factories (6.7GJ and 3.76GJ); these two figures were divided by the average number of hours of curing (which is 8 hours); the resultant figures (0.8375 GJ and 0.47 GJ respectively) were converted to TOE and divided by the average tonnage production per bed – resulting in 0.000374 and 0.000667 TOE/ tonne respectively. The TOE/ eco-point conversion factor (2.69) was then used to convert to Eco-points, giving 0.00101 to 0.00179 eco-points per tonne of product.

D7 – Option I. Use of discharged water and wet (un-set) concrete residue internal recycling and reprocessing systems:

There will be environmental savings in water use reaching between **0.000548** to **0.000484** eco-points per tonne of production. Savings in wet concrete waste could reach around **0.265** to **0.3** tonnes per casting. This is around **0.00106** to **0.0018** eco-points per tonne (depending on product depths and cast bed length). Moreover, there are substantial economic savings (up to 40%) in water costs. These were calculated as following:

- The generic eco-point score for Hollowcore and prestressed beam is 0.00137 and 0.00121 eco-points respectively. Savings from the water recycling system in PFF3 reached around 40%, this means that applying the same system in other factories will make savings in water reaching 0.000548 eco-points per one tonne of Hollowcore and 0.000484 eco-points per one tonne of prestressed beam.
- The 0.265 to 0.3 tonnes per casting wet waste figures were taken from the waste survey (Figure 6.8):

1. The minimum amount (0.265 tonnes) is divided by the longest available cast bed (150 metres), this will offer an amount of 0.00176 tonnes of wet waste for each tonne of cast product. This is around 0.00106 eco-points per tonne.
2. The maximum amount (0.3 tonnes) is divided by the shortest available cast bed (100 metres), this will offer an amount of 0.003 tonnes of wet waste for each tonne of cast product. This is around 0.0018 eco-points per tonne.

- The 40% rate is based on water savings made by PFF3.

D7 – Option II. Reuse of local crushed concrete in production:

Successfully recycling and reusing hardened concrete waste content can save around **0.046** eco-points per tonne of production from waste. The calculations of other figures in 'Drawbacks' are demonstrated in D5/ D6 Options I to IV:

- Given that the amount of hardened concrete waste is around 2.5 tonnes in a 100 metre cast bed holding around 32.5 tonnes of concrete (all figures are from PFF1 information). This is around 0.0769 tonnes per one tonne of production. That figure is multiplied by 0.6 to convert into eco-points – giving 0.4614 eco-points.

D8 – Option I. Change the major production systems employed to more environmentally acceptable ones (casting system, curing fuel, internal transport machinery, etc):

Considerable savings can be made if some major production systems were replaced: savings in internal transport energy can possibly be around **38.88 MJ/ tonne**. Savings in curing energy may reach **1.3-2.94 GJ** per casting (19 to 44%), this reduction would occur if fossil fuel boiler-based systems were switched to electricity. Savings in energy due to casting can vary between **3 – 11.4%** (depending on product being cast). Moreover, there are savings in waste due to casting, reaching an average of **2.5** tonnes per casting.

- The savings in internal transport were calculated by identifying the difference between the maximum (86.31 MJ/ tonne) and minimum (47.43 MJ/ tonne) internal transport energy consumption levels in the factories considered in the study.
- The amount of energy consumed in casting in PFF1 is 6.7 GJ; the amount of energy consumed per casting in PFF2 (if the casting bed length was 100 metres) is 3.76 to 5.4 GJ (depending on waste levels in hollowcore and prestressed beams production).

Accordingly the savings in energy consumption per casting will be between 1.3 to 2.94 GJ – which is a 19 to 44% reduction.

- The calculations for the 3 – 11.4% savings in casting energy can be found in D2/D3 option I.
- The 2.5 tonnes per casting waste average was calculated during the study (see Figure 6.8).

D8 – Option II. Carry out a few changes to some of the employed systems (such as changing the length of the curing beds, or installation of a power control and bed heating control facilities for the curing):

Increasing the length of casting beds from 100m to 150m can help in reducing concrete waste (at bed ends) from **3%** to **2%** of gross production (this takes place when beds are lengthened). This was calculated as follows:

- This statement is based on a basic calculation: changing the bed length from 100 to 150 metres will increase production – but this will have no impact on waste at the ends of the casting bed: from 3.6 m^2 of 120 m^2 (3%), to 3.6 m^2 of 180m^2 (2%).

D8 – Option III. Maintain the major production systems and invest in operational and maintenance systems:

Several energy savings could be made; these can reach up to 40% for curing energy.

- This ratio was mainly based on the study findings in Section 6.4.2

D9 – Option I. Abandoning accelerated curing and leaving products to cure naturally:

Savings could possibly reach around 56% to 62% of total factory energy.

- This ratio is based on the energy breakdown findings – see Figure 6.15

D9 – Option II. Reduce timing for accelerated curing and use other means of curing (such as accelerators):

There are savings in curing energy consumption; a reduction of one hour of curing saves around **0.47 GJ** to **0.8375 GJ** per bed (this is around **0.000374** to **0.000667 TOE** per 1 tonne of production, which is around **0.00101** to **0.00179** eco-points per tonne of product).

- Curing takes 8 hours in average, therefore a one hour reduction saves around $^1/_8$ of the curing energy – the curing energy consumed in casting was identified in the study to be between 3.76 GJ and 6.7 GJ per bed. The eighth of these amounts are 0.47 GJ and 0.8375 GJ per bed (respectively).

- These energy amount are converted in TOE: 3.76 GJ = 3.76 x 0.0239 TOE
  6.7 GJ = 6.7 x 0.0239 TOE
- These amounts are converted to eco-points (multiplied by 2.69) – giving 0.00101 and 0.00179 respectively.

D9 – Option III. Development of a pre-programmed curing energy control system rather than using an ON/ OFF system:

Proper control of energy for precast can lead to reductions of 27 kW – such savings can cut electrical curing energy by **18%**. There can also be substantial economic savings exceeding **£7.73** per casting. This was calculated as follows

- The supply of electrical energy during curing is stable at 150 kW (See Figure 6.16). A reduction of 27 kW as claimed by Neilsen (2005) can offer savings reaching 18%.
- The £7.73 figure was calculated using a number of factors:
  1. As found in the study, the curing energy consumed per casting is 5.4 GJ, this is around 1230.012 KWh (5.4 x 227.78).
  2. The total cost of such amount of energy (electricity consumed in one casting) according to 2002 prices is £42.964[1].
  3. 28% saving from that cost is £7.73 per casting.

All other figures in options associated with D9 are supported by references in the thesis or calculations in preceding sections.

D10 – Options I and II

There would be savings in internal transport energy, possibly reaching around **38.88 MJ/ tonne**; this is **0.0025 eco-points/ tonne** for hollowcore and beams. These were calculated as follows:

- The calculations for savings in internal transport energy (38.88 MJ/ tonne) can be found in calculations made for D8-Option I in this Appendix.
- That figure is converted to TOE/tonne: 38.88 x 0.0000239 = 0.0009292 TOE/ tonne.
- The conversion to eco-points/ tonne: 0.0009292 x 2.69 = 0.0025 eco-points/ tonne

[1] www.dti.gov.uk/energy/inform/ energy_prices/tables/table_314.xls

Appendix L: Prompt sheet used in focus group sessions

Precast concrete manufacture and sustainability
Manufacturers' perceptions focus group
(Prompt Sheet)

Sustainability and environmental impacts List:

See Slides 9, 10

- Energy consumption at accelerated curing.
- External Transportation impacts (energy, emissions).
- Concrete waste.
- Cement content in concrete mix (CO_2 emissions).
- Energy consumption at concrete mixing, casting.
- Hazardous waste (contaminated aggregate, waste oil, etc).
- Internal transportation impacts (energy, emissions).
- Water consumption.
- Health and safety measures.
- Other energy impacts (lighting, office use, machinery, etc.)
- Concrete Waste recycling.
- Discharged water (pH levels, contamination, etc.).
- Use of recycled aggregates.

Regulations/ taxes (governmental sustainability measures) List:

See Slides 9, 10

- Aggregate tax (we don't directly pay it, but it's sometimes forwarded in Aggregate price).
- Climate Change Levy (included in energy prices).
- Chromates content in cement EU regulations (to be included in cement price).
- IPPC framework regulation (associated with EA inspections).
- Landfill Levy (concrete is excluded; however, economic impacts come through haulage contracts).
- Working time directive (to affect transportation costs).

Appendix M: Script for the Technical managers' Focus Group session

Names of the 10 members are anonymised.

Date: 25th November 2004-11-25

Start with a brief on the general concept of the study and aims/ objectives of the focus group. The first proceedings of the study (handling the first two questions) are not being included here. The proceedings start with Question NO. 3;

Proceedings:

Hafiz	What do you think about the measures employed by the government; taxes, levies and things like that, right now we don't directly pay for the aggregate levy For example. But, somehow you have to pay for it, because sometimes it is being passed through the aggregate price. So, do you think this might affect the way you do business?
Respondent 1	I believe that the tax on aggregate is the most severe action that the government has taken without necessarily justifying it.
Hafiz	So, do you think it is justified?
Respondent 1	I would question if it's justified.
Respondent 2	If everybody is paying it, does it matter?
Respondent 1	Yes. Because, it's only the concrete industry is paying it. The timber industry doesn't..
Respondent 3	Steel? Steel industry isn't paying it?
Respondent 1	Yeah... I think it's very effective that one.
Respondent 3	????[1]
Respondent 1	Yeah
	What do you think about the way the government is handling things right now; they always talk about the stick they never talk about the carrot. There is no rewards, there is no (let's say) exemptions, or benefits passed to the government.
Respondent 1	I query the way they handled that, they just imposed it.
Respondent 3	They could've given the industry an opportunity to ????. This was but forward but...
Hafiz	We can go for another question: What does sustainability mean to most of you? I mean, do you hear people talking about sustainability; do you come by it when doing your day-to-day business, does it affect you by any means.

[1] Refers to unclear and hard to detect parts of the recorded conversation.

Most respondents	NO
Respondent 4	We tend to read about it normally in articles, but no one has been involved in working on what to do about sustainable construction.
Hafiz	Which are the things that you think might be the most vital or important on sustainable development (please look at the prompt sheet).
Respondent 5	I'd think the cost of transport is one of the huge effects (cost of diesels for truck drivers). Precast concrete in particular.
Hafiz	What about concrete waste for example, do you think you produce lots of waste, or?
Respondent 6	I know we do, We're trying to get huge efforts to cut it down. That's justified.
Respondent 7	I think we all do, don't we; there is no point in making it and throwing it away.
Hafiz	Unfortunately, I don't have figures with me right now, but I can show you that the LCA study shows that the amount of concrete waste can be considerable. Because most of you sometimes go for customisation of products, you happen to have portions being cut out to meet the specifications of the design. So, this amount of waste is not usually being considered by manufacturers as waste. However, this amount is considerable as it might reach 70-60% of the total concrete waste. It does have an impact and I think that many manufacturers should consider this issue
Respondent 7	It comes back to building design, doesn't it though? Obviously, if we're making a 1200 wide unit, and the people designing the building don't use that as a module, we will keep cutting these bits and throwing it away. You can't keep stacking the bits you've got left. So, it depends on the designers to come up with a sensible design so we can get most of what we make.
Hafiz	This is right, but it also depends on the way you do business either manufacturing per stock or per order. But it also comes to the way products are being manufactured, because I found out that manufacturers using wet casting, they happen to have less waste than those using extrusion or slipform. So, there are lots of things ???? ???? ????. So if we can go to the next group of questions. These five: When we talk about sustainability; when we talk about energy consumption, and such things, what do you think are the things that would move or urge your organisation to seek sustainability? Is it just to comply with the regulations, or thinking about doing the right things, or the image of your organisation? Or...
Respondent 4	I think regulations and levies is the high driver, isn't it?
Respondent 8	It's never discussed that we'd reduce climate level because of sustainability; it's because of regulation, this is it, that's the main driving force.

Respondent 1	So is profitability.
	Agreement by other respondents
Respondent 4	There is also something about things like the chromate and cement; we're only driven to do it because of regulations.
	Agreement by other respondents
Hafiz	What about the other ones; like doing the right thing or...
	Laughs by most respondents!!
Hafiz	Or using it as a marketing tool and a competitive advantage that might help you in competing with others in the sector or others in the timber or steel sectors. Do think that sustainable development or being sustainable might help you in winning bids or...
Respondent	It doesn't have an effect at all. Not at all, it's all about leading in prices, availability of price.
	(agreement by other respondents)
Respondent 9	Indeed, looking at the prompt sheet, all these things we do because it makes sense and makes it cheaper for us. Not because we want to be sustainable.
Respondent 3	Even when the timber industry make such a fuss about how green they think they are; ???? for good campaign
Respondent 4	At the end of the day, what will win an order for concrete floor, it is price delivery not whether companies got their parts sustainable or...
Respondent 7	It is not as quite as though, By the time the floors come along, they would've decided whether it's a timber floor or a concrete floor, and we're...err... competing with timber further down the line; whether its your concrete floor or someone's else's concrete floor that's price and delivery. But whether it's concrete or timber, I don't think ?????? is complacent to do it.
Respondent 4	When the engineer specifies the ... what he wants; the floor to start with...
Respondent 7	Yeah, I don't think ???? price ????
Respondent 4	No I think, we'll only be up against the timber in housing market, aren't we? I don't really know what sort of building concept they want us... sort of sustainable construction whether it's houses or office, industrial, commercial.
Hafiz	It's houses mostly, because people usually spend 50 or 60% of their time in houses. So, I'm quite sure that 80-90% of your production usually goes for housing projects. ???? an organic product, and timber manufacture is being sustainable because it doesn't cost that much energy to provide a timber flooring, so did this at any time affect the way you do business, or do you think this might at any time affect your business in the future, your market.
Respondent 8	Maybe, it will become more important when sustainable is on, but at the moment, what is only important is client driven ???? ???? criteria.

Hafiz Yes, customers' focus.

Respondent 9 If there was a need for a BREAAM certificate for their property, like in the gherkin (Norman Foster's). That's were they get that BREAAM certificate saying that they're complying with ... whatever!! That's a statement for them; for their reputation, but for us we have to comply with what they want, that decision is made way down the line before we even get involved in it.

Hafiz OK! What about the last one; number 10.

