1 Introduction: Challenges to the Fish-Processing Industry in a Resource-Starved World

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1.1 INTRODUCTION

The overriding interest of this book is the sustainability of the fish-processing industry (FPI) by addressing the issues of efficient raw material utilization, energy usage, environmental impact, water usage, packaging and transport among others. However, the industry does not exist alone but, as with any processing industry, sits between the suppliers of the raw material and the consumer. Factors that affect either of these constituencies will have an impact on the processing sector. The size of the impact on the sustainability of the industry will depend on how wide the boundaries of the FPI are drawn. If the boundaries are drawn very narrowly, and just include the activities within the processing unit itself, the impact of outside influences will be very little. However, if the boundaries are drawn to include other activities, the impact will be greater – especially if the transport of raw material and finished products is taken into account.

This chapter will serve as an introduction to the later chapters on specific processes by giving the background to the current state of the World fisheries defined by supply and demand. How this, together with factors such as climate change, fossil fuel depletion and the current economic downturn, can be addressed will command the attention of the industry in the immediate future. All is not doom and gloom and an optimist will see the challenges as opportunities for diversification and process improvement.

1.1.1 Defining sustainability

Although seen as a fashionable sphere of activity today, sustainability, or Sustainable Development (SD), is a discipline that has long been of interest to scientists, technologists, politicians and business alike. Thomas Malthus in his *Essay on the Principle of Population* of 1798 proposed that the power of population increasing in a geometric ratio would outstrip the power of the earth to sustain mankind increasing in an arithmetic ratio. Thus a link was made between population and sustainability which became the centre of heated and prolonged argument over the policies which would alleviate the problem. In more recent

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times (1972), the United Nations (UN) held its first major conference on environmental issues entitled the 'United Nations Conference on the Human Environment (the 'Stockholm Conference')', which recognized political connotations, the 'North–South Divide', and environmental problems such as greenhouse gas emissions and depletion of the ozone layer. A major outcome was the setting up of the United Nations Environmental Programme (UNEP) with headquarters in Nairobi, the first UN agency in Africa. In 1980 the International Union for the Conservation of Nature, the World Wildlife Fund and UNEP published the World Environmental Strategy, which included the words 'Sustainable Development' in its subtitle (IUCN, 1980).

Consequently, the UN set up a commission in the 1980s to study the issues of global inequality and resource redistribution (World Commission on Environment and Development, 1987) which became known as the Brundtland Commission (after the Chair, Gro Harlem Brundtland, Prime Minister of Norway). The report (also known as 'Our Common Future') suggested that economic growth should be wedded to social equality and environmental protection. They also strongly promoted the idea of a sustainable level of world population as an issue to be tackled to achieve these goals. Their oft-quoted definition of SD is:

> Sustainable Development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987).

The SD debate often revolves around the meaning of 'needs', as opposed to 'wants', in society.

Overall, the Brundtland Commission report suggested that SD issues could be boiled down to the three principles mentioned above, which are environmental concerns, social justice and economics, and overstating the case for any one of these will not achieve SD. A judicious balance between these competing elements is regarded as the 'Triple Bottom Line' (TBL) for any enterprise (Figure 1.1). Achieving the TBL has been taken up by business through the adoption of practices under the ethos of 'Corporate Social Responsibility' (CSR) as a means to legitimize their activities. There is much debate about the sincerity, practicality and even the legitimacy of these models when applied across the spectrum of nations in view of their wealth, economic life style, cultural attitudes and legislative procedures.

Five years on from the Brundtland Commission, in 1992, the UN held the 'United Nations Conference on Environment and Development' (UNCED) in Rio de Janeiro (variously known as the 'Rio Summit' or the 'Earth Summit') to report on progress and to respond to new threats such as climate change. The meeting addressed the tensions between the need for environmental protection (proposed by the developed nations) and the desire of developing nations for the social and economic benefits enjoyed by the developed world. The rate of consumption of the Earth's resources and population growth were also high on the agenda. Looked at in these terms the Rio Summit came up with a declaration that 'the right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations'.

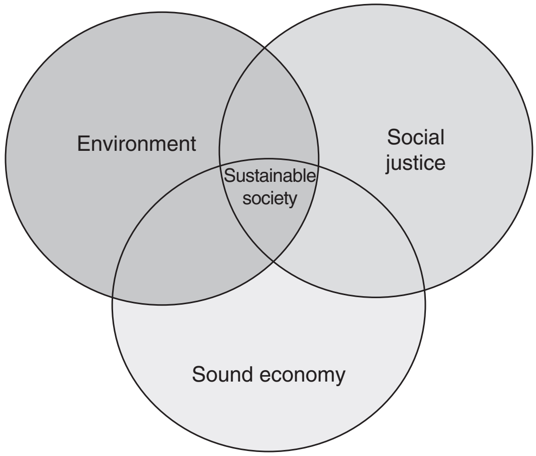

Figure 1.1 The three components of SD – the 'Triple Bottom Line'.

The practical outcome of the conference was a series of major treaties and calls to action which were considered to cover all the SD issues raised by the Brundtland Commission. The five outcomes were:

(i) The Convention on Biological Diversity (an agreed treaty);
(ii) The Framework Convention on Climate Change (an agreed treaty);
(iii) Principles of Forest Management (an agreed treaty);
(iv) The Rio Declaration on Environment and Development;
(v) Agenda 21, which was seen as a blueprint for SD.

Agenda 21 was intended as a means of engaging nations, industry and peoples in SD in order to tackle problems at a local, regional and national level whilst adhering to the TBL principles. A Commission on Sustainable Development (CSD) was set up to monitor the nations (initially 178) which signed up to Agenda 21 and to the principles of the UNCED. Areas of particular concern were: food security and health; energy and transport; consumption and waste; poverty and overpopulation; deforestation and loss of biodiversity. It was noted that any practical steps to solve these issues would require technological change AND demand a behavioural change by individuals and governments, a change in current (and desired) lifestyles and the recognition of our impact on the environment. Agenda 21 was reaffirmed as the plan of action at another UN World Summit on Sustainable development (WSSD) in Johannesburg in 1997. The world approach to fisheries management, production practices, processing and trade encompasses all the SD issues neatly – although there is nothing neat about the solutions, given that capture fisheries occur on the open seas and fish (products) are traded internationally.

It is not possible to address the wider SD debate (or indeed the science of climate change) at length here but the reader is urged to engage with it in their interpretation of SD within the FPI. However, it is appropriate to define some specific SD concepts as tools to allow an analysis of the FPI and these will be addressed below.

1.1.2 Sustainable development concepts for FPI

Table 1.1 gives selected data for the World fisheries production (for 2000, 2004 and 2006) to exemplify the trends that will have an impact on the sustainability of the FPI (FAO, 2007a, 2009). Total capture production in 2004 (95.0 million tonnes) was about twice that of aquaculture but in comparison with 2000 the contribution of aquaculture had increased rapidly and this trend had continued by 2006. Certain social trends are associated with this pattern of production so, for example, the number of people engaged in fisheries has increased, but mainly due to the growth in aquaculture activity.

In 2004, approximately 41 million people were estimated to work (full- or part-time) in the fisheries sector (the number had increased to 43.5 million people in 2006) with the vast majority situated in Asia (about 36–37 million people). Of the total number about 25% are involved in aquaculture, although this rises to about 30% for Asia. China alone accounts for 31% of all fishermen

Table 1.1 Selected world capture and aquaculture production and utilization (million tonnes).