Respondent I'm not quite sure.

Respondent We're not getting any pressure from the client, only specifiers

Hafiz Is there any pressure from your employer or shareholders, to be more sustainable, to do something that might boost or enhance that competitive advantage?

Respondent 8 I think there is certainly a marketing advantage there, quite aware of how it affects xxxxxx. But certainly as far as public xxx.

Hafiz Ok, I think we should go for the next obstacles, these are more into the technical side; things like lack of expertise or investment in research and development on alternatives for cement... We do have some few examples.... I think you know about the last EU court rule regarding the use PFA (being considered waste) which means you can't use it in your production as a replacement for cement. Number 13 is we have discussed this from a different view. Number 14 ????, regarding transport systems, during the last LCA work I found out that between 5 to 20% sometimes even 30% of the CO_2 emissions are due to transportation. Raw material transportation and deliveries transportation don't have a great impact on entire environmental profile; however, it does have an impact on the EPDs for example. So, it might be some kind of a challenge. No 15 is about the amount of work that you do, it might mean that there is no chance for proper planning or proper implementation of ????. The last thing of course is about customisation, impacts associated with customisation such as waste ????.

Respondent 4 This question; lack of environmental policies and strategies is that from the government or within our own firm

Hafiz Within your own firm, it is possible that most of the sites still don't have, let's say, ISO 14001 or they may have. But, we're still in the learning curve to develop and implement. Do you think we might still need some guidance regarding this?

Respondent ????

Hafiz That's right, yes.

Respondent You may have this policy on a board and say we are that and that, but having ISO 14001, does this make a difference to the company? I don't know, does anyone else have ISO 14001?

Respondent 4 Yeah we have

Respondent Does it make a difference to you?

Respondent 4 Yes, a lot more things have to be monitored, recorded, and reported. It didn't change the concrete at the end of the day...

Respondent ? Didn't change the products

Respondent ?? There should be a guy in charge of it?

Respondent Somebody is monitoring it as part of their job

Respondent 4 Yeah

Respondent You have that, so more is expected from that work.

Respondent 8 Did it affect your profitability? Did you have more sales because you have that ISO 14001 stamp

Respondent 4 ... No! When you fill these questionnaires to become approved supplier to people, it's no more than a tick in a box: Are you an approved ISO 14000 supplier (yes or no); if yes; miss out, questions 1 to 37! If no supply all this and that.

Respondent x Is it perceived as another trough that needs to be done in terms of complying with, and therefore you will have to implement X, Y, and Z, that you wouldn't do normally, but because you have to maintain the level.

Respondent 4 No none of it, ????? the things in this first prompt sheet, you look at your consumption, heating, waste

Respondent X But do you think that is being looked at on day to day ???? it's a benefit, people would go: oh... let's go and look into this, oh ???? is ????, let's go and look into that; fill like these 6 pages.

Respondent 4 No... I don't know. Luckily, I don't have to do this: go and fill in, checking, and monitoring...

Respondent Monitoring and doing something with it... You don't say ??? do that, you need to do something with it. Or ???? because you have to. Then it becomes a choice ???? ????.

(Agreement by most respondents)

(Respondent 4 thinking of a response!!)

Respondent (Addressing respondent 4) you need to think about this.

Hafiz Do any of the manufacturers have experience in using alternative material? Many of these materials, like fly ash, might have fewer prices than cement. Did any of the manufacturers thought of that?

Respondent It depends on what flooring product you're talking about, for some of our stuff we do, but not with things like hollowcore. But other precast we do we use fly ash. It's the suitability of using it in the particular product.

Respondent 4 We use PFA in hollowcore.

Respondent There was a report in Concrete magazine about using recycled glass in concrete, different direction.

(Agreement by other respondets)

Hafiz Do you think that these things being done; studies being done; do you think that these technologies are being implemented? Should

	more research be put into these issues?
	We know that fly ash has been there for decades but the use of fly ash is still limited. The same thing for other alternatives.
Respondent 4	I think the use of fly ash is actually widespread;
Hafiz	It is widespread, but there isn't enough research put into the limitations of fly ash for example.
Respondent 4	I think there is, I always get info from suppliers of those materials.
Hafiz	Ok, I think we can skip number 13 and work on No 15:
	Transport systems might be more into logistics, but, do think that it is justified to, say, modify your transportation systems in order to meet cost needs or sustainability needs.
Respondent 1	To modify it?
Hafiz	Yes, other than using a mobile plant, you use a crane or other form; do you think that such great move would be justified.
Respondent 1	I think we're all trying to be as efficient as we can, but I don't think that anyone will go for a sudden change.
Respondent 4	I think we might end up looking at the best way now for a change.
Respondent 1	Best way available at the moment, Yeah
Hafiz	When you choose your suppliers, do you look at the distances for example;
Respondent ?	Yes we do
Respondent 1	You consider it by looking at the price, don't you
Respondent ?	No, in the main we say we don't want to go further than 100 miles from our factory.
Respondent 1	From the supplier, of the raw material.
Respondent ?	Yes, but we must use limestone and that comes by train.
Hafiz	Ok! So, what about number 15, do you think that the work intensity might affect planning and implementation of sustainability.
Respondent 9	I think we plan to be as efficient as possible, but we're being fed by a supply chain that have problem inherent and consistent, we're sometimes being fed the wrong information. So there is an issue here of reducing waste because the information we've got at the time. It depends on where you are in the supply chain.
Hafiz	Yes, other parts of the supply chain should be affected as well.
	These are all the questions, the last one is again about customisation; do you thing there might, somehow, consider the way you produce to minimise waste
Respondent 4	It is being considered on a day-to-day basis, it is not something that we would consider as an obstacle, it is more as a challenge.
Respondent	It might apply for concrete product rather than flooring, isn't it? You will definitely say, you know, if we go for customisation, that's a far big option.

Respondent You're right to some extent, it comes down to cost, doesn't it? We might look at a very complicated shape building, and we would say we will put all these bits in hollowcore, but all these awkward shapes will make in precast, because we've got factories side by side. Rather than cutting hollowcore to fit these awkward shapes. But as far as it goes, people design horrible shape buildings.

This is a big problem! We've got a rectangular product, and they come with splays and circular base, do they know what they're doing.

Respondent 8 There might be an impact from shapes of sites and the lack of building space these days; this might increase I suspect.

Hafiz There was something about the Egan Report 6 years ago; it recommends standardisation to save on waste and cost. It is sad that none of this is being followed

Respondent But people don't want to see rectangular buildings anymore they want to see nice buildings, curved buildings. So, that's an issue isn't it?

Hafiz Such things are being pursued, I mean mixing between standardisation and customisation, I think the Japanese has been working on this for a number of years, in housing, you'll find that every single house is different, however, you will find that all the components are similar, it's just put in a different way, so they are able to keep their economies of scale (mass production) and at the same time maintain customisation ?????.

So, that's it gentlemen, thank you for your help and thanks for the opportunity.

(The Focus Group concluded)

2. Perception of threats to the environment

Although all respondents agree about the importance of sustainability, views on the nature of the environmental threat are very different. For this question, 20% of respondents believed that threats to the environment are exaggerated. Moreover, between 30 – 50% of included groups (40% in all) provided what can be considered as a politically correct answer: *I don't know*. No more than 40% (in all) believe that there is an actual unexaggerated threat to the environment.

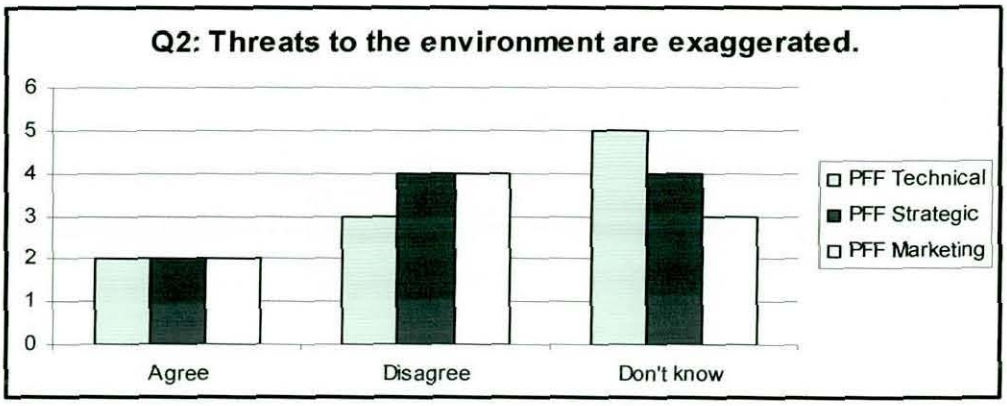


Figure 2. Responses to Q2: Threats to the environment.

Only 3 to 4 members in each session group (36.67%) believed that environmental threat is not an exaggeration. Although many sustainability issues have been the subject of high-profile public news for more than a decade, respondents still have doubts about the entire issue. Taken at face value, this could have a catastrophic effect on the entire research approach, however this result should be read in conjunction with all other results received, in sections 3 to 9

3. Perceptions of government sustainability measures (I)

Regarding the question exploring levels of satisfaction with sustainability measures imposed by the government (see focus group prompt sheet in Appendix K), group answers were surprisingly different. Figure 3 below shows a worrying contradiction between answers from strategic managers on one side, and technical/ financial managers on the other. On the other hand, the numbers of those who genuinely '*Don't know*' or who are reluctant to offer an answer is much higher in the financial/ marketing managers' group than the other two groups combined. Reading these results in conjunction with other qualitative information (in section 7.2 in Chapter Seven) yields important findings in this regard.

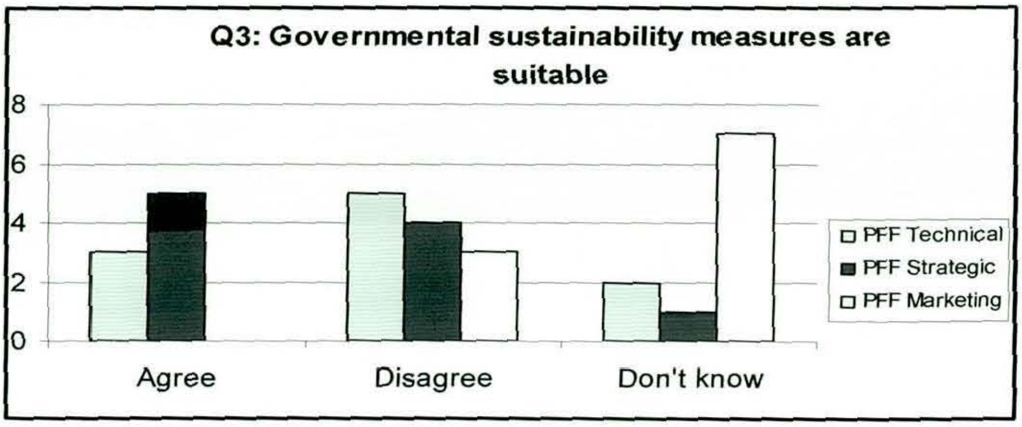


Figure 3 Responses to Q3: Suitability of governmental sustainability measures.

4. Perceptions of government sustainability measures (II)

This question was used only during the strategic and technical managers' focus groups. The question was designed to measure the level of possible frustration with the different measures (levies, taxes, and regulations) imposed. Strategic managers were far more aware of the full financial and practical impacts of governmental measures, and this should be considered when these results are read. During the discussion of this question, the respondents were mainly concentrating on the Aggregate Levy. The results show clearly the level of frustration with the way in which the Levy was introduced and implemented.

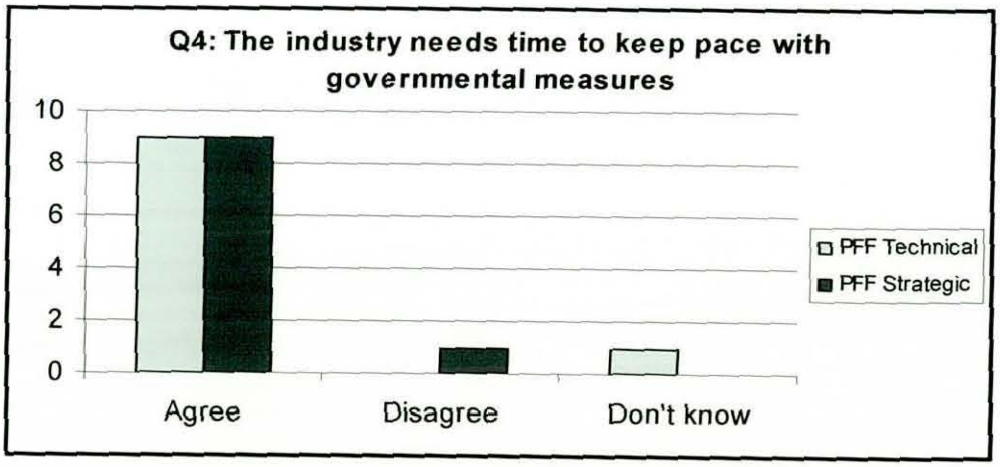


Figure 4. Responses to Q4: Time for the industry to get up to speed with governmental regulations (first and second sessions).

5. Perceptions of government sustainability measures (III)

Unlike the preceding question, this question is more straightforward: six to seven of the strategic and technical managers felt that the use of taxation was harmful to business.

When reading these results in conjunction with sections 3 and 4, an error in completing the survey can be found: in the replies from at least two members in the strategic committee and one member at the technical committee. However, when comparing this to qualitative replies from respondents, it is quite possible that respondents were trying to make a point; one respondent justified this by noting that: '*we don't do something unless we're kicked*'.

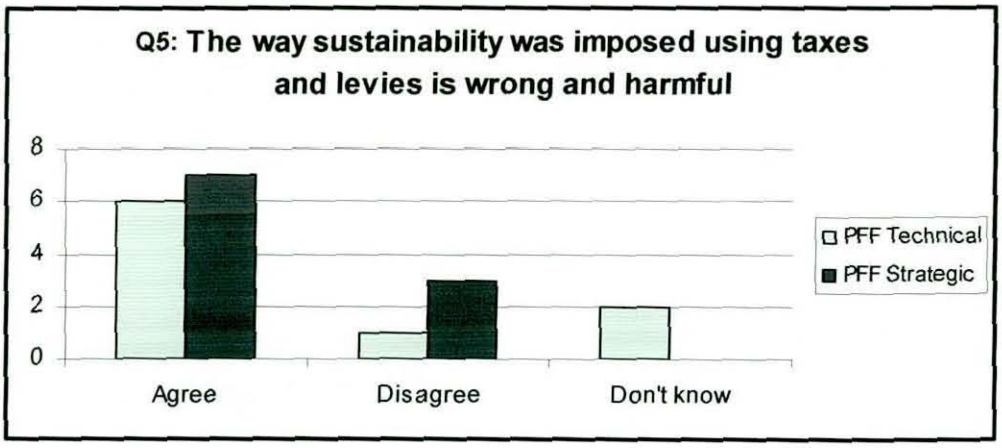


Figure 5. Responses to Q5: View on the way sustainability was imposed.