	2000	2004	2006
Production			
Inland			
Capture	8.8	9.2	10.1
Aquaculture	21.2	27.2	31.6
Total	30.0	36.4	41.7
Marine			
Capture	86.8	85.6	81.9
Aquaculture	14.3	18.3	20.1
Total	101.1	103.9	102.0
Total capture	95.6	95.0	92.0
Total aquaculture	35.5	45.5	51.7
Total world fisheries (TWF)	**131.1**	**140.3**	**143.6**
Utilization			
Direct human consumption (DHC)	96.8	105.6 (75%)	110.4 (77% TWF)
Non-food uses (NFU)*	34.2	34.8 (25%)	33.3 (23% TWF)
Live/fresh fish	–	55.0 (39%)	66.6 (46% TWF)
Processed fish (PF)	–	86.0 (61%)	77.0 (54% TWF)
PF DHC	–	51.0 (59%)	57.0 (74% PF)
PF NFU	–	35.0 (41%)	20.0 (26% PF)
PF-DHC†			
Freezing	–	27.0 (53%)	28.5 (50% PFDHC)
Canning	–	12.2 (24%)	16.5 (29% PFDHC)
Curing	–	1.7 (23%)	12.0 (21% PFDHC)
International fish traded in processed form	–	90%	
International fish traded in live/ fresh form	–	10%	

* NFU is mainly as fishmeal/oils.
† Varies greatly by continent.
Source: From FAO (2007a, 2009).

(8.5 million) and aquaculturists (4.5 million). Whilst the numbers associated with aquaculture have risen there has been a decline in those employed in capture fisheries by 13% from 2001 to 2004. Overfishing has led to the reduction in fishing fleets through scrapping policies and subsequent redeployment of fishermen, many of whom have gone into aquaculture. The same trends have been seen in the industrialized nations (such as Japan and Norway) but capture fisheries have been very badly hit with numbers of fishers down by 18% from 1990 to 2004, although this is in part due to more efficient running of the fishing vessels which need less personnel as a consequence. At the same time, the average age of the fishermen has increased as younger people do not see fishing as an attractive, lucrative career with long-term prospects. Such people can be replaced by workers from the traditional (and poorer) fishing nations so that there is movement of fishermen around the globe. Finally, as much fishing is seasonal there has been an increasing casualization in the industry with an increase in the numbers of those who class themselves as part-time fishermen.

As ever, there is an incomplete picture of the role of women in fisheries although they are heavily involved in onshore activities such as preservation, processing and marketing. This can be either at the artisanal scale (fish smoking in Africa for example) or the industrial scale (as in the shrimp-processing factories of South-East Asia). Aquaculture is an occupation equally suited to women as men, so an increase in this sector might provide more employment for women.

In 2004 the world capture fleet had stabilized at about 4 million vessels and open boats outnumbered decked boats by 2:1. China operated the biggest fleet in terms of numbers, tonnage and power (over 500,000 vessels, over 7 million gross tonnes and 15.5 million kW, respectively). Virtually all the decked fishing boats were mechanized/powered but only about one third of the open boats were powered, usually by the addition of an outboard motor to a traditional craft. As mentioned above, overfishing has led to a reassessment of fleet capacity with several attempts to restrict and/or reduce numbers being made through compensation schemes, in the EU and China for example, but with little effect on the rate of decline in fishing vessel numbers (FAO, 2009). The imposition of a 200 mile Exclusive Economic Zone (EEZ) by many countries has hit the long-distance fleets of developed countries such as Iceland, Japan, the Russian Federation and Great Britain. The remaining, smaller fleets do, however, consist of bigger, more powerful vessels which offer greater safety and catching power and economic benefit. Inshore fleets (well within the EEZ limit) have grown and the balance between new vessels and scrapping/decommissioning has kept overall numbers steady. The sustainability concerns of an increasingly mechanized and more powerful world fleet are centred on fuel cost and efficiency, especially for distant-water vessels and the increased catching power of the traditional inshore fishery vessels once mechanized. The ability to convert fish oils to fuel (as biodiesel) would seem to be a possible means of maintaining fishing activity and utilizing an FPI by-product in an innovative manner, thus hitting two sustainability targets. On-board processing with mother ships and attendant fishing vessels might be another economic approach for certain fisheries (see Chapter 8).

The degree of exploitation of most fisheries is still a concern, whilst some are improving through good management and the introduction of governance schemes such as Regional Fisheries Management Organizations (RFMO). At the same time, trade in fishery products is at record levels (worth US$71.5 billion in 2004 and rising to US$85.9 billion in 2006) with all exporting countries showing increased trade and with intra- and inter-regional trade high. Such is the importance and value of fish exports (and in many cases the lack of alternative income) that for many countries' attempts to control fishing activity by national or international fleets are resisted. A recent report on efforts to restore overexploited fisheries showed that ***the average rate of exploitation*** (my italics) had declined in five out of ten well-studied ecosystems to a level at which a maximum sustainable yield could be achieved for seven of the systems. However, 63% of assessed fish stocks still require rebuilding and this is only achievable if a combination of fisheries management, catch restrictions, modification of fishing gear and closed areas are applied (Worm *et al.*, 2009). The issue of overfishing would be the subject of a whole book itself and cannot be tackled here, but whatever the outcome of attempts to restore and preserve fisheries it is incumbent on the FPI to make the best use of the catch which comes its way.

Table 1.1 also indicates the trends in fish utilization (for 2004) whereby 61% (86 million tonnes) of the TWF was processed (for DHC and NFU) and of that 59% was for DHC. By 2006 these proportions had changed, with 54% (77 million tonnes) being processed for DHC and NFU (a decrease compared to fresh fish used for DHC) but the proportion of PF for DHC had increased to 74%. Year-to-year figures are difficult to interpret but the decrease in the capture fishery from 2004 to 2006 should lead to less fish being processed for NFU as this sector is dominated by the anchoveta fishery for fishmeal/oil production and so fluctuations in this fishery will lead to less fish being processed for NFU. This would lead to less fish being processed overall, but a greater proportion being processed for DHC, hence the changes. Better reporting of inland fisheries and aquaculture in Africa and Latin America (FAO, 2009) would increase the fresh fish utilization figures as this is the preferred option in these areas. China dominates the freshwater fishery and aquaculture sectors and is suspected of over-reporting these sectors, so future figures will show more changes in these statistics (FAO, 2009).

The market for fish is unusual in that the demand for fresh and live fish is always greater than for PF in nearly all societies but the perishability of fish necessitates some form of processing. When fish is processed, the favoured method is freezing (53% in 2004), canning (24% in 2004) and curing (23% in 2004), with the proportions for 2006 being very similar (see Table 1.1). It should be noted that there are marked regional differences in the processing methods employed due to history and the availability of technology. When fish is traded on the international market it is overwhelmingly in the processed form (90%). PF NFU is mainly for fishmeal/fish oil production and hence a proportion will find its way into overall fish production as aquaculture feed.

Table 1.2 Food fish supply by continent and economic grouping in 2003 (FAO, 2007a).

Region	Total supply (million tonnes live weight equivalent)	Per capita supply (kg/yr)
World	104.1	16.5
World (excluding China)	71.1	14.2
Asia (excluding China)	36.3	14.3
China	33.1	25.8
Europe	14.5	19.9
North and Central America	9.4	18.6
Africa	7.0	8.2
South America	3.1	8.7
Oceania	0.8	19.9
Industrialized countries	27.4	29.7
LIFDCs (excluding China)	23.8	8.7
Developing countries (excluding LIFDCs)	15.8	15.5

LIFDC, Low-Income Food Deficit Countries.