Delegates in the third focus group (financial and marketing managers) were not asked this question.

6. Push/ pull factors: Regulations and associated levies[1]

Results for this question show an interesting twist; whilst technical managers, including those supposedly not directly associated with financial gain and loss issues, suggest that sustainable development is mainly about regulations and associated levies (all respondents offering *high* votes), strategic managers offer a more moderate opinion. However, the views of financial and marketing managers were surprising (offering the most modest and idealistic vote). See Appendix D for more information on the questions asked.

[1] Two different approaches were used in the focus group sessions. The first two sessions included no more than five categories of push/ pull factors, whereas in the third session ten detailed push/ pull factors were included. See Appendix D.

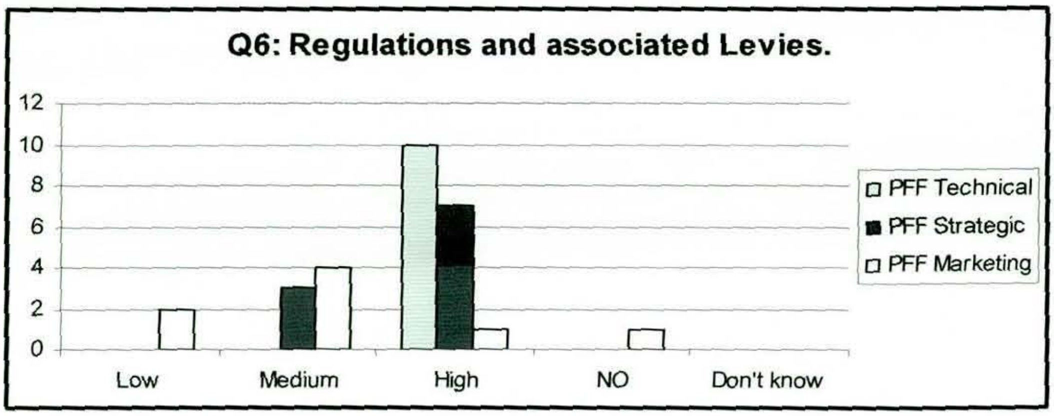


Figure 6. Responses to Q6: Regulations as a driver for sustainability – Technical and strategic managers sessions (Q5 in marketing managers' session).

This result can be interpreted further when considering votes provided by marketing and Financial managers on other issues such as the Aggregates Levy and the cost burden question (Figure 6). They addressed the Aggregates Levy separately, concentrating on its cost.

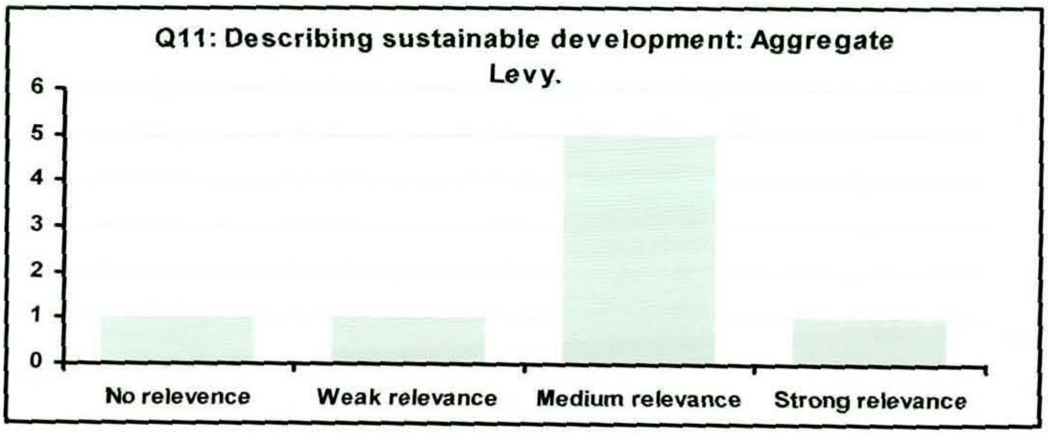


Figure 7. Responses to Q11 (marketing managers Session): Aggregates Levy as a sustainability driver.

7. Push/ pull factors: 'Doing the right thing' (moral obligations)

It should be noted that results from the moral obligation and social responsibility question were affected by the desire of some respondents to offer politically correct answers. Results show a more conventional profit-based approach on behalf of the technical managers, followed by strategic managers, and then marketing managers (see Appendix D).

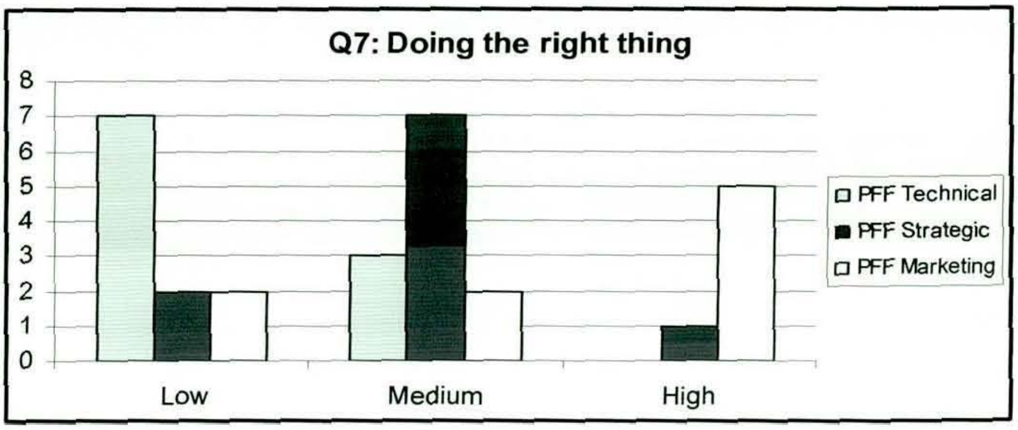


Figure 8. Responses to Q7: 'Doing the right thing' as a driver for sustainability – Technical and strategic managers' sessions (Q13 in marketing managers session).

The fact that the final session (marketing and financial managers) was carried out two weeks prior to the *Live-8* international concerts and the Gleneagles *G8* summit events (in summer 2005) might have had some influence on respondents' opinions.

8. Push/ pull factors: Marketing, corporate image and customer focus

Results from the technical and strategic managers' sessions show considerable differences. While technical managers don't see any potential in sustainability (from their points of view), strategic managers tend to see more potential.

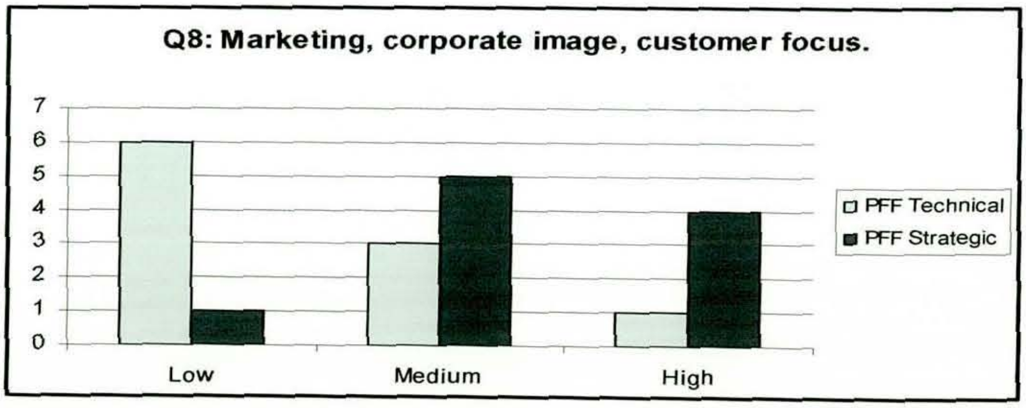


Figure 9. Responses to Q8: Marketing, corporate image, customer focus as drivers for sustainability (strategic and technical managers' sessions).

Indeed, this is a vision which is shared by marketing and financial managers. Their results show that the potential for corporate image improvement is higher than that for customers' needs (questions 9 and 12 in marketing managers' session). This is also supported by qualitative results demonstrated in Section 7.2 (Chapter Seven). However, 50% of the marketing managers offer *Weak* or *No relevance* to customers' needs. This might offer some insight on the influence of external factors (such as customers) on the adaptability to sustainability solutions (Figure 9).

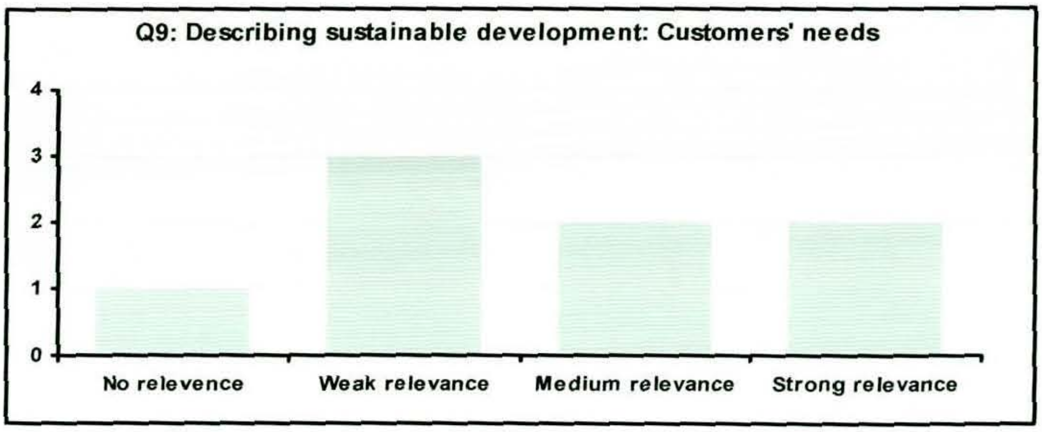


Figure 10 Responses to Q9: Customers' needs as a sustainability driver (marketing managers' session).

9. Push/ pull factors: Potential competitive advantage

Results from the three groups offer different levels of optimism, with strategic managers as the most optimistic, followed by marketing, and then technical managers. However, in total, 10 respondents believed that the potential for competitive advantage is *high*, 10 respondents believed that the potential is *medium*, while eight (none of whom was a strategic manager) believe that the potential is *low*. The general scepticism in answers offered by technical managers was investigated in a question directed during the strategic managers' focus group. More details are presented in Section 7.2 (Chapter Seven).

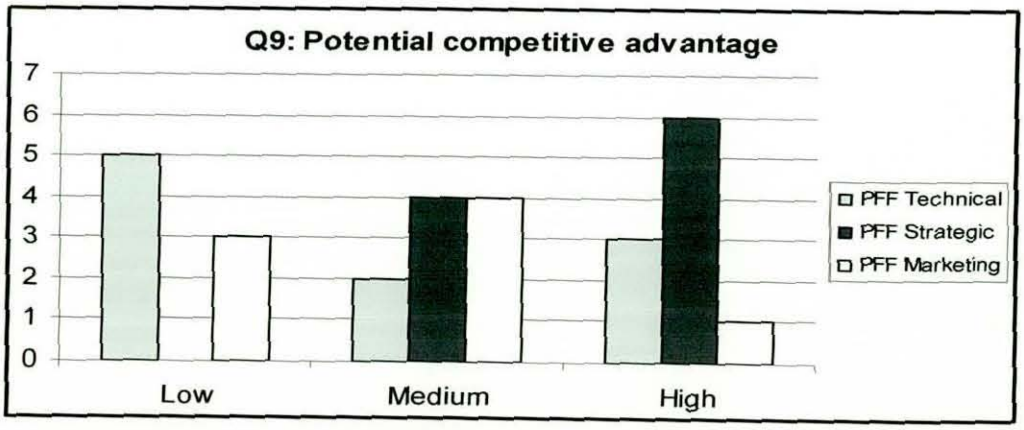


Figure 11. Responses to Q9: perceptions on sustainability as a competitive advantage.

10. Push/ pull factors: Lack of strongly convincing factors

The result of this question is slightly harder to interpret; results from strategic managers provide a more confusing, yet more optimistic, response than technical managers.

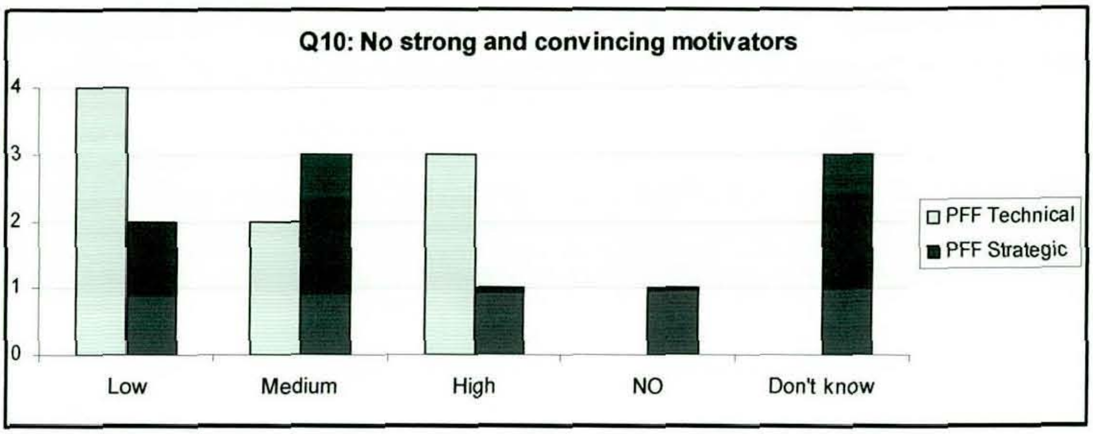


Figure 12. Responses to Q10: negative perceptions of manufacturers on sustainability (Technical and strategic managers' sessions).

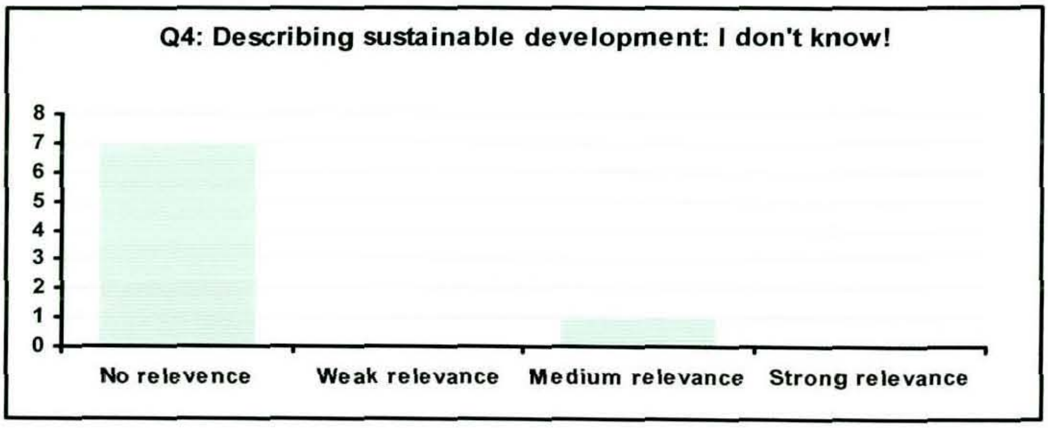


Figure 13. Responses to Q4: knowledge on sustainability (marketing managers' session).

However, responses from the marketing/ financial managers' focus groups were more comprehensive, with precise impressions on what they felt about sustainability.

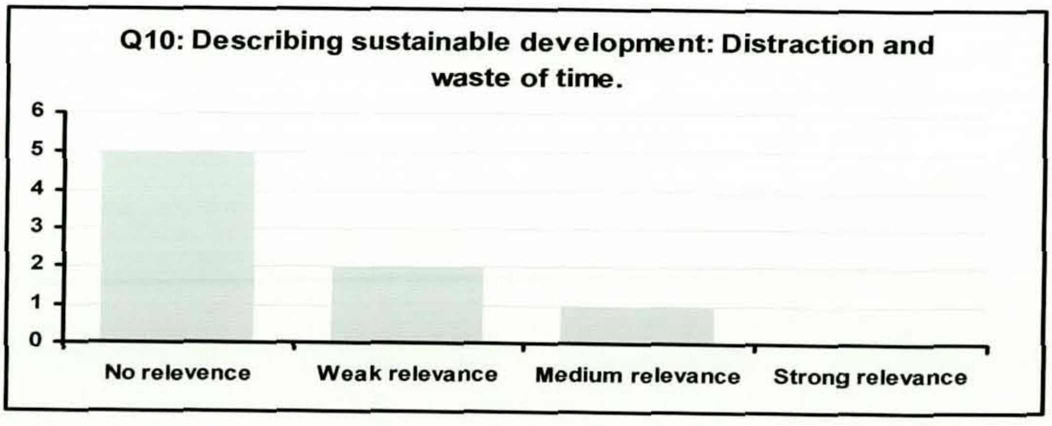


Figure 14. Responses to Q10: Perception of impact of sustainability on business (marketing managers' session).

Unlike strategic managers, only one marketing manager admitted a lack of knowledge of sustainability. Although marketing managers (in general) believed that the issue is not a waste of time, most of them admit that there is a cost burden involved.

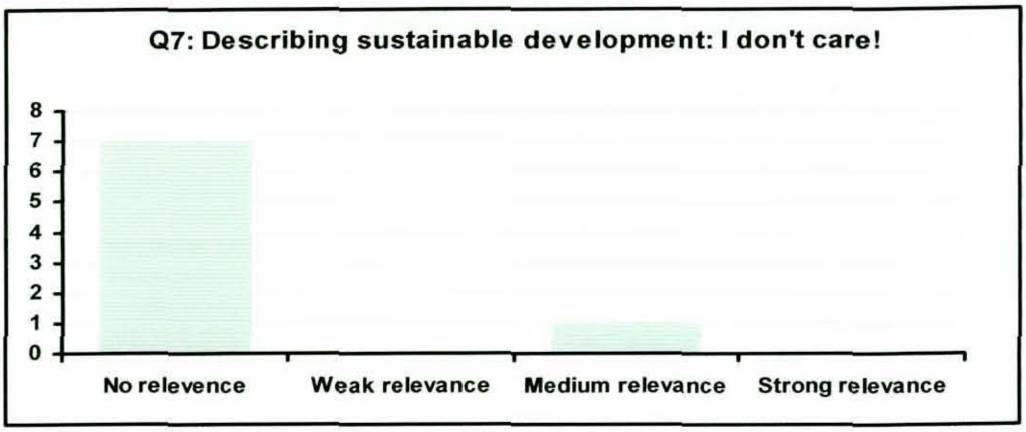


Figure 15. Responses to Q7: care and interest in sustainability issues (marketing managers' session).

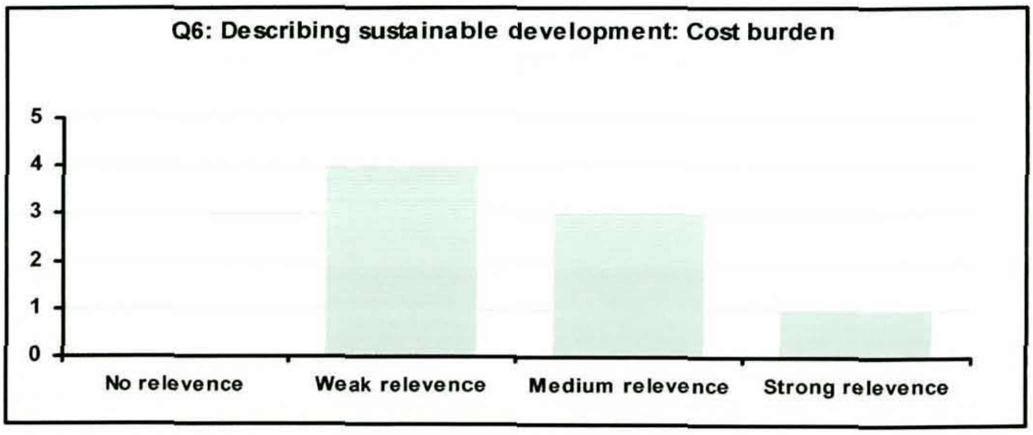


Figure 16. Responses to Q6: perceptions of sustainability as a cost burden (marketing managers' session).

11. Obstacles: Lack of environmental policies and strategies

The results from technical managers show more confusion than the results received from strategic managers. Within the technical focus group, three respondents believed that lack of strategies and policies in the sector had a *low* impact on the individual environmental performances of manufacturers, another four offered a *medium* rate answer, and another three believed that this was a major influence on organisations' environmental performance.

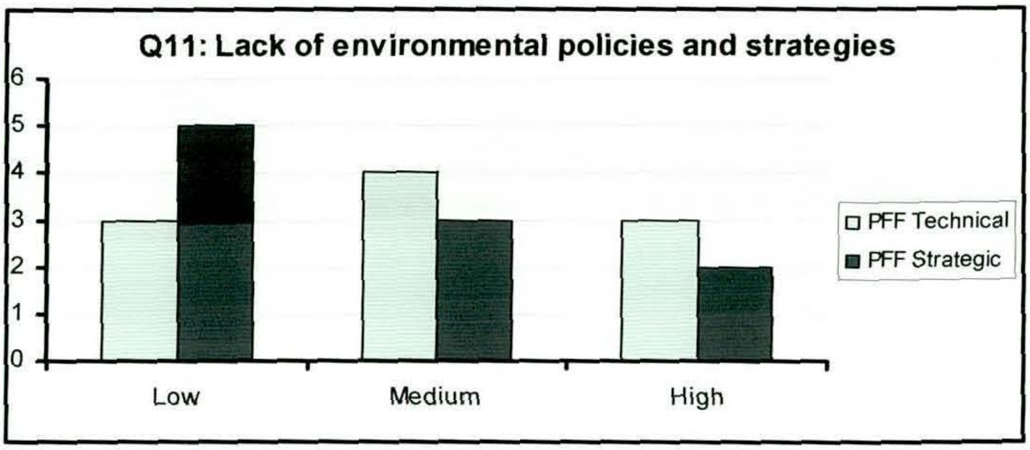


Figure 17. Responses to Q10: perceptions of sustainability policies' influence (strategic and technical managers' sessions).

Results from strategic managers were more consistent, with a tendency to disagree that the lack of sector-based policies and strategies can considerably influence individual companies' environmental performance.

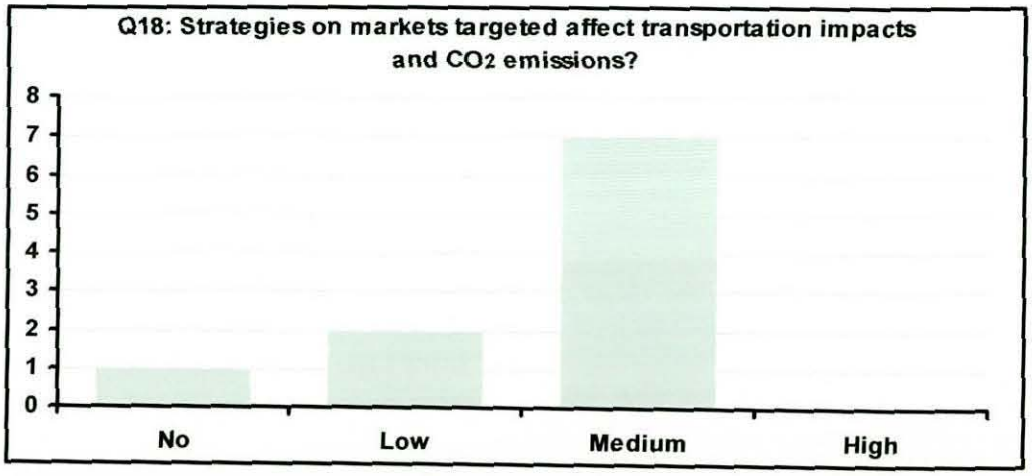


Figure 18. Responses to Q18: perceptions of marketing strategies' influence on transportation impacts and CO_2 emissions (marketing managers' session).

This question was not included in the third focus group, but a similar strategy based question was included. This question is related to a totally different type of strategy: marketing strategy employed in markets and used by manufacturers in directing production. These strategies obviously affect product shapes (Housing, Offices, etc.) and regional markets to be targeted, most focus group respondents agree with this view (7-9 out of 10).

12. Obstacles: Lack of expertise and investment on recycling

This question/suggestion was rejected by some of the delegates during the technical managers' focus group; the answers provided by the technical and strategic focus groups to the question are still confused in the survey. In the third focus group, the question was amended to address supply chain issues. Replies from the marketing managers showed that they believed it is not the most urgent, challenging problem, with half the panel rating it as a *medium* level threat and only one respondent rating it as *high*.

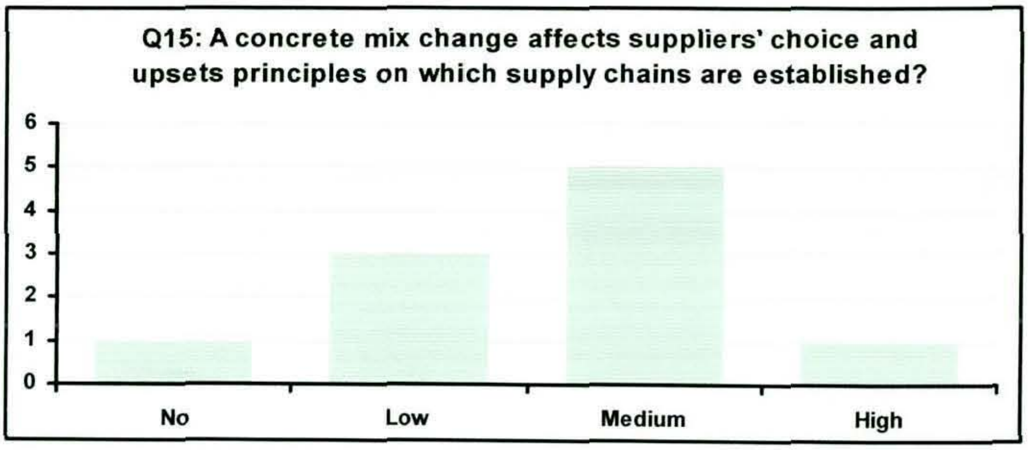


Figure 19. Responses to Q15: perceptions of concrete mix and effect on supply chain (marketing managers' session).

More useful qualitative information was received from the debates taking place in the focus groups (see Section 7.2 in Chapter Seven).

13. Obstacles: Difficulties in selling sustainability

The same pattern of optimism (and political correctness) is found in answers provided in this question. While strategic managers are less confident about selling sustainability compared to other flooring sectors, technical managers offer a slightly brighter view into their products' sustainability; this can be understood further when more qualitative information is presented in analysis. Surprisingly, marketing managers offered the most optimistic view regarding competition with other flooring products. This contradicts their answers in section 8.

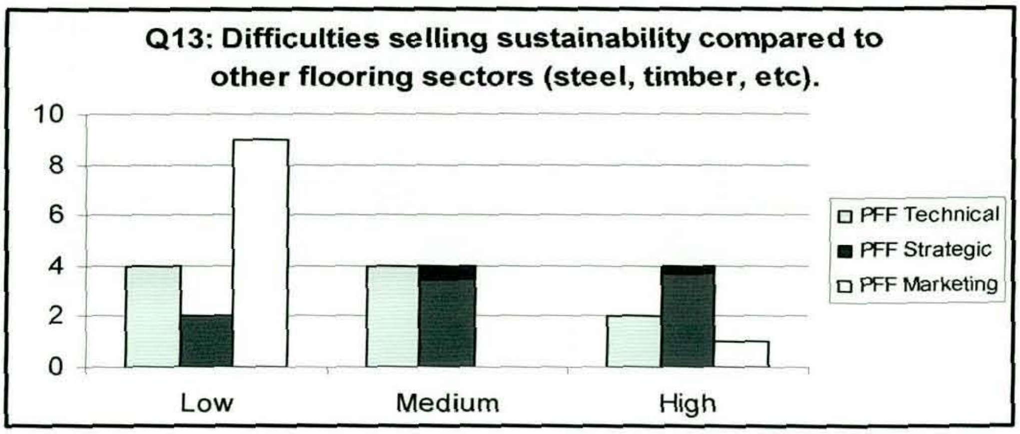


Figure 20. Responses to Q13: perceptions of competition prospects.