Table 1.2 indicates the world food fish consumption by continent and by economic grouping in 2003. Per capita consumption of food fish has been increasing steadily (from 9.0 kg/yr in 1961 to 16.5 kg/yr in 2003), with China contributing greatly to the increase. There are also marked regional differences as shown by comparing the consumption for China (alone) and Asia (excluding China) to that for Africa and for the LIFDC as a whole. Currently, there are 82 countries described as LIFDC, of which exactly half are in Africa and 25 in Asia. Given that fish is highly nutritious (supplying minerals, proteins and essential fatty acids) attempts to increase consumption in these countries would seem a necessity but may be impeded by the export of fish products to the industrialized countries. The figures do, indeed, suggest a marked difference based on the economic rating of countries. The high consumption in industrialized countries (29.7 kg/yr in 2003 up from 20.0 kg/yr in 1961) has come about, partly, by the availability of high-value products such as shrimps, salmon and bivalves which are produced by aquaculture. The figures for 2005 (FAO, 2009) show little change from those given above: world per capita consumption was 16.4 kg/yr; consumption for industrialized countries 29.3 kg/yr and consumption for LIFDCs 8.3 kg/yr. The differences in consumption by economic grouping also suggest that there is a movement of products from developing/transition counties to the industrialized countries – this has both economic and social impacts and sustainability issues relating to the transport itself and the level of processing needed to make such transport possible, as mentioned above. Figure 1.2 illustrates the value of international trade in fish and fish products in 2003, with the balance being overwhelmingly from developing to developed countries (US$32 million) and between developed countries (US$23.8 million) compared to trade between developing countries (US$8.3 million) and from developed to developing countries (US$4.1 million) (Emerson, 2005).

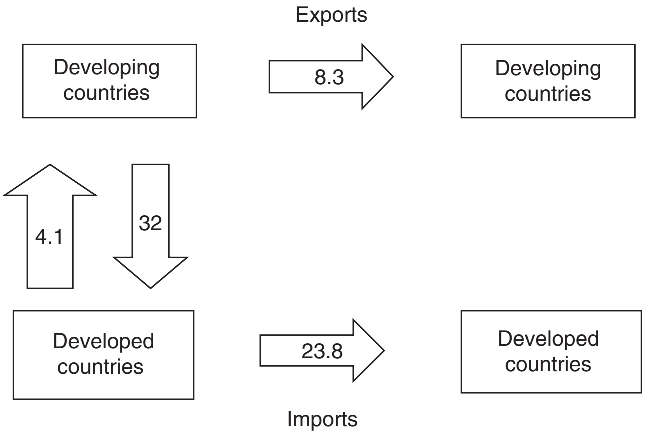

Figure 1.2 International fish trade, 2003 (US$ millions). (After Emerson, 2005.)

Table 1.3 SD implications of trends in world fisheries.

Activity	Implications
Fleet operation	Mechanization and powered vessels lead to fuel consumption and GHG – ameliorated by reduced number and changes in fleet movements
Aquaculture increases	Energy for feed production, pollution loss of habitat and biodiversity
International trade increases	Fuel for transport, GHG generated, energy for processing and storage – freezing, canning and drying
Frozen fish increases	Energy for cooling, storage and transport
Post-harvest losses	Fuel for smoking/drying inefficiently applied – nutritional quality lost

1.2 SUSTAINABILITY TOOLS

The SD implications of the trends described above are shown in Table 1.3 and can be described by two carbon-management concepts – carbon footprinting (CF) and carbon labelling (CL) – which are popular indicators to consumers that their purchasing is ethical. A third concept – life cycle assessment (LCA) – can also be used to investigate the SD impact of the FPI. Increasingly, these concepts are being applied across the 'Supply Chain', which brings into focus the activities of the companies which supply the central operation under assessment (the FPI here) and also those companies they sell to or who distribute and dispose of their products. The development of the appropriate tools to describe the impact of human activity on the environment is essential if the issues involved are to be argued in reasoned rather than emotive terms. They also give credence to claims by governments, industry and interest groups which can be trusted by the general public.

1.2.1 Carbon footprinting

CF is a measure of the greenhouse gases (GHG) associated with the manufacture of products taking into account raw material sourcing, processing, packaging and distribution and waste treatment. Emissions are described as 'direct' when associated with the main process or activity and 'indirect' when associated with upstream and downstream activities. The term 'GHG' can be defined as carbon dioxide only, or include other gases, particularly methane (with a GHG effect over 20 times that of carbon dioxide), or as carbon dioxide equivalents. In some cases it is difficult to convert an activity or process into GHG units and conversion factors are not uniform. Hence several definitions of CF have been proposed, some more rigorous than others, as described by Wiedmann and Minx (2007), who proposed the following definition of the term:

> The carbon footprint is a measure of the exclusive total carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product.

As mentioned above, the size of the CF can vary depending on how many core and peripheral activities relating to the product are included, for example the activities of suppliers to the principal manufacturer and even the GHG associated with the consumer travelling to buy the goods. Again, this is a contentious issue as the calculation of the CF is complex and there is ample scope for misleading an uneducated public. For example, what is the CF for frozen fish, produced by aquaculture (and so fed on fishmeal which was derived from the by-catch for a species used for DHC), which is then exported from the producer country to another?

In the fisheries sector emissions have been estimated, particularly with respect to raw material supply, processing methods and transport/storage with significant differences between fishery sectors (capture or aquaculture) and processing methods (FAO, 2009). In the capture fishery, fuel efficiency is related to the GHG emissions, the fuel used and the weight of catch achieved. The average ratio of carbon dioxide emissions was estimated as 3 Tg of carbon dioxide per million tonnes of fuel used. For aquaculture, energy consumption must include that used to produce feeds, and is higher for shrimp and carnivorous fish than for omnivorous fish, molluscs, bivalves and algae farming. Estimates for the ratio of edible protein energy output to industrial energy inputs vary from 1.4% to over 100% for these groups respectively. The international nature of fish trading has been mentioned already and this has an impact on the CF of the FPI. Airfreight may emit 8.5 kg of carbon dioxide per kilogram of fish transported which is 3.5 times that for sea freight and 90 times that for local transportation – defined as within 400 k of catching point (FAO, 2009). Actions to reduce these GHG emissions can give opportunities for new products and more local markets and/or a drive to more sustainable raw material supply, processing, transport and storage options.

1.2.2 Carbon labelling

Carbon labelling is a system that can enable the consumer to judge the green credentials of a product from the packaging in a similar manner to that for nutritional information. The form of the CL and the method for determining it are again open to interpretation and not as yet subject to international coding or scrutiny. A system of ecolabelling does apply in the fisheries sector following FAO guidelines drawn up in 2005 which were designed to improve fisheries practices through a market-driven approach based on consumer demand for environmentally friendly products (FAO, 2005). Ecolabels are given to products considered to have less environmental impact than their competitors including criteria such as 'dolphin-safe tuna', fish caught from sustainable fisheries or using selective fishing gear to reduce by-catch or from organic aquaculture practices. Such labels take several forms: self-certification by producers, certification by producer trade organizations or by third-party (independent) schemes. The latter include the United Kingdom-based Marine Stewardship Council (MSC) and the Marine Aquarium Council (MAC) based in the United States (ICTSD, 2006). In all cases compliance, trade restrictions if products are not certified and the scientific basis for the claims are all contentious issues. The developed economies have driven ecolabelling as an issue, as one would expect, and companies use it as a marketing tool for their products. Unilever have a Fish Sustainability Initiative (FSI) and work with the MSC, and J Sainsbury & Waitrose (the United Kingdom) and Whole Foods Markets (the United States) are other examples of this approach (Roheim and Sutinen, 2006). The effectiveness of ecolabelling is not proven in terms of market share or impact on fisheries (ICTSD, 2006). Iles (2007) argued that seafood producers are invisible to the consumer who only recognizes the well-known retailers of their products, so consumer pressure on producers was less telling than that of the production chain community (see Section 1.2.4). However, the demand by developed country consumers for ethically sourced fish products (according to the criteria described above) has now been extended to include the processing methods used. These should be equally ethical with due respect to the environment and societal impacts employed by the FPI (FAO, 2009). Thrane *et al.* (2009) discussed the use of ecolabelling for wild-caught seafood products and suggested that LCA studies showed that significant environmental impacts were attributable to post-landing operations such as processing, transport, cooling and packaging. Criteria reflecting these post-landing operations should be included in an LCA, and energy consumption, materials and waste handling and waste water highlighted.