14. Obstacles: Internal and external transport systems monitoring

Responses on the issue of internal and external transport were collected for one group only (technical managers). Results showed most respondents (8 out of 10) classified this as a *low* to *medium* level obstacle.

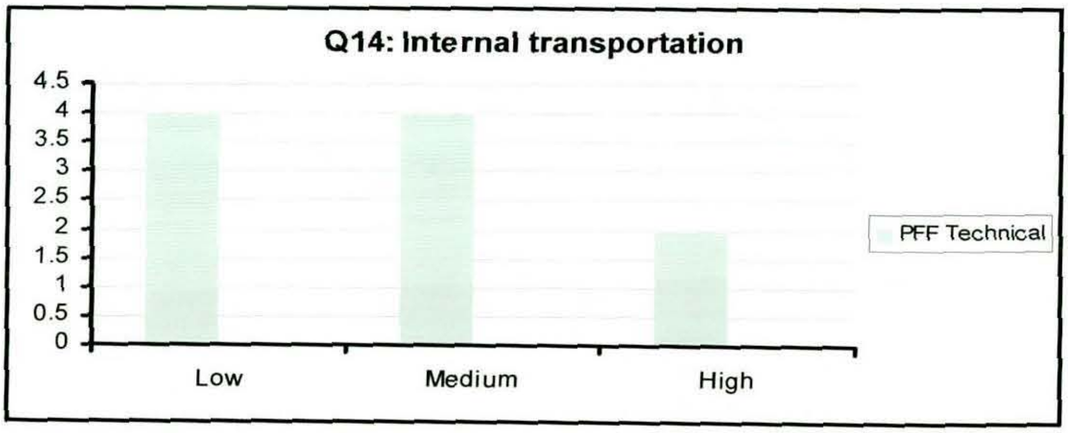


Figure 21. Responses to Q14: perception of internal transport challenges (technical managers' session).

It should be noted that these results should also be read and interpreted in conjunction with results in Figure 18 where the transportation issue was raised for marketing/ financial managers.

15. Obstacles: organisation of works and orders

This question was presented in two different ways in the three focus groups carried out. However, discussions in the three focus groups were used on the same principle of linking energy impacts to works and orders organisation. Results from the first two focus groups (technical and strategic managers' groups) show technical managers' acknowledgement of the magnitude of orders and works organisation on sustainability criteria with 9 out of 10 respondents rating it as a *medium* to *high* threat. However, this is met by denial from the strategic management group with 6 out of 10 respondents taking it as a *low* to *no threat*.

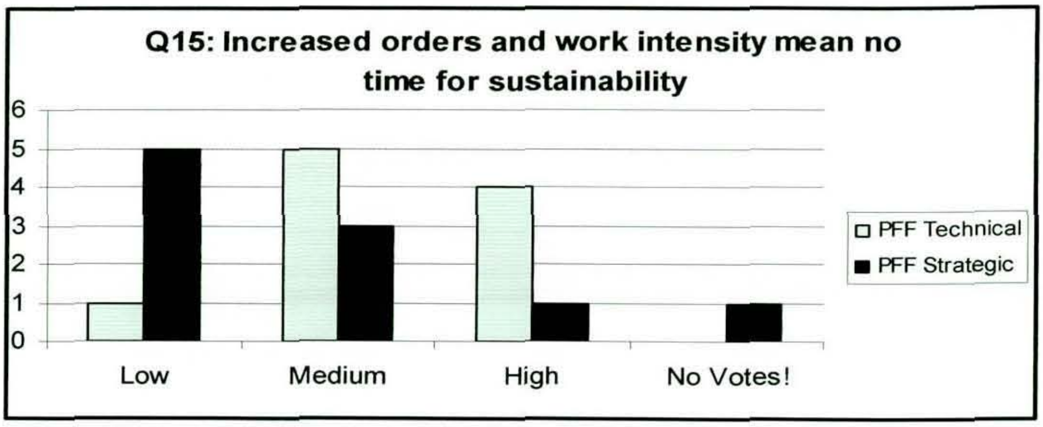


Figure 22. Responses to Q15: perceptions of work intensity and orders (technical and strategic managers' sessions).

It is very hard to identify a possible reason for these results. The question in the third focus group was changed slightly to exclusively investigate the flow of orders to the shop-floor level and its impact on environmental performance (notably energy consumption). Respondents clearly identified the impact of some flow-associated issues (such as economies of scale). However, they still believed it was not the most urgent and challenging problem, with only one respondent rating it as *high*.

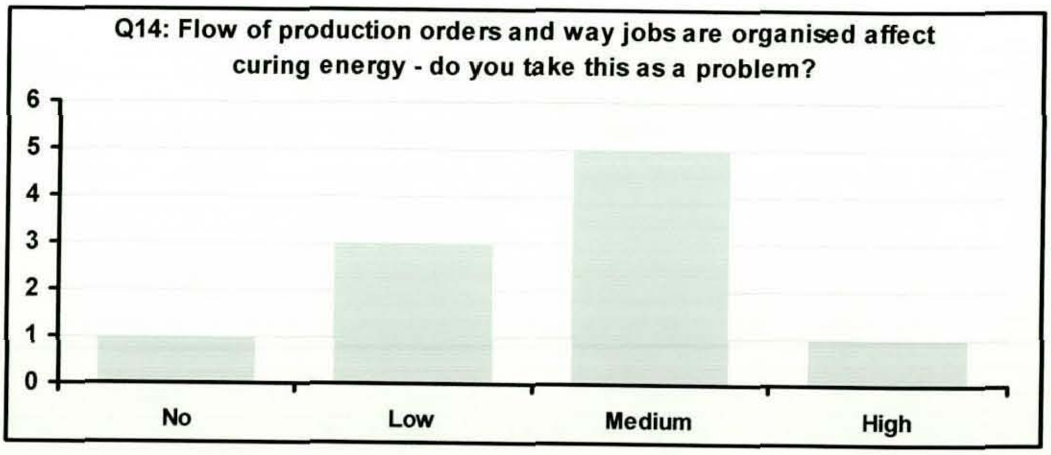


Figure 23. Responses to Q14: perceptions of flow of orders as a challenge (marketing managers' session).

16. Obstacles: Customisation and generation of waste

In each of the first two focus groups, there was an obvious split in votes, with 4 to 5 respondents in each group rating customisation as a *low* risk challenge, 3 to 4 respondents rating it as a *high* risk, and 1 to 2 respondents in the each focus group taking it as *medium* risk issue. Marketing managers classified customisation impacts as a *low* to *medium* risk issue; none of the marketing managers classified this challenge as a *high* risk issue.

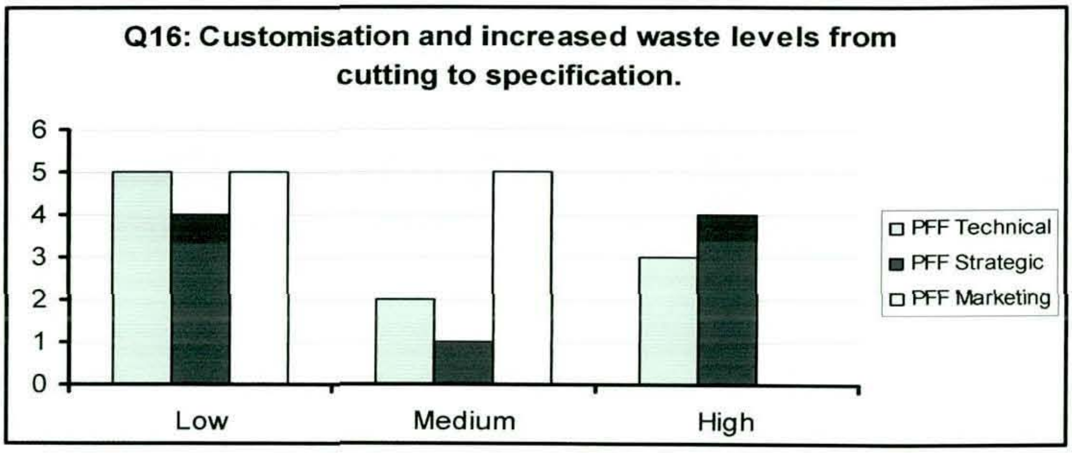


Figure 24. Responses to Q16: perceptions of customisation activities as an obstacle

This clearly demonstrates the strong views of manufacturers on one of the main strategic profit-achieving measures implemented by their organisations. Earlier contacts with manufacturers (during the LCA study) showed the importance of offering product customisation. It is not clear whether manufacturers are prepared to cross over this critical red line area to improve their sustainability or environmental credentials. Unfortunately, the focus groups' results do not explore whether manufacturers are willing to customise less wastefully. This is discussed in more detail in Chapter Eight (Sections 8.2.2.2 and 8.3.2).

Appendix P: Ratings for the environmental solutions developed

	Environmental Solution/ option	Doable	Likely	Never
D1: Supply chain structure and suppliers choice for manufacturer				
D1/I	Maintain supply chain choice impacts and concentrate on means of transport (more efficient vehicles, use of rail, etc.)	66.6%	-	33.3%
D1/II	Consider sourcing distance as a factor in choosing suppliers and jobs to be taken	66.6%	-	33.3%
D1/III	Use more energy efficient raw materials' transport trucks.	66.6%	-	33.3%
D1/IV	Ignore impacts from transportation and concentrate efforts on something else.	25%	75%	-
D2: Product depths manufactured by the factory/ D3: Levels of customisation of products				
D2(DA3) /I	Replace the used concrete cast system	37.5%	50%	12.5%
D2(DA3)/II	Tackle customisation impacts through reuse and recycling of sawed/ discarded portions	37.5%	62.5%	-
D2(DA3)/III	Maintain customised waste. Instead work on increasing production per energy consumed.	62.5%	25%	12.5%
D2(DA3)/IV	Ignore problem and invest in other energy saving activities	12.5%	12.5%	75%
D4: Size and flow of jobs/ orders coming to the shop-floor				
D4/I	Consider production per stock to maintain stable flow in production	37.5%	12.5%	50%
D4/II	Modify the way jobs are set and organised (such as: never to cast products with less than the full length of the bed).	75%	25%	-
D4/III	Additional tasks for managers to work with shop-floor in reorganising orders to enable productive flow	50%	50%	-
D4/IV	Allowing for more production control through increase of orders' lead-times	18.8%	43.8%	37%
D4/V	Ignore the problem and pass it on to the shop-floor personnel	-	-	100%
D5: Cement content within products' concrete mix/ D6: Accelerating hardening and curing through changes to product's content.				
D5(D6)/I	Reduce cement content and use a partial replacement by-product (PFA, GGBS, other).	66.6%	33.3%	-
D5(D6)/II	Reduce cement content and increase fined-lime levels in the mix.	33.3%	66.6%	-
D5(DA6)/III	Reduce cement content and use plasticizers/ accelerators	33.3%	66.6%	-
D5(D6)/IV	Reduce cement and let cast products take more curing time.	-	33.3%	66.6%

Table 1. Ratings for the 29 solutions presented to the main decision makers in the industry (%).

	Environmental Solution/ option	Doable	Likely	Never
D7: Reuse and recycling of materials and products				
D7/I	Use of discharged water and concrete residue internal recycling and reprocessing systems.	66.6%	33.3%	-
D7/II	Reuse of local crushed concrete in production.	100%	-	-
D8: Type of production systems employed				
D8/I	Change the major production systems employed to more environmentally acceptable ones (casting, curing, etc.)	50%	33.3%	16.7%
D8/II	Carry out few changes to some of the employed systems	33.3%	66.7%	-
D8/III	Maintain the major production systems and invest in operational and maintenance systems.	50%	50%	-
D9: Operation of curing beds, concrete bullets, gantry systems, and internal transport plants.				
D9/I	Abandoning accelerated curing and leaving products to cure naturally	-	-	100%
D9/II	Reduce timing for accelerated curing and use other means of curing (such as accelerators) – to be checked with technical managers' replies	50%	50%	-
D9/III	Development of a standardised curing energy control system rather than using an ON/ OFF system	25%	75%	-
D9/IV	Only heat beds with casts. Keep beds unheated when not used.	25%	50%	25%
D9/V	Use advanced heat insulation (covering blankets system, etc).	50%	50%	-
D10: The layout of the factory				
D10/I	Modify the layout of the factory to bring stockyards and production halls much closer.	50%	-	50%
D10/II	Use of more energy efficient and flexible internal transport systems (combination of cranes and forklifts).	50%	50%	-

Table 2. Ratings for the 29 solutions presented to the main decision-makers in the industry (%).

References

- **Ackoff**, R. L. (1981) *Creating the Corporate Future*. Wiley, New York, 1981 (cited by Hicks, 1991)
- **Adair**, J (1985) *Management Decision Making*. Gower Publishing Ltd, UK.
- **Addtek** (2000) *the Addtek 2000 Environmental Report*. Published by Addtek (Consolis Ltd.). World-wide web address: http://www.consolis.com/easydata/customers/consolis/files/Annualreports/AnnualReport2001.pdf
- **Adebahr**, S (1995) *Stoff- und Energiebilanzen für Konstruktionsholz*, Diplomarbeit an der Universität Hamburg, Fachbereich Biologie.
- **Aggregate Industries Plc** (2006) *Business Overview* [online]. Worldwide Web: http://www.aggregate.com/group/index.html?./Business_Overview/index.shtml&2
- **Aggregate Industries Plc** (2001) *Annual Report 2001*. Copyright © Aggregate Industries Plc. Markfield, Leicestershire – UK.
- **Alexander**, S.; Skjelle, A.; Suikka, A.; Vamberski, J. (2003) *Environmental Issues in Prefabrication* ; State-of-art report prepared by Task Group 3.1 (Ninth Draft), FIB.
- **Alexander**, S. (1998) Precast concrete manufacture seen from an ecological point of view. *Betonwerk + Fertigteil + Technik*, Vol.64, No.3, March. Pp 105-112.
- **Anderson**, J; **Edwards**, S (2000) *Addendum to BRE Methodology for Environmental Profiles of Construction Materials, Components and Buildings*. DETR Framework Project: Support for Government Policies on Sustainable Development. © Building Research Establishment Ltd 2000.
- **Anderson**, N. (1992) 'Work group innovation: a state of the art review', in D.M. **Hosking** and N. Anderson (eds), *Organisational Change and Innovation: Psycological Perspectives and Practices in Europe*. London: Routledge. Pp. 149-60.
- **Anderson**, J; Shiers, DE; Sinclair, M. (2001) *Green Guide to Specification*, 3rd Edition. Oxford, Blackwell Science. ISBN 0-632-05961-3.
- **Ansoff**, I (1968) *Stratégie du développement de l'entreprise*, Hommes et Techniques, Puteaux. Cited by Hicks (1991).
- **Artill**, P.; **Mclaney**, E. (2001) *Accounting and Finance for non-specialists*. 3rd Ed. © Pearson Education Ltd. 2001. ISBN 0-273-64632-X.

- **Arup** (2006) *SPeAR®: Product overview* [online]. Worldwide Web: http://www.arup.com/environment/feature.cfm?pageid=1685
- **The Asphalt Institute** (1979) *Energy Requirements for Roadway Pavements,* the Asphalt Institute, College Park, MD, IS-173, 1979.
- **Asumnaa**, A. O. (1999) *Optimising Environmental Effects of Prefabricated Concrete Building Frames.* Helsinki University of Technology. (Cited by Alexander *et al*, 2003).
- **Athina Sustainable Materials Institute – SMI** (2005) *The Environmental Impact Estimator* [online]. Worldwide web Addresses: http://www.athenasmi.ca/tools/docs/Athena_Institute-Software.pdf http://www.athenasmi.ca/about/lcaModel.html
- **Atis**, C. D. (2003) Accelerated carbonation and testing of concrete with fly ash. *Construction and Building Materials*, Vol. 17 (2003) pp. 147–152.
- **Avadikyan**, A.; Llerena, D.; Ostertag, D. (2001) Organizational mechanisms in environmental management: an evolutionary analysis confronted with empirical facts. *International Journal Environmental Technology and Management*, Vol. 1, No. 1/2, 2001. Copyright © 2001 Inderscience Enterprises Ltd.
- **Azar**, J.; Barko-Boateng, V.; Calkins, P.; deJong, E.; George, J.; Hilbert, H. (1995) Agent of Change: Xerox Design for the Environment. *Proceedings of the IEEE International Symposium on Electronics and the Environment.* Pp. 3-9. Orlando, Florida. May, 1995.
- **Bailey**, G; Fielding, A; Trevorrow, A. (2002) The Use of Reclaimed Product in the Prestressed Concrete Flooring Industry. *3rd International Conference of Decision Making in Urban and Civil Engineering – DMinUCE*, London November, 2002.
- **Bailey**, G. (2005) personal contact: Geoff Bailey is a Technical manager at Tarmac Top-floor, Derbyshire.
- **Ball**, B (2002*) High Volume Fly Ash Concrete; Pre-cast RPT 2000 Platform Beams.* Con-Force Structures Ltd. November, 2002. Worldwide Web [online] address: http://www.ecosmart.ca/kbase/filedocs/csrskytrainbeam.pdf
- **Barbour**, R. S.; **Kitzinger**, J. (1999) *Developing Focus Group Research: politics, Theory, and Practice.* SAGE publications Inc. ISBN 0-7619-5567-4.
- **Beckenstein**, A., R.; **Gabel**, H., L. (1986) 'The economics of antitrust compliance', *Southern Economic Journal,* Vol. 52, 3, pp.673-92. (Cited by Avadikyan *et al*, 2001).

- **Bennett**, S. (2005) Social Responsibility Issues in Small and Medium-sized Enterprises: Evidence from Cornwall, *Business Strategy and the Environment Conference*, Leeds. September, 2005.
- **BIBM** (2002) *An Environmental Manifesto: Precast Concrete is a natural construction product.* Bureau International Du Béton Manufacture (BIBM) publishing.
- **Bijen,** J.M. (2002) Environmental Information on Concrete; Sustainable concrete construction. *Proceedings of the International Congress on Challenges of Concrete Construction; Sustainable Concrete Construction.* (Eds R K **Dhir**, T D Dyer and J E Halliday), University of Dundee, 9-11 September 2002. Pp. 57-67.
- **Bison Ltd** (2006) Hollowcore Floors: Speed and Strength [online]. Worldwide web: http://www.bison.co.uk/pdf/hollowcorefloors.pdf
- **Bissacco,** I; Maccarone, P; Spinelli, C. (2005) the Strategic Approaches to CSR by Large Companies: A contingent model. *Business Strategy and the Environment Conference*, Leeds. September, 2005.
- **Blismas,** N.G., **Gibb**, A.G.F. and **Pasquire**, C.L. (2003) *IMMPREST*, Loughborough University, Loughborough, January 2003. ISBN 0-947974-13-X. Cited by Pasquire and Connolly (2003).
- **Boehm**, R. F. (2005) *Developments in the design of thermal systems.* Edited by Robert F. Boehm. Cambridge, Cambridge University Press, 2005.
- **Bogeskar**, M; Carter, A; Nevén, C-O; Nuij, R; Schmincke, E.; Stranddorf, H. K. (2002) *Evaluation of environmental product declaration schemes, Interim report.* European Commission DG Environment, Environmental Resources Management. Oxford, 2002 (cited by Alexander *et al*, 2004).
- **Bovea**, M. D.; **Wang**, D. (2002) Integration of customer, cost and environmental requirements in product design: An application of Green QFD. *VI International Congress on Project Engineering.* Barcelona, Spain. http://www.gid.uji.es/docs/articles/BoveaMD_02_02.pdf
- **Bowditch**, J; **Buono**, A. (1990) *A Primer on Organisational Behaviour*, 2nd Ed. © John Wiley and Sons. ISBN 0-471-61785-7.
- **BRE**, (2003a) Building a sustainable business, MaSC Getting Started Workshop. *Managing Sustainable Companies (MaSC) tool initiative*. July 2003. BPCF, Leicester.
- **BRE** (2003b) Draft report to BPCF; *proposal for the "Closing the loop on off-site manufacturing"*. Partners in Innovation (PII) project.

- **BRE** (2000) *Reclaimed product in precast concrete.* Partners in Innovation – DETR (Contract cc1528). BRE, Watford, March, 1999.
- **Bresnen**, M.; Goussevskaia, A.; Swan, J. (2004) Embedding New Management Knowledge in Project-based Organisations. *Organisation Studies*, 25 (9). Pp 1535-1555. SAGE Publications. London.
- **Briscoe**, G.; **Dainty**, A. (2005) Construction supply chain integration: an elusive goal? *Supply Chain Management*, Volume 10, Number 4, April 2005, pp. 319-326(8).
- **British Precast** (2004) *The BPCF Annual Waste Minimisation Award 2004*, Entry by a precast concrete manufacturer (company/ site name anonymised).
- **Brown**, S. (2003) personal contact: Shaun Brown, operations manager of Hanson plc. Hoveringham factory, Nottinghamshire.
- **Brown**, G. (2002) *protecting the environment (Chapter 7), steering a steady course: Delivering stability, enterprise and fairness in an uncertain world.* Pre-Budget Report 2002. Copyright © H M Treasury. Worldwide web [online] address: http://www.hm-treasury.gov.uk/pre_budget_report/prebud_pbr02/report/prebud_pbr02_repchap7.cfm
- **Bryman**, A.; **Burgess**, R. (1999) *Qualitative Research.* SAGE Publications Ltd. ISBN 0-7619-6243-3.
- **Bryman**, A. (1989) Research Methods and Organisation Studies. *Contemporary Social Research Series – No. 20.* Published by the academic division of Unwin Hyman Ltd, London.
- **BSI** (2006) *BS 8900: Guidance for managing sustainable development.* British Standards Institution, London.
- **BSI** (2000) *BS EN ISO 14043: Environmental Management – Life Cycle Assessment – Life cycle interpretation.* British Standards Institution, London.
- **BSI**, (1998) *BS EN ISO 14041: Environmental Management – Life Cycle Assessment – Goal and scope definition and inventory analysis.* British Standards Institution, London.
- **BSI**, (1997) *BS EN ISO 14040: Environmental Management – Life Cycle Assessment – Principles and framework.* British Standards Institution, London.
- **BSI** (1996) *BS EN ISO 14001: Environmental management systems —Specification with guidance for use.* British Standards Institution, London.
- **Buettner**, D; **Becker**, R (1998) *PCI Manual for the Design of Hollow Core Slabs.* Chapter Six: Fire Resistance of Assemblies Made with Hollow Core Slabs. 2nd Ed. Precast/ Prestressed Concrete Institute. ISBN 0-937040-57-6

- **Burgess**, R. (1984) In the Field: An introduction to field research. *Contemporary social research Series; 8*. London: Allen & Unwin, 1984.
- **Burrell,** G.; **Morgan**, G. (1979) *Sociological paradigms and organisational analysis: elements of the sociology of corporate life*. London: Heinemann Educational, 1979.
- **Butter,** F. den; **Hofkes**, M., W. (2001) Endogenous technology and environmental quality in economic models. *International Journal of Environmental Technology and management*. Vol. 1, No 1 /2, 2001. Copyright © 2001 Inderscience Enterprises Ltd.
- **Carlson**, L., Grove, S. J., and Kangun, N. (1993) A Content Analysis of Environmental Advertising Claims: A Matrix Method Approach. *Journal of Advertising* 22 (3): 27–39.
- **Carson**, R. (1962) *Silent Spring*; Mariner Books. ISBN 0-618-24906-0 (Pbk.). (Cited by IISD).
- **Carter**, M. and **White**, R. (2005) Marley Eternit's use of Life Cycle Assessment (presentation). *Sustainability and the Concrete Producer Conference*, organised by British Ready Mixed Concrete Association. (BRMCA) and British Precast Concrete Federation (BPCF). December, 2005.
- **Casella Stanger** (2003) Sustainability Accounting. *Partners in Innovation topic briefing – PII: 39/3/671*. In partnership with Forum for the Future, Carillion plc, and Construction Industry Research and Information Association (CIRIA), 2003.
- **Casey**, E. J., Jr. (1992) A Plan for Environmental Packaging. *Journal of Business Strategy* 13, July–August 1992. Pp 18–20. Cited by Mathur and Mathur (2000).
- **Christiansen**, K. (1997) *Simplifying LCA – Just a Cut?* Final Report of SETAC – Europe, LCA Screening and Streamlining Working Group, SETAC-Europe, Brussels.
- **Clark**, T.; Varadarajan, P. R.; Pride, W. M. (1994) Environmental Management: The Construct and Research Propositions. *Journal of Business* Research, Vol. 29 Issue 1. Pp. 23–38.
- **Clemens**, B. (2005) Economic incentives and small firms: Does it pay to be green? *Journal of Business Research, JBR-06132*. © Published by Elsevier. *Article in Press*.
- **Cole**, A. G. (1996) *Management: theory and practice*, London: Letts. Educational publications; 5th Ed. ISBN 1-8580-5166-5.
- **Collins**, D. (2003) *Sustainable Development and the cement and concrete construction sector*. © British Concrete Association.
- **Concrete Society** (2001) *Concrete and the Environment* (Fact sheet); Working Party of the Concrete Society's Materials Group, Concrete Society, 2001.

- **Copeland**, S. (2005) personal contact: Simon Copeland Technical manager at Tarmac Top-floor, Derbyshire.
- **Crawley**, D.; **Aho**, I. (1999) Building environmental assessment methods: Applications and development trends. *Building Research and Information.* 27 (4/5), pp 300-308. © E & FN Spon, 1999.
- **Crossley**, R. (2002) *Reputation, Risk, and Reward: The business case for sustainability in the UK property Sector* [online]. Sustainable Construction Task Group. BRE, Watford, UK. Worldwide Web access. http://www.projects.bre.co.uk/rrr/RRR.pdf.
- **CSTEE - Scientific Committee on Toxicity, Eco-toxicity and the Environment** (2002) *Risks to health from chromium VI in cement; opinion expressed at the CTSEE 32nd plenary meeting.* Brussels, C2/AST/csteeop/ChromiumVI 27062002/D (02), European Commission (EC).
- **Darnton**, G.; **Darnton**, M. (1997) *Business Process Analysis*. International Thomson Business Press, UK. ISBN: 1861520395.
- **DeGeer**, B; **Ford**, J.; **Innes**, S. (2002) *Demonstrations of sustainability.* Copyright © Rethinking Construction publication.
- **DETR** (2003) *DETR: Transport Energy Good Practice Case 374.* Worldwide Web site [online] address: http://www.transportenergy.org.uk/vpo/downloads/letter/GPCS374.pdf
- **DETR** (2000), *Building a better quality of life;* a strategy for more sustainable construction, HMSO, London, UK.
- **DETR**, (1999), *a better quality of life*; a strategy for sustainable development, HMSO, London, UK.
- **Deutsche-bauchemie** (1999) *Concrete Admixtures and the Environment, state-of-the-art report.* Copyright © 1999 DEUTSCHE-BAUCHEMIE e.V. ISBN: 387382–036–1.
- **Dhir**, R. K.; **Jones**, M. R. (1999) Development of chloride-resisting concrete using fly ash. *Fuel (Journal)*, Volume 78, Number 2, January 1999, pp. 137-142 (6). © Elsevier Science.
- **Dickie**, I; **Howard**, N. (2000) Assessing environmental impacts of construction. Industry consensus, BREEAM and UK Ecopoints. – *BRE Digest 446*. Copyright © BRE, May, 2000.
- **Dong**, C.; Zhang, C.; Wang, B. (2003) Integration of green quality function deployment and Fuzzy Multi-Attribute Utility Theory-Based Cost Estimation

for Environmentally Conscious Product Development, *International Journal of Environmentally Conscious Design & Manufacturing*, Vol. 11, No 1, 2003.