1.2.3 Life cycle assessment

Life cycle assessment (also called life cycle analysis) is the investigation and evaluation of all the environmental impacts of a given product, process or service (see Figure 1.3). Concepts such as CF and ecolabelling rely on LCA for their credence as it provides a methodology which has some international standing and uniformity. An early definition of LCA was as follows:

> [T]he process of evaluating the effects that a product has on the environment over the entire period of its life cycle … extraction and processing; manufacture; transport and distribution; use, reuse and maintenance; recycling and final disposal (UNEP, 1996).

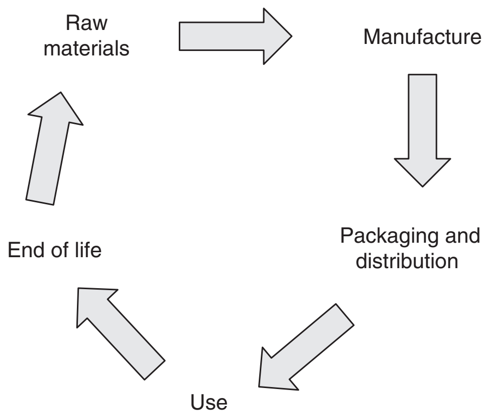

Figure 1.3 LCA: cradle-to-grave.

However, there are variants on the basic LCA definition, some being broader or narrower than others – a full LCA is sometimes called 'cradle-to-grave' – including all activities from raw material sourcing to disposal of all components after use. The LCA can be used for specific elements of a product stream such as energy, water, packaging and raw materials. As with the CF (a means of defining the LCA) there is scope for error due to the complex supply chains involved (in the FPI). An LCA can be used to develop an environmental management system. The description of an LCA process given here is based on that of the International Organization for Standardization 14040 series which is generally recognized (ISO, 2006).
As shown in Figure 1.4 an LCA will normally be divided into four activities:

Phase 1 – Goal and scope: The goal decides which aspects of the operation are included (setting the system boundaries), whether all aspects are included or specific aspects such as energy or water usage. The system boundaries are set by the scope definition and can be divided into four phases: (1) pre-manufacture, (2) manufacture, (3) packaging and distribution, and (4) use and end of life. Consideration of all phases would be 'cradle-to-grave', as mentioned above, or can be more limited such as 'cradle-to-factory gate', which would only include the first two phases. This phase also decides the purpose of the LCA and for whom it is being done as this will affect the data collected and its conversion to meaningful units. For SD the environmental impacts (see below) are important, and also energy and water usage and effluent production.

If a processing plant produces more than one product (co-products) then there must be an allocation of impact between them. The simplest approach is that of system allocation, which can be made on the simple basis of the mass of product or the economic value of the product. However, this approach does not seem to discern between any differences in process operations which lead to the co-products – not all process operations have equal impact. An alternative approach (preferred by the ISO 14040 series) is system expansion

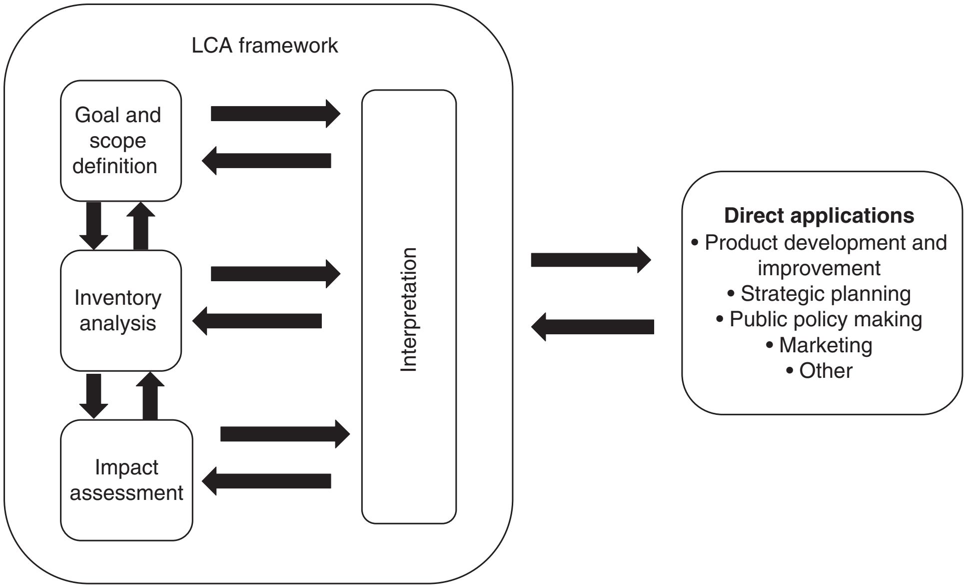

Figure 1.4 Stages in an LCA. (After ISO, 2006.)

whereby the co-products are considered as alternatives to other products available globally and an allowance made for this substitution in calculating the impact for the main process. This inclusion of alternative products necessarily involves an 'expansion' of the LCA to include their production processes – hence the name. The two approaches give rise to different results: the allocation approach only deals with the impact of the process under consideration whilst system expansion allows a consequential approach and can thus indicate the consequences of a change in process or market conditions on the LCA.

Phase 2 – Inventory analysis: This is a data collection phase and includes all inputs (e.g. energy, water and raw material), outputs (products) and emissions (to air, water, soil and solids) or those selected for inclusion. Accurate, relevant information is essential and must be available or derived from secondary data such as utility bills for water, gas and electricity. Various databases exist for generic activities such as electricity generation, transport and packaging and some for specific food processes to make life easier. This activity is the most time-consuming and challenging if a company has not attempted any such exercise before. A production system can be broken down into unit processes, batch or annual production, whichever best defines the system in meaningful numbers – this is called the functional unit.

Phase 3 – Life cycle impact analysis: In this activity the inventory analysis information is processed and first of all assigned to an environmental impact category with appropriate units which may conform to systems such as ISO 14000 series or be process-specific. Six common environmental impact categories are:

(i) ***Global warming*** where the main contributor is combustion of fossil fuels for various reasons and expressed as carbon dioxide equivalents.
(ii) ***Acidification*** which affects waters, forests and in some cases buildings is caused mainly by combustion for electricity, heating and transport and expressed as sulphur dioxide equivalents.
(iii) ***Eutrophication*** which leads to algal blooms and oxygen depletion and fish deaths is caused mainly by fertilizer nitrogen run-off into waters and expressed as nitrate equivalents.
(iv) ***Ozone depletion*** caused by man-made halocarbons (CFCs, HCFCs, etc.).
(v) ***Land use*** in the production of products and expressed as hectares per year (or square metres per year).
(vi) ***Photochemical*** smog from volatile organic compounds (VOCs) produced from unburnt petrol and diesel and organic solvents causes respiratory problems and reduces agriculture yields – expressed as ethane equivalents.

These categories are not exclusive and for certain applications the energy, water and effluent categories can be simplified from those above or made process-specific. Once categorized any emissions should be converted to the reference units for that category using equivalence factors. For CF, all inventory items are equated to GHG emissions and will require conversion to carbon dioxide equivalents for other gases, such as methane.

A sensitivity check will determine the accuracy of the inventory data whilst a normalization process will compare the relevant data to a reference system such as an existing process, for example. Normalization gives a relative magnitude of the process under consideration against impacts which are known and already quantified.

Finally, the inventory data can be weighted in terms of the most important environmental impact. The weighting criteria are, again, areas of debate and can be based on the judgement of a panel of experts, financial considerations and targets set by the company or government edict.

Phase 4 – Life cycle interpretation: The results of the impact analysis are compared with the original goal and scope of the project and judged, somewhat subjectively, against them. This analysis need not be left until the end of the LCA process but can take place continuously to ensure that the LCA is really achieving the goals and the scope is correct. This iterative approach to the interpretation of data will allow incremental improvements and/or changes to the goals and scope as necessary. The final interpretations should indicate the completeness of the data, the appropriateness of the analysis and reach conclusions and lead to recommendations for process improvement.

These four core elements of LCA are available in several software packages which lead the user through the phases, provide generic categories and conversion factors and impact assessment models. Variants for specific applications and sectors abound and international cooperation has led to greater uniformity and consolidation of methodologies (Finkbeiner *et al*., 2006). The importance of sustainability for the fishing sector has been recognized for some time and the environmental impact of the sector led to the early use of LCA to investigate the problems (Ziegler, 2003). A recent review of LCA in the food industry (Roy *et al*., 2009) described its use for a variety of agricultural products (bread making, dairy and meat among others) but also included packaging, land and water use and waste management considerations. Common problems were a lack of common functional units, the influence of non-food usage of crops such as for biofuels and the purpose of LCA itself in a world with population, land and water pressures. To reflect the latter case the functional unit could be the provision of a secure, healthy, balanced diet and the production, distribution and consumption of foods should reflect this in any LCA.

1.2.4 The supply chain

Successful companies, particularly those large companies with many business interactions, have used interventions in the supply chain to streamline operations and gain commercial benefits through increased efficiency and productivity, product development and reduced waste. A reasonable question to ask is, can the same approach reduce GHG emissions and promote SD? The answer is undoubtedly 'Yes' but when GHG emissions, an LCA or a CF are taken into account, current operations along the supply chain might require change to have a positive environmental impact. Actions to reduce the CF, such as energy or water usage reductions, will also give overt economic benefits (or might not be considered for implementation at all) but can also contribute to good public relations (contributing to CSR and the TBL). The supply chain approach must be applied in an all-embracing manner, rather than each company in the chain (including the central operation) looking only at the contribution of their own activities with a cumulative effect, which would be the traditional way to proceed. Such a coordinated approach demands collaboration (and trust) up and down the supply chain, around the central operation, with savings being identified for the product as a whole. The Carbon Trust in the United Kingdom is one organization which has developed supply chain models and supported case studies (Carbon Trust, 2006). Figure 1.5 illustrates the components of the supply chain carbon savings methodology.

The food industry (and thus the FPI) which processes primary products for the consumer is a prime example of the supply chain approach. The emissions associated with supplying food to the plate can be divided into direct emissions from energy consumed in the home, indirect emissions from the supply chain and travel emissions in getting the food to the home. Direct emissions in the home represent about 23%, indirect emissions along the supply chain are 69% and transport is 8% (Carbon Trust, 2006). Thus, the food industry has a large supply chain component which, if mobilized appropriately, could have a massive SD impact, and the central company by influencing its suppliers could have global impact and deliver genuine TBL benefits. The FPI with its emphasis on trade, and particularly developing-to-developed country product flows (see Figure 1.2), could be a prime example of beneficial supply chain interventions. Iles (2007) argued that seafood producers could be made more accountable through a production chain view and associated pressures, making them more transparent in the process, and suggested ways to achieve this, such as:

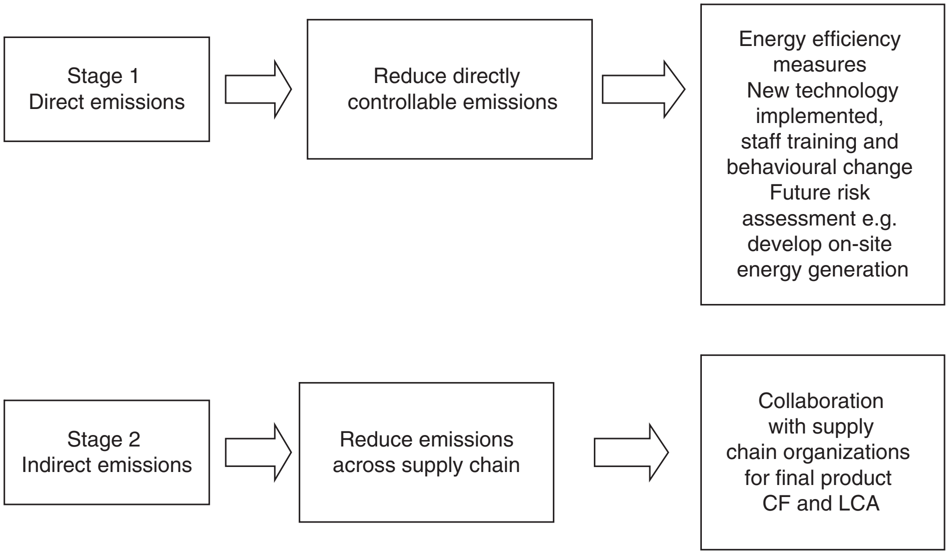

Figure 1.5 Supply chain carbon reduction methodology (a possible 'carbon offsetting' Stage 3 has not been included).

- identify and track companies to remove their invisibility;
- develop product chain campaigns so that companies influenced each other;
- develop mechanisms to compare companies to improve industry practices;
- develop methods to track consumption, production and management changes;
- develop interactive consumer tools so that consumers get feedback on their purchasing habits, which can also be fed back to the producers.

Thrane *et al*. (2009) emphasized the importance of the supply chain approach for ecolabelling which would include not only the fishing operations but also the post-lending operations, which have been shown to have high environmental impact.

1.3 CLIMATE CHANGE

The phenomenon of climate change (global warming) overarches any of the issues relating to the world fisheries with impacts which will lead to some detrimental and some beneficial effects. It is not possible to enter into the wider debate on climate change here as it is still under fast-moving discussion and global political negotiation but the relevance to fisheries and FPI can be highlighted. There is much international research activity dedicated to monitoring climate change and to forecasting impacts using computer modelling. Government activity both internal and international is directed to the reduction of GHG (and hence global warming) through the setting of ambitious targets for the near future and by adaptive measures towards the inevitable consequences of the current situation. The lead for this activity dates from the Kyoto Protocol of 1997 which came into force in 2005 and directed the industrialized nations to cut their collective GHG emissions by 5.2% from their 1990 levels (with varying individual national targets). The Kyoto Protocol also defined flexible mechanisms to help different economies to achieve these GHG emission limits, which include Emissions Trading, the Clean Development Mechanism and Joint Implementation.

In fisheries, the scientific networks and monitoring systems currently in place to address stock management are ideally suited to tracking the effect of climate change on fisheries – for example, the systems used for predicting, 'El Nino', and, 'La Nina', events (FAO, 2009). This scientific expertise should be adapted to generating the knowledge and evidence base to deal with the uncertainty surrounding climate change and its impact on aquatic ecosystems and the fisheries that depend on them. Some of the effects of climate change include:

- ***Displacement*** of warm-water species towards the poles.
- ***Changes in habitat size and productivity*** with lower latitudes (current tropical and subtropical bodies of water) becoming less productive and the higher latitudes becoming more productive.
- ***Changes in fish physiology and seasonality*** may affect reproductive cycles, migratory movement patterns, body composition and the spread of diseases and resistance to them.
- ***Extreme events*** such as floods, droughts, storms and 'El Niño' style events will increase due to differential warming between the land and the seas.
- ***Physical changes*** such as sea-level rise, melting glaciers, ocean acidification and changes in rain patterns will affect aquatic habitats as varied as coral reefs, estuaries and lakes.

What will be the effect of these changes on fisheries, both capture and aquaculture? Effects will be felt mostly by those fisheries dependent on specific water conditions such as those based on coral reefs or upwellings; estuarine fisheries will be prey to sea-level rise and salt invasion; and most low-lying coastal and island communities will be prone to physical disruption by extreme events. Aquaculture is concentrated in Asia where aquatic systems will be affected by water temperature rise and flooding or drought whilst the promise of increased aquaculture in Africa and Latin America will depend on adaptation of the sector to the new conditions. Overall, the vulnerability to climate change of any fishery- or aquaculture-dependent community is a combination of (FAO, 2007b):

- their exposure to climate change;
- sensitivity of the fishery (importance to national economy);
- potential impact (PI = exposure + sensitivity);
- adaptive capacity (AC = ability to cope with climate change).

$$\therefore \text{Vulnerability} = \boldsymbol{f}\,(\text{PI, AC})$$

As ever, the impact of climate change will bring new opportunities to those able to perceive them. There will be access to new fish species which thrive in the new conditions of higher water temperature and salinity and access to 'new' waters as dams are built to buffer the new rainfall patterns (World Bank, 2009). The FPI will need to change along with the fisheries supply sector by being creative and adaptive and ***paying attention to sustainability*** through fuel, energy and processing efficiency which will reduce the contribution of the sector to GHG and climate change. The climate change and global warming situation is ongoing, open to debate and becoming increasingly political. The mitigation of its impact on fisheries and the FPI will of necessity involve governments and sector representatives (local, national and international) in real communication at a level which presents information in an understandable form for often very different audiences (FAO, 2009). The World Bank Report 2010 on Development and Climate Change says that countries which share water courses must agree between themselves how to manage them for the greater good. For example, about one fifth of the world's renewable freshwater resources cross international borders but only 1% of these waters are covered by treaties and some of these treaties do not include all interested parties or are not enforced through a lack of national ratification (World Bank, 2009).

1.4 THE CAPTURE FISHERY

1.4.1 Current production levels

Marine capture fisheries still dominate world fish production, with the North-West and South Pacific regions being most prolific and countries bordering these regions (China, Peru, the United States and Chile) are the top producers. Anchoveta species provide the vast bulk of the fish caught, followed, at a distance, by Alaska pollock (*Theragra chalcogramma*) and various species of tuna. The North-West Atlantic is showing signs of recovery due to heavy management. Inland capture fisheries are dominated by Asia (64.8% of total catch) and Africa (24.7%) and the top three producers are China (26.2% of total catch), India (8.7%) and Bangladesh (7.9%). The most caught species are *Tilapia* and *Carp* although a vast number of miscellaneous species are recorded, reflecting the difficulty in obtaining accurate information from many African countries compared with Asian countries.

1.4.2 Future trends and fisheries management

There is a view that the marine capture fishery is at its peak and continued production is likely to remain between 80 and 90 million tonnes per annum. The FAO reported that between 25% and 30% of marine fish stocks were overexploited or depleted, about 50% were fully exploited with catches at or close to their maximum with no room for expansion and the proportion of underexploited stocks had declined from 40% (in the mid-1970s) to 20% by 2007 (FAO, 2009). This does not mean that the fishery is static in terms of regional differences, species caught and management practices being implemented. Adaptation to change is a constant factor and whilst the overall catch might remain level the components will differ from year to year. Fisheries management is recognized

Table 1.4 Important international fisheries and aquatic environment agreements which promote sustainable fisheries.

Date	Agreement title	Purpose
1946	International Whaling Convention	Established the International Whaling Commission (IWC) to proper conservation of stocks
1953	North-East Atlantic Fisheries Commission	Conservation and optimum utilization of the North-East Atlantic area
1971	Ramsar Convention on Wetlands of International Importance Especially as Wildfowl Habitat	National and international action for the conservation of wetlands and their resources
1982	UN Convention on the Law of the Sea	Comprehensive regime of law and order for the world's oceans and seas and their resources (EEZ)
1995	FAO Code of Conduct for Responsible Fisheries	Established principles and standards for national policies for responsible conservation of fisheries and management
1999	FAO International Plan of Action (IPOA) on Management of Fishing Capacity	Eliminate excess fishing capacity and match effort to sustainable fisheries resources (voluntary)
2001	FAO IPOA to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (IPOA-IUU)	Focuses on all states and entities and their fisher's responsibilities, market measures and research related to IUU (voluntary)

as crucial to maintaining the catch in some regions and to the recovery of depleted stocks. As mentioned earlier the recovery in the North-West Atlantic is due to severe management practices. Table 1.4 summarizes some of the important fisheries and environmental agreements which have come into force to protect aquatic environments and their role as food resources. The agreements cover a wide range of fisheries and related activities. Individual species (e.g. whales), ocean regions (e.g. the North-East Atlantic), habitats which are used by fishers (e.g. wetlands), conduct of fisheries (e.g. capacity) and governance (e.g. illegal operations and EEZ) are all covered by a series of widely recognized, often UN-based, initiatives. Some may argue that these agreements are not honoured by all nations and that they represent a heavy-handed regulatory approach. On the other hand, when applied properly they can protect and sustain fisheries and, given the reality and ubiquity of EEZ, they prevent a free-for-all which would eradicate some fisheries all together. The impact of climate change (see Section 1.3) will also have to be factored in to fisheries management plans and international agreements to allow mitigation and adaptive responses (FAO, 2009).

Freshwater capture fisheries information tends to be unreliable, particularly for subsistence fishing, so trend spotting is difficult. Overall, the fishery is robust with scope for improvement in Africa particularly and the main threat to the fishery comes from other pressures exerted on freshwater usage such as irrigation, hydroelectric generation schemes (damming) and drinking water provision.

Table 1.5 Aquaculture production in 2004: top producers by volume and top producers by growth (2002–4).

Producer	Quantity (tonnes)	Average annual percentage growth rate
Top five producers		
China	30,614,968	5.0
India	2,472,335	6.3
Vietnam	1,198,617	30.6
Thailand	1,172,866	10.8
Indonesia	1,045,051	6.9
Top five by growth		
Myanmar	400,360	45.1
Vietnam	1,198,617	30.6
Turkey	94,010	24.0
The Netherlands	78,925	20.4
Republic of Korea	405,748	16.9

Source: From FAO (2007a).

1.5 CONTRIBUTION OF AQUACULTURE

1.5.1 Current production levels

As shown in Table 1.1 the growth in aquaculture has been impressive between the year 2000 and 2004 and continued into 2006 (see also Table 1.5), and this trend is expected to continue – but at what rate it is debated. The worldwide average yearly rate of growth was 11.8% from 1985 to 1994 and 7.1% in the following decade (FAO, 2009).

China is by far the biggest contributor to aquaculture by any criterion (see Table 1.5) and will probably continue to be so but, in theory, there is great scope for aquaculture to expand in sub-Saharan Africa and Latin America as well. That being said, after China, the next biggest producers are India, Vietnam, Thailand and Indonesia and, in all, Asia represents over 90% of world aquaculture production. In fact, for the period 2004–6 the same five countries top world aquaculture production (FAO, 2009). The major species cultivated are carp followed by crustaceans (shrimps and prawns) although in terms of value the latter is a more valuable product. Growth in production of aquaculture products for DHC is still good being very high for finfish. Freshwater aquaculture accounts for about 56.6% of production, mariculture about 36% and brackish water about 7.0% (but 16.3% by value, as crustaceans in particular).

1.5.2 Future trends

Aquaculture production is expected to reach 53 million tonnes by 2010 if production outside China increases at about 8% – even if production in China stagnates (FAO, 2007a). Latin America and sub-Saharan Africa, as mentioned above, are considered as areas where increased growth is possible. For sub-Saharan

Africa this is critical because the consumption of fish has decreased (from 9.9 kg per capita in 1982 to 7.6 kg in 2003) against a world average of 16.5 kg per capita in 2003 (FAO, 2007a). The barriers to aquaculture development in the region are no different to others but intensified by political instability and the governance of business activity. The reality is that the top five aquaculture countries by growth for 2002–4 (see Table 1.5) include three Asian countries whose total production dwarfs that of Turkey and the Netherlands which appear in the list. However, the top five for growth for 2004–6 were Uganda (141.83% average annual percentage growth rate, APGR), Guatemala (82.20% APGR), Mozambique (62.24% APGR), Malawi (43.05% APGR) and Togo (40.72% APGR), although their combined output in 2006 was a mere 54,379 tonnes. The high growth rates for the African nations can be attributed to starting from very low numbers so that increases are small in real terms but large in relative terms; an influx in foreign capital and expertise to supply an export market; and public support for aquaculture in countries with above-average economic growth rates (FAO, 2009).

1.5.3 Barriers to increased production

As with the freshwater capture fishery there are outside pressures on availability of sites for aquaculture against demands for irrigation, drinking water and hydro-electric schemes. One solution may be more intensive aquaculture but this runs the risk of higher input costs, vulnerability to disease and environmental problems. An alternative view is for less intensive aquaculture combined with agriculture to balance water demands and risks, and to maintain the price of the product. This probably means that there must be a considered reassessment of current subsistence techniques with their balanced interactions between land animals, crops and aquaculture and their implementation in a commercial setting (Edwards, 1991). Such an approach if applied widely and over a period of time might also militate against the impacts of climate change mentioned in Section 1.3.

The major limitation to the growth of conventional aquaculture could be the provision of specialist feeds based on fishmeal and fish oils. The world price of fishmeal from 2000 to 2005 was US$500–700 per tonne but in 2006 it rose to US$1400 per tonne and has remained above US$1000 per tonne ever since. The aquaculture sector used 56% of world fishmeal supplies and 87% of fish oil supplies in 2006. The source of these materials is the capture fishery either deliberately or through by-catch and trash fish. Whilst progress is being made in finding alternatives to fishmeal, based on terrestrial sources, success has been largely limited to herbivorous finfish and crustacea, although the use of fishmeal in salmon feeds has declined from 50% to 30% (Klinkhardt, 2007). The International Fishmeal and Fish Oil Organisation estimates the use of fishmeal to increase by 5% (2.87–3.02 million tonnes) from 2002 to 2012 and fish oil demand to grow by 17% (0.83–0.97 million tonnes) in the same period (Tacon *et al.*, 2006). China is the dominant aquaculture producer (as in many other fisheries) so any speculation on world fisheries must pay close attention to changes happening there. Mitigating influences are that the demand for fishmeal for animal production may decrease and feed efficiency will increase. In addition, the use of fishmeal is limited to intensive aquaculture and the greater proportion of the sector based on home-produced feeds will grow despite changes in fishmeal availability via a less intensive production system as mentioned above.

The FAO State of World Fisheries and Aquaculture Report for 2008 (FAO, 2009) describes a series of scenarios for aquaculture development in eight regions of the world: sub-Saharan Africa, Latin America, South Asia, China, South-East Asia, and Europe, North America and Japan (as a group). The scenarios describe the factors affecting development such as demand growth for fish, satisfying demand growth, the possibilities for aquaculture and the effective constraints to development such as knowledge gaps and social concerns. Each region will face different challenges in these areas and need different solutions and policies to overcome them.

1.6 INDUSTRIAL FISH PRODUCTION

1.6.1 Current levels

The term 'industrial fish' is a positive way of redefining low-value trash fish or by-catch, indicating that such fish have a role to play. They have been defined as 'fish with low commercial value by virtue of their low quality, small size or low consumer preference – they can be used for human consumption (often heavily processed or preserved) or fed to livestock/fish, either directly, or through reduction to fish meal and fish oil' (FAO, 2007a). The amount used for DHC varies by country – being high in Bangladesh (60,000 tonnes from 71,000 tonnes of the capture fishery) and about 25% of the marine capture fishery in Asia as a whole. Processing the low-value fish into fish sauces and pastes gives added value to the catch. However, the vast majority of the industrial fish is caught deliberately and destined for fishmeal and about one third of this is provided by the Peruvian Anchoveta (*Engraulis ringens*) alone, making supply unreliable because of the fluctuations caused by the El Niño effect. The discussion above about the expansion of aquaculture has already mentioned the dependence on fishmeal availability, so the world approach to this resource will have an effect on aquaculture practices and on fish for DHC.

Industrial fish also appear as by-catch, the unintentional capture of non-target species when fishing for more valuable species. Such fish may be kept on-board for processing but may be discarded at sea as of low value although some is discarded due to regulatory requirements. Kelleher (2005) estimated recorded discards at about 8% of the total recorded landings by weight and shrimp, and demersal finfish trawl fisheries accounted for over 50% of these discards but only 22% of recorded landings.

Discarded fish can have environmental impacts in addition to being a waste of resources and fishing effort (Kelleher, 2005). Harrington *et al.* (2005) reported on by-catch and discards in the United States and found great regional differences although these differences reflected the fisheries found there. For example, shrimp trawl fishing generates the highest by-catch/discards rates and this is reflected in high figures for the South-East Atlantic and Gulf of Mexico areas where this fishery is prominent. Overall, the discard rate was 28% of the target landings, one of the highest in the world. The problem was being addressed by a range of measures ranging from the introduction of selective fishing gear, a complete change in fishing methods, regulatory controls appropriately applied and management programmes which might include limiting fishing capacity. The authors also noted that the lessons of by-catch prevention should be applied to new fisheries from the start as it is more difficult to change accepted practice once established.

1.6.2 Future trends

An argument can be made that every effort should be made to convert low-value fish into foods for DHC rather than the inefficient conversion into fishmeal and then food fish via aquaculture. This argument is based on economic and ethical (SD) ideas. For example, the small trash fish form part of the food chain for the larger (human food) fish and their removal will hurt the overall fishery. Secondly, converting the trash fish into fishmeal requires intensive high-energy processes not matched by the food value of the products. However, converting the trash fish into added-value products acceptable to the consumer may require energy, which must be justified by the consumption of the products. These arguments are at the heart of the SD debate in FPI and require a set of rigorous standards of comparison for judgements to be made in terms of inputs (energy, water and technology) and outputs (product type, consumer preference and volumes of product) and the management of both (a full LCA in other words). Products based on traditional fermentations under ambient conditions might be energy efficient but the products have limited application as foods. Currently, they are used as condiments to make bland rice-based diets appealing but are not major nutrient sources. Again, a reassessment of these traditional technologies is needed in the light of the challenges of energy supply and cost.

1.6.3 Redefining 'industrial species'

As any fish species could be considered for NFU it can be argued that all fish are potentially industrial species. The high-quality food fish will always be used for DHC whilst the rest must be assessed for diversion from fishmeal into foods for DHC. Technology can be applied to reduce the industrial fish to zero starting with selective fishing gear to prevent by-catch, bans on deliberate fishing and protecting juveniles followed by better utilization of the catch, new products and the development of new aquaculture feeds. For the FPI, better utilization and new product development are contributions that can be made (bearing in mind the caveats in Section 1.6.2). One particular contribution could be the conversion of processing by-products into speciality compounds, which enhance aquaculture feeds formulated from inputs other than fishmeal.

1.7 IMPLICATIONS FOR THE PROCESSING INDUSTRY

1.7.1 Efficiency in processing

As mentioned earlier the FPI acts as an intermediary between the raw material supplier and the consumer, preserving fish or transforming it into forms acceptable to the latter. Processing will inevitably mean the deployment of resources such as energy, water, equipment and management that add value to the raw material but at a price. In the past this price has been monetary with the environmental cost often being ignored – as long as the raw material, basic services and processing staff were plentiful and cheap. Increasing awareness about pollution has, over the years, led to improved environmental protection and increasing competition has led to more efficient processing operations (Roeckel *et al.*, 1996; Garcia-Sanda *et al.*, 2003). Where does this leave the SD agenda to have an impact? The answer is by addressing the same issues in the light of diminishing resources and increased trade and being more innovative in finding solutions based on the application of appropriate technology (see Section 1.7.5).

1.7.2 Food security and trade

Fish and fish products are widely traded commodities (and high value at US$85.9 billion in 2006), with over 194 exporting countries being involved and about 37% (live weight equivalent) of the total world production being exported as a wide variety of products in 2006 (FAO, 2009). The top five exporters were China, Norway, Thailand, the United States and Denmark although once again China dominated in volume and growth rate, and the main importers were Japan, the United States, Spain, France and Italy.

The most commonly traded commodities are (FAO, 2009):

- ***Shrimp*** (17% of total value of internationally traded fish products), although its value is falling despite growing volumes. This is leading some shrimp farmers to look at added-value products or diversification.
- ***Salmon*** (11% by total value and rising) mainly from Northern Europe, and North and South America.
- ***Groundfish*** such as cod, hake, haddock and pollock (10% by total value) are characterized by a high level of species substitution and new supplier countries which keeps the market steady.
- ***Tuna*** (8% by total value) but unstable due to fluctuations in catch levels.
- ***Fishmeal*** (5% of total value) and in high demand for aquaculture but susceptible to fluctuations when supply from the anchoveta catch off South America varies. Demand for fishmeal in the aquaculture sector is high (60% of fishmeal production) but even higher for fish oils (85% of total production mainly for salmon farming). The demand for fish oils for DHC is also keeping prices high – from US$915/tonne in 2007 to US$1700/tonne in 2008.
- ***Cephalopods*** (4.2% of total trade) from countries such as Thailand, Spain, China and Argentina with Spain, Italy and Japan as the main importers.

In addition to these groups the growth in aquaculture has introduced species such as bass, bream, tilapia and catfish to new markets and they are increasingly sold as processed fillets. There is much intra-regional trade, particularly in the EU where 84% of exports and 50% of imports are to/from member counties. The value of fishery exports from developing countries has become significant (see Figure 1.2 for export and import values for 2003) and the quantity exported for DHC rose from 43% in 1996 to 53% in 2006.

The monetary value of fish product exports is in fact far greater than that for well-known developing country products such as coffee, bananas, rubber and sugar (Emerson, 2005). In addition, these exports have tended to change from raw material supply to added-value processed products such as canned and frozen fish. In some cases fish is imported into these countries for processing and then re-exported through outsourcing of processing. Outsourcing brings fishing activity and FPI into the supply chain of large retail concerns which can be an influence for good in sustainability (see Section 1.2.4) but make it difficult for small-scale fish producers to enter international markets (FAO, 2009).

As mentioned earlier about 90% of fish is traded as processed products. The infrastructure needed to sustain the export of added-value processed products is at a high level, with a need for reliable services (water, sanitation and electricity), refrigeration, efficient transportation and roads and telecommunication systems. In addition there are other barriers to trade to overcome such as technical barriers, sanitary and phytosanitary standards, anti-dumping measures and quality standards (ICTSD, 2006; FAO, 2009).

The wider SD issues connected with trade are obvious in terms of the impact of long-distance transportation, supply chain relationships, working conditions in developing countries and the degree of openness with consumers when labelling products. The CF/LCA for such products can be difficult to define but the necessity to do so will lead to efforts to achieve a realistic approach. Responsible companies with a global reach can act as agents for good by passing down their SD ethos through their supply chain, driving up standards – rather than simply exporting the cost of dealing with sustainable production to low-wage, poorly governed regions. The TBL idea is very well demonstrated by the relationships between the fishermen, processors, import-exporters and distributors for fish products. Getting the balance right is difficult over physical and cultural distances. There is a need for transparency and accountability in the seafood industry at all levels although the tools needed to achieve this are well advanced (Iles, 2007).

Food security has been defined as a situation

> when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 1996).

The reliable supply of safe goods will also be enhanced by tackling SD as the threats to supply and quality and to sustainability are broadly the same and can be removed by the same approaches.

1.7.3 Introducing new food species

As mentioned in Section 1.4.2 the marine capture fishery is dynamic with operations and the species caught changing to reflect economic and governance situations. However, the ability to change from one species to another must be based on reliable data about the influence of such a change on the whole ecosystem. The relationship between prey and predator species has been long understood (Christensen, 1996; Christensen and Pauly, 1997) so that changes in a fishery to species up (and down) the food chain should be made with care.

A new fishery can open up opportunities for new products or variations on conventional products based on experience with the traditional species. Differences in performance should not be seen as inferior but merely different and experimentation should be encouraged. A good example is the use of species other than Alaska pollock for the production of surimi. Although pollock might be the preferred 'gold standard' species, stock reduction and the closure of certain fisheries have led to a search for substitutes (Hall and Ahmad, 1997 and see Chapter 5).

In aquaculture the issues are different as the major species grown can be controlled more easily and a change from one species to another can be made in a well-managed manner. Disease resistance and transfer are important in intensive systems and in the developing ornamental fish-farming sector. A transfer from low-value, low-intensity species to higher-value species can be done quickly but contributes to a 'boom and bust' cycle of events with unwelcome environmental and social outcomes.

1.7.4 Post-harvest losses

Post-harvest losses can include those fish discarded immediately at sea (bycatch) or converted to fishmeal, but the term is more usually associated with the losses in small-scale, artisanal fishing after some form of processing. In this case fish are not discarded at sea but landed, processed and distributed and sold in markets. Losses are rarely physical but economic as spoilage, poor processing and a poor road infrastructure lead to a product with low market value. In Africa these losses are commonly estimated at 20–25% of the catch but might reach 50% at times of glut when processing capacity is overwhelmed and raw material spoilage inevitably occurs. These losses are significant because many sub-Saharan countries have LIFDC status and post-harvest losses of any magnitude would be detrimental.

Spoilage can start on-board if there is inadequate, or no, icing combined with poor handling of the catch and long distances from fishing ground to port. On land the fish can be sun-dried, salted/cured or smoked or processed by combinations of all three processes. High temperature and humidity hinder sun-drying and lead to rapid microbial spoilage and the presence of a large variety of insects leads to infestation. Poor roads lead to physical disintegration of brittle, over-processed fish.

One critical issue with these traditional processes is the lack of control when the process depends on nature (sun-drying) or quality of salt (curing) or heat distribution (smoking). It is difficult to reproduce these processes, without instrumentation or careful management, at a cost that can be borne by the consumer. From an SD view such control is essential for maximum fuel efficiency (smoking) and maximum recovery of quality nutrition (sun-drying and curing). Considerable effort has gone into the application of new technology and systems to reduce post-harvest losses but these efforts are in vain if the increased price of the resulting, better products are beyond the means of the consumer (see also Chapter 3, Section 3.5).

1.7.5 Environmental impact of fish processing

The TBL approach would suggest that attention to the environmental impact of FPI would give economic advantages, either in cost savings or through the development of new products from material previously considered waste. The social benefits accruing from this approach could be directly in job security and profits shared at all levels, and indirectly through the long-term sustainability of the industry.

The SD agenda for the FPI can also be encapsulated here in the concept of 'Cleaner Production' (CP), where the processing side of the fishery business aims to reduce waste, generate new products and reduce energy and water consumption as a contribution to the LCA of fisheries (Ayer *et al*., 2009). The authors recognized the importance of sustainability for renewable natural resources like fisheries which are limited in supply and can be overexploited and that we must optimize the 'eco-efficiency' of fishery systems and fish processing and consumption. Thus, CP contributes to eco-efficiency and so through to SD.

CP can be defined as

> the