- **Doppelt**, B; **Nelson**, H. (2001) *Extended Producer Responsibility and Product take-back: Applications for the Pacific Northwest*. The Centre for Watershed and Community Health, Portnland State University – Worldwide Web [online]: www.upa.edu/CWCH/: 28.Feb.06.
- **Drenth**, P.J.D (1998) Research in work and organisational psychology: Principles and Methods. *Handbook of Work and Organisational Psychology*, Vol. 1, 2nd Ed. Pp. 11-46. Psychology Press, Hove.
- **DTI** (2004a) *Corporate Social Responsibility, A government update* [online] Department of Trade and Industry. © Crown Copyright. Worldwide web: www.dti.gov.uk/DTI/Pub 7201/1k/05/04/NP.URN 04/1112. May, 2004.
- **DTI** (2004b) Energy consumption in the UK; the DTI website at: http://www.dti.gov.uk/energy/inform/energy_consumption/ecuk.pdf
- **DUKES** (1997) *Digest of UK Energy Statistics*, 1997. Department of Trade and Industry, UK.
- **Dunphy**, D.; Griffiths, A; Benn, S. (2003) *Organisational Change for Corporate Sustainability; A guide for leaders and change agents of the future*. Routhledge, NY. ISBN 0-415-28740-5 (hbk).
- **Edwards**, S. (2004) The family of tools for Sustainable Construction Products, presentation in BRE; *Latest Developments for Construction Products in Sustainability Tools: One Day Seminar*. BRE- July, 2004.
- **Edwards**, S.; Barlett, Ed.; Dickie, I. (2000) *Whole life costing and life-cycle assessment for sustainable building design*. Digest 452. © Copyright BRE 2000. ISBN 1-86081-441-7.
- **Environment Agency- EA** (2004) Environment Agency website [online], Accessed in November, 2004. Worldwide Web site address: http://www.environment-agency.gov.uk/subjects/waste/232021/799638/799655/?lang=_e
- **Egan** *et al* (1998) *Rethinking Construction: the report of the Construction Task Force to the Deputy Prime Minister, John Prescott, on the scope for improving the quality and efficiency of UK construction*. Published by Department of the Environment, Transport and the Regions, London. ISBN 1-8511-2094-7 (pbk.).
- **Elhag**, H.K., Glass, J., Gibb, A.G., Clarke, M.A, Budge, C.J., Bailey, G. (2006) Developing a structured approach to implementing sustainability improvements in a

manufacturing context: the precast concrete industry, *International Journal of Environmental Technology & Management* (Article in press).

- **EPA- Environmental Protection Agency** – (2003) The *EPA Ozone Depletion website* [online]: http://www.epa.gov/ozone/.
- **Epps**, Jon A., *Energy Requirements Associated with Highway Maintenance and Rehabilitation,* Texas A&M, College Station, TX, 1977.
- **Easterling,** D., Miller, S., and Weinberger, N. (1995) Environmental consumerism: A Process of Children's Socialization and Families' Resocialization. *Psychology and Marketing* 12 (6), Sept. 1995. Pp. 531–550. Cited by Mathur and Mathur (2000).
- **EU** (2003a) *Integrated Product Policy; communication from the commission to the council and the European parliament*; Draft for inter-service consultation.
- **EU,** (2003b) *Green paper on greenhouse gas trading within the European Union* [online]. Worldwide Web address: http://www.gert.org/links/documents/pdf/March%208,%202000%20EU%20Green%20Paper%20on%20GHG%20Emission%20Trading.pdf.
- **Fairbrass,** J.; O'Riordan, L.; Mirza, H. (2005) Corporate Social Responsibility: Differing definitions and practices? *Business Strategy and the Environment Conference,* Leeds. September, 2005.
- **Fellow,** R; **Liu,** A. (2003) *Research Methods for Construction.* 2nd Ed. Published Blackwell Science Ltd. 2003. ISBN 0-632-06435-8.
- **Fielding,** N. G.; **Fielding,** J. L. (1986) *Linking Data. Qualitative research methods*; Vol.4 .ISBN: 0803925638. Beverly Hills; London: Sage, c1986.
- **Figge,** F; Hahn, T; Schaltegger, S; Wagner, M. (2002) The Sustainability Balanced Scorecard - Linking Sustainability Management to Business Strategy. *Business Strategy and the Environment* 11(5): pp. 269-284.
- **Friedman,** M. (1970) The Social Responsibility of Business is to increase its Profits. *The New York Times Magazine,* September 13, 1970. Copyright © by the New York Times Company.
- **Flick,** U. (2002) *an introduction to qualitative research.* SAGE Publications Ltd. ISBN 0-7619-7435-0.
- **Fluitman,** A; **deLange,** (1996) *Comparison of the environmental effects of three concrete story floors.* V.P.A.: CREM Report no. 95.107. Amsterdam, 1996 (cited by Alexander *et al,* 2003).
- **Frosch,** R (1992) *Industrial Ecology: A philosophical Interoduction.* Proc. National Academy of Science, Washington D.C. Vol. 89, PP 800- 803, Feb. 1992.

- **Gani**, M. S. J. (1997) *Cement and Concrete*. Published by Chapman and Hall, London, UK. ISBN 0-412-79050-5.
- **Gauntlett**, D. (2002) *Media, Gender and Identity: An Introduction*. Published by Routledge. ISBN: 0415189608.
- **Gibb**, A. G. (1999) *Off-site fabrication: prefabrication, pre-assembly and modularisation.* Loughborough University. Whittles Publishing; Scotland.
- **Giddens**, A. (1986) *The Constitution of Society*: University of California Press Publication. April 1986. ISBN 0520057287.
- **Gilbert**, M. (2005) Sustainability Defined. *Sustainability and the Concrete Producer Conference*, British Ready Mixed Concrete Association. (BRMCA) and British Precast Concrete Federation (BPCF). December, 2005. Loughborough.
- **Gillham**, B. (2000) *Developing a Questionnaire,* Continuum, London. ISBN 0-8264-4795-3.
- **Glass**, J.; **Gibb**, A. G. (2003) Off-site and sustainable manufacturing. *Proceedings of the Three Hot-topics seminar, part of the British Precast Concrete Federation Annual General Meeting*. May, 2003. Leicester, UK.
- **Glass**, J.; **Pocklington**, D. (2002) Economics, Sustainability and Concrete. *Proceedings of the International Congress on Challenges of Concrete Construction; Sustainable Concrete Construction.* (Eds R K **Dhir**, T D Dyer and J E Halliday), University of Dundee, 9-11 September 2002. pp 683-694.
- **Glass**, J. (2000) *the future for precast Concrete in Low-rise Housing*. © British Cement Association publication. ISBN 0-9536773-0-3.
- **Glavind**, M.; **Munch-Petersen**, C. (2002) Green Concrete- A Life Cycle Approach. Sustainable concrete construction. *Proceedings of the International Congress on Challenges of Concrete Construction; Sustainable Concrete Construction.* (Eds R K **Dhir**, T D Dyer and J E Halliday), University of Dundee, 9-11 September 2002. Pp 771-786.
- **Gray**, C. (2002) Benchmarking (Lecture). *Part of the Production engineering Module - MSc in Construction Management presentation.* Reading University. Reading, 2002.
- **Gray**, C.; **Fowler**, C. (2000) *Hybrid Concrete Construction; Barriers to efficient production.* Reading Production Engineering Group- Draft Report.
- **Gray**, L.C. (1913) the economic possibilities of conservation. *Quarterly Journal of Economics* 27, 497– 519. Cited by Ruth (2005).

- **Gray**, L.C. (1914) Rent under the presumption of exhaustibility. *Quarterly Journal of Economics* 28, 466– 489. Cited by Ruth (2005).
- **Green**, S. D. (1994) Beyond Value engineering: SMART value management for building projects. *International Journal of Project Management*, 12(1), 49-56.
- **Greenfield**, T. (1996), *Research Methods; guidance for postgraduate*. London: Arnold, 1996.
- **Griffin**, H.; **Fawcett**, T. (2000) *Country Pictures*, Energy and Environment Programme, Environmental Change Institute, University of Oxford, UK.
- **Groenewegen**, P. and **Vergragt**, P. (1991) Environmental issues as treats and opportunities for technological innovation, *Technology Analysis & Strategic Management*, Vol. 3, No. 1, pp.43–55. Cited by Avadikyan (2001).
- **Goring**, P.G. (2002) Rethinking Sustainable Concrete Construction, *Proceedings of the International Congress on Challenges of Concrete Construction; Sustainable Concrete Construction*. (Eds R K **Dhir**, T D Dyer and J E Halliday), University of Dundee, 9-11 September 2002.
- **Guinée**, J.-Ed. (2002) *Handbook on Life Cycle Assessment, operational guide to the ISO standards*. © Kluwer Academic Publishers, ISBN 1-4020-0228-9.
- **Hadley Centre** (2005) *Climate change, rivers and rainfall* [online]. Website: http://www.metoffice.com/research/hadleycentre/pubs/brochures/B2005/COP11.pdf
- **Hahn**, T.; **Scheermesser**, M. (2005) Different Types of Approaches to Corporate Sustainability among German Companies - Evidence from an Online Survey. *Business Strategy and the Environment Conference*, Leeds. September, 2005.
- **Hague**, P. (1993) *Questionnaire Design*, Published by Kogan Page Ltd. ISBN 0-7494-0917-7.
- **Hanson Plc.** (2001) Annual review and summary financial statement report [online]. Worldwide Web address: http://www.hanson.biz/managed_content/sub_sites/reports/2001anrep/flash/index.htm
- **Heerwagen**, J. (2000) Green Buildings, Organisational Success and Occupant Productivity. *Building Research and Information*. Vol. 28, Issue 5/6. Pp. 353 – 367.
- **Heijungs**, R., J. Guinee, G. Huppes, R.M. Lankreijer, H.A Udo de Haes, A. Wegener Sleeswijk, A.M.M. Ansems, P.G. Eggels, R. van Duin & H.P. de Goede (1992) *Environmental Life Cycle Assessment of Products, Guide and Backgrounds*. CML, Leiden University, Leiden. (Cited by Guinee, 2002).
- **Hicks**, M. (1991) *Problem Solving in Business and Management: Hard, soft and creative approaches*. 1st ed. Chapman & Hall, London. ISBN 0-412-37490-0.

- **Higgins**, D; Parrott, L; Sear, L (2000) Effects of ground granulated blast-furnace slag and pulverised-fuel ash upon the environmental impacts of concrete, *part of Defining and improving the environmental performance of concrete, Concrete Industry Alliance project report*, January 2000, DETR Project reference 39/3/487, CC1553.
- **Hillary**, R. (2004) Environmental Management Systems and the smaller enterprise. *Journal of Cleaner Production.* Vol. 12 (2004). Pp 561–569. © Elsevier Ltd.
- **HMCE** (2004) *Landfills* [online]. HM Customs and Exercise – HMCE Worldwide Web: http://www.hmce.gov.uk/business/othertaxes/landfill-tax.htm
- **Holland**, R. (2001) *Selling Price, Gross Margin and Mark-Up Determination.* Agricultural Development Centre. University of Tennessee. Worldwide Web site [online] address: http://cpa.utk.edu/pdffiles/adc12.pdf
- **Hotelling**, H.C. (1931) the economics of exhaustible resources. *The Journal of Political Economy*, Vol. 39. Pp 137– 175. Cited by Ruth (2005).
- **Howard**, N.; Edwards, S.; Anderson, J. (1999) *BRE methodology for environmental profiles of construction materials, components and buildings*, Construction Research Communications Ltd. ISBN 1-86081-294-5.
- **Howes**, R. (2002) *Environmental Cost Accounting: An Intorduction and Practical Guide.* Chartered Institute of Management Accountants (CIMA) Publication, London. Cited by Casella Stanger (2003).
- **Huovila**, P.; **Koskela**, L. (2000) Contribution of the Principles of Lean Construction to Meet the Challenges of Sustainable Development. *6th Annual Conference of the International Group for Lean Construction (IGLC 98).* Guaruja, Brazil.
- **IISD- International institute of Sustainable Development** (2004) *Sustainable Development timeline*, IISD report. Worldwide web [online] access: http://www.iisd.org/rio+5/timeline/sdtimeline.htm. http://www.iisd.org/susprod/principles.htm
- **International ad hoc detection group** (2005) Detecting and attributing external influences on the climate system: a review of recent advances, *Journal of Climate*, Vol. 18, pp. 1291-1314
- **IPCC- Intergovernmental Panel on Climate Change** (2001) *Climate change 2001: summary for policymakers*, Cambridge University Press, Cambridge, http://www.ipcc.ch.
- **International Panel for Climate Change (IPCC)** (2001) *Climate Change: The Scientific Basis*; 3rd Ed. A UNEP report. ISBN: 0-5210-1495-6.

- **Jelinski**, L. W.; Graedel, T. A.; Laudise, R. A.; McCall, D. W.; Patel, K. N. (1992) *Industrial Ecology; Concepts and Approaches*. Proc. National Academy of Science, Washington D.C. Vol. 89, Pp. 793- 797, Feb. 1992
- **Jiménez-González**, C., S.; **Kim**, M.R.; Overcash (2000) "Methodology for Developing Gate-to-Gate Life Cycle Inventory Information," *International Journal of Life Cycle Assessment*, 5 (3). Pp. 153-159.
- **Jennings**, D. and **Wattam**, S. (1998) *Decision making – an integrated approach*, 2nd ed., London, Prentice Hall.
- **Johansson**, L. (2002) ISO-14001: one for all, or just for some [online]. *ISO Management Systems*, September- October, 2002. pp 51- 56. Worldwide Web address: http://www.iso.org/iso/en/iso9000-14000/addresources/articles/pdf/viewpoint_5-02.pdf
- **Jones**, M. R.; Dhir, R. K.; Magee, B. J. (1997) Concrete containing Ternary blended binders: Resistance to Chloride ingress and carbonation. *Cement end Concrete Research*, Vol. 27, No. 6, pp. 825-831. © 1997 Elsevier Science Ltd.
- **Kandelaars**, P. (1998) Material-Product Chains: Economic Models and Applications. Thesis Publishers, Amsterdam.
- **Katz**, M; **Rosen**, H. (1998) Microeconomics, *Irwin/McGraw-Hill advanced series in economics*. Boston Massachusetts. Irwin/McGraw-Hill, c1998.
- **Kaysser**, D; **Kott**, M. (2002) the future in view: Production-integrated environmental protection in the production of concrete and reinforced concrete components for building construction in precast plants. *Betonwerk + Fertigteil + Technik*, Vol.68, No.11, Aug. Pp 52-57.
- **Kautto**, P; **Melanen**, M. (2004) How does industry respond to waste policy instruments—Finnish experiences, *Journal of Cleaner Production* Vol. 12 (2004), pp. 1–11.
- **KPI Working Group** (2000) KPI report for the Minister for Construction. DETR, January 2000. © Crown Copyright 1999.
- **Krueger**, R.A. (1994) *Focus Groups: A practical Guide for Applied research*. Sage Publications, Inc. ISBN 0-8039-5566-9.
- **Lawson**, W. (1995) Embodied energy of building materials. *Royal Australian Institute of Architects* 2: 1.
- **Levitt**, M. (1982) *Precast Concrete: Materials, Manufacture, Properties and Usage*, Applied science publishers Ltd. Essex, England. ISBN 0-85334-994-0.

- **Li**, G.; **Zhao**, X. (2003) *Properties of concrete incorporating fly ash and ground granulated blast-furnace slag.* Cement & Concrete Composites, Vol. 25 (2003), pp. 293–299.
- **Lincoln Green Ltd** (1999) *Energy Breakdown report for the* [company name anonymous].
- **Lumsdaine**, E.; **Lumsdaine**, M. (1995) *Creative problem solving: thinking skills for a changing world.* New York; London : McGraw-Hill, 1995. ISBN 0071134786.
- **Lyons**, A.R. (1997) *Materials for Architects and Builders: An Introduction.* Published by Arnold Ltd.; a member company of the Hodder Headline Group. ISBN 0-340-64556-3.
- **M4I- Movement for Innovation** (2001) *Concrete Thinking; A prospectus for change in the UK concrete industry; "Making the business case for Concrete".* Rethinking Construction and British Cement Association (BCA) publishing.
- **Mathur**, L.; **Mathur**, I. (2000) an analysis of the wealth effects of Green Marketing strategies. *Journal of Business Research.* No. 50, Pp. 193–200. © 2000 Elsevier Science Inc.
- **McGeorge**, D. **Palmer** A. (1997) *Construction Management: New Directions.* Oxford, Blackwell Science LTD.
- **McMichael**, F. C.; **Mellon**, C. (1999) Economic Input-Output Life Cycle Analysis [EIOLCA] meeting presentation, MIT, April, 1999. Worldwide web [online] site: http://msl1.mit.edu/msl/meeting_04161999/fran_bw.pdf.
- **Milbank Ltd.** (2006) *Welcome to Milbank Floors* [online]. Worldwide Web access: http://www.milbank-floors.co.uk/index.shtml
- **Milne**, G; **Reardon**, C. (2004) *Embodied Energy: Design for lifestyle and the future* (fact sheet). Part of the "your Home" initiative. © Commonwealth of Australia, can be found at www.greenhouse.gov.au/yourhome/technical/fs31.htm- Last modified March, 2004.
- **Miyazaki**, Y. (1998) Applying Eco-Balance to Management Control: Combining Economic and Ecological Accounting. *The APIRA Accountancy Conference*; Osaka, August- 1998.
- **Monden**, Y. (1998) *Toyota Production System, An integrated Approach to Just-In-Time.* Norcross, Ga.: Engineering & Management Press, 3rd Ed. ISBN 0898061806.
- **Murdoch**, J; **Hughes**, W. (2001) *Construction Contracts Law and Management* - 3rd Ed. Spon Press, 2001.

- **National Statistics** (2004) *Mineral Extraction in Great Britain: Business Monitor - PA1007*, based on the Annual Minerals Raised Inquiry, © Crown copyright 2004. Published with the permission of Her Majesty's Stationery Office (HMSO).
- **Natsource Europe Ltd.** (2005) Natsource Europe Ltd. update newsletter. By Tim Atkinson, March – 2005.
- **Neville**, A. M. (1995) Properties of Concrete (4th Ed.). Longman Scientific and Technical, 1995. ISBN 0-47023-527-6.
- **Nielsen**, C.V. (2005) Environmental Performance of a Danish Precast Factory. Proceedings of 18th BIBM International Congress and Exhibition – Meet the future of precast concrete. Amsterdam, 11-14 May 2005, BIBM.
- **Nixon**, P. J. (2002) More sustainable construction: the role of concrete. *Proceedings of the International Congress on Challenges of Concrete Construction; Sustainable Concrete Construction.* (Eds R K **Dhir**, T D Dyer and J E Halliday), University of Dundee, 9-11 September 2002. Pp 1 – 13.
- **Nixon**, P. J; Quillin, K.; Summersville, G. (2003) *Sustainable Concrete Construction by Service Life Design*, Draft report; pre-publication.
- **Oberg**, M. (2002) Integrated Life Cycle Design: Application to Concrete Multi-dwelling Buildings. *Report TVBM-3103*. Lund, 2002. ISSN 0348-7911 TVBM.
- **Odum**, H. T. (1996) *Environmental accounting: EMERGY and environmental decision making*. New York: John Wiley and Sons.
- **Oppenheim**, A.N. (1992) *Questionnaire Design, Interviewing and Attitude Measurement*. Pinter Publishers. ISBN 1-85567-043-7 (HBK).
- **Pasquire**, C. L.; **Connolly**, G. E. (2003) Design for manufacture and assembly. *International Group of Lean Construction 11th Annual Conference*, July (2003). Virginia Tech, Blacksburg, Virginia, USA.
- **Paterson**, L. (2000) *Principles of research design in the social sciences / Frank Bechhofer and Lindsay Paterson*. London, Routledge, 2000. ISBN 0415214424.
- **Pava**, ML; **Krausz**, J. (1996) the association between corporate social-responsibility and financial performance: the paradox of social cost. *Journal of Business Ethics*; Vol. 15, Pp 321–57.
- **Pearce**, D. (2003) the Social Cost of Carbon and its Policy Implications. *Oxford Review of Economic Policy*, Vol. 19, No. 3, Pp 362-384.
- **PFF- Precast Flooring Federation** – (2001) *General and Technical Information Manual*, Published by the PFF, 2001.

- **Pine**, J (1993) *Mass customization: the new frontier in business competition.* Forwarded by Stan Davis. Boston: Harvard Business School Press, c1993.
- **Pocklington,** D. *et al* (2004) Memorandum by the British Precast Association to the United Kingdom Parliament on Emissions Trading. *Minutes of Evidence*, ordered by the House of Lords to be printed 19 October 2004. Website: http://www.publications.parliament.uk/pa/ld200304/ldselect/ldeucom/179/4050501.htm
- **Pré Consultants** (2005) *Eco-Indicator 99: impact assessment & ecodesign method* [online]. Worldwide Web address: http://www.pre.nl/eco-indicator99/default.htm
- **Punkki**, J (2001) Sustainable Prefabrication. *fib symposium proceedings, Concrete and Environment*. Berlin 2001. ISSN 1464-4177 (Cited in Alexander, 2003).
- **Quality Ash Association** (2003) the Role of PFA for Enhanced Stabilised Capping. *Technical Data Sheet No. 6.9.* March, 2003. QAA, UK.
- **Richardson**, J. G. (1991) *Quality in Precast Concrete; Design- Production-Supervision.* 1st Ed. Longman Group UK Ltd. ISBN 0-582-05066-9.
- **Rikhardsson**, P. (2005) accounting for Health and Safety Costs: Review and Comparison of selected methods. *Business Strategy and the Environment Conference.* Leeds University, UK.
- **Roberts**, S. (2003) Supply Chain Specific? Understanding the Patchy Success of Ethical Sourcing initiative, *Journal of Business Ethics*, Vol. 44, 2003, pp159-170.
- **Roome**, N. J. (1998) *Sustainability Strategies for the Industry*, Greening of industry network series, Washington, D.C.: Island Press, c1998 . ISBN 1-5596-3598-3.
- **Roudebush**, W. H. (1998) An Environmental Value Engineering application to assess the environmental impact of construction waste. *3rd Annual Southeastern Green Building Conference*. March 2-4, 1998 at Greenboro, NC.
- **Rouwette**, R. and **Schuurmans**, (2001) A. (INTRON): *LCI and LCA of Concrete, Goal and scope definition.* Joint Group document IN 00/25, Brussels, 2001.
- **Rush**, H. (2005) Good CoPS/ Bad CoPS: Innovation Management Approaches in Complex product systems. *12th Annual EPSRC Research Methodology Workshop for Manufacturing and Technology Management.* 4th – 5th April 2005, Wolfson College, Cambridge.
- **Ruth**, M. (2005) A quest for the economics of sustainability and the sustainability of economics. *Ecological Economics*. Accepted in 14 Sept. 2005 (Article in press). © 2005 Elsevier B.V. All rights reserved.

- **Schmidt**, M; Fehling, E; Teichmann, T; Bunje, K; Bornemann, R (2003) Ultra-high performance concrete: Perspective for the precast concrete industry. *Betonwerk + Fertigteil + Technik*, Vol.69, No.3, March. pp 16-29.
- **Seale**, C. (2004) *Social Research Methods: A Reader*. Routledge, New York. ISBN 0-415-30083-5 (hbk).
- **Shipworth** (2001) The Environmental Impact of the Built Environment. *Sustainable Development Module – Part of the course for MSc in Construction Management*, Reading University. Reading.
- **Silverman**, W. (1985) *Qualitative methodology and sociology: describing the social world*. Aldershot: Gower, c1985. ISBN: 056600884X.
- **Smart**, B (1992) *Industry as a metabolic activity*. Proc. National Academy of Science, Washington D.C. Vol. 89, PP 804- 806, Feb. 1992.
- **Smith**, R.A.; Kersey, J.R.; Griffiths, P.J. (2002) *the construction Industry Mass Balance: resource use, wastes and emissions*, Viridis Report VR4. ISSN 1478-0143.
- **Sugihara**, A; Okamoto, H; Horio, T. (2005) Effects of UVB on fascin expression in dendritic cells and Langerhans cells. *Journal of Dermatological Science,* Volume 40, Issue 3, December 2005, Pages 177-185.
- **Suh**, S. (2004) Portrait of Wassily Leontief (Editorial). *International Journal of Life Cycle Assessment*. Vol. 1, No. 1, pp.1 – 2004.
- **Sutcliff**, B.; **Murphy**, K. (2003) On-Site Waste Reduction, Report CGPP 2004/19 (part of the Cleaner Greener Production Plan- CGPP). Published by the Environmental Protection Agency. Ireland, 2004.
- **Symonds Group Ltd.** (2001) Construction and demolition waste survey: *National survey of the production, recycling and disposal of construction and demolition waste in England and Wales 1999-2000*, Environment Agency Technical Report P402, Environment Agency - ISBN 1-85705-450-4
- **Threlfall**, A.J. (2002) *an Introduction to Pre-stressed Concrete*. British Cement Association, ISBN 0-7210-1586-7
- **TruCost** (2005) *Press Release: Trucost helps Defra produce Environmental KPI's* - Reporting Guidelines for UK Business - published for consultation. 27th July 2005. Worldwide Web: http://www.trucost.com/2005defrarelease.html
- **Tucker**, R. L.; Rogge, D. F.; Hayes W. R.; Handerickson F. P. (1982) Implementation of Foreman Delay Surveys, *ASCE Journal of Construction Division,* 108, No CO4, pp 577- 591.

- **Tukker**, A. (2000) Life Cycle Assessment as a tool in environmental impact assessment, *Environmental Impact Assessment Review.* Vol. 20, pp. 435-456.
- **QPA – Quarry Products Association** (2003) *QPA Assessment of the impacts of the Aggregate Levy* [online], Worldwide web address: www.qpa.org/pdf/AggLevyDoc.pdf
- **UN** (1992) *Agenda 21: programme of action for sustainable development. Rio declaration on environment and development.* Statement of forest principles: the final text of agreements negotiated by governments at the United Nations Conference on Environment and Development (UNCED), 3-14 June, 1992, Rio de Janeiro, Brazil. ISBN 9-2110-0509-4.
- **UNEP – United Nations Environmental Panel** (1996) *Life Cycle Assessment: What it is and how to do it.* United Nation Environment Programme. Industry and Environment, Paris.
- **Valuation Office Agency** (2004) Minerals and Waste management Industries. *The Valuation Office Agency property Market Report* – July, 2005. © HM Revenue and Customs, UK.
- **Van Berkel**, R.; Van Kampen, M.; Kortman, J. (1999) *Opportunities and constraints for Product-oriented Environmental Management Systems (P-EMS),* Journal of Cleaner Production; Vol. 7 (1999) pp. 447–455
- **Vares**, S.; **Hakkinen**, T. (1998) *Environmental Burden of concrete and concrete products.* Technical paper from Technical Research Centre, Finland. VTT building Technology. Published by Nordic Concrete Research; Publication No.21. Worldwide Web: http://www.itn.is/ncr/publications/doc-21-10.pdf.
- **Weizsacker**, E., V.; Lovins, L.; Lovins, A. (1998) *Factor Four; Doubling Wealth. Halving Resource use.* Published by Earthscan Publications Ltd.
- **WCED – World Commission on Environment and Development** (1987) *Our Common Future.* Oxford University Press, Oxford. ^ Brudtland report^.
- **Bernard Williams Associates** (2006) *Benchmarking of Construction Efficiency in the EU member states (Scoping Study).* European Commission. March, 2006.
- **Womack**, J.; **Jones**; D. (1997) Lean Thinking: *Banish Waste and Create Wealth in your corporation.* Simon & Schuster Ltd. ISBN 0-684-81976-7.
- **WRAP** *et al* (2005) *Quality Protocol for the production of aggregates from inert waste.* revised Edition. WRAP, Sept. 2005. ISBN 1-84405-217-6.
- **Yin,** R. K. (1994) Case study research: design and methods. 2nd Ed. *Applied social research methods series*; V. 5. Thousand Oaks, Calif.; London: Sage, 1994.

- **Zilahy**, G. (2004) Organisational factors determining the implementation of cleaner production measures in the corporate sector. *Journal of Cleaner Production.* Vol. 12 (2004) pp 311–319.
- **Zinkhan**, G. M.; **Carlson**, L. (1995) Green Advertising and the Reluctant Consumer. *Journal of Advertising* Vol. 24, Issue 2. Pp. 1–6. Cited by Mathur and Mathur (2000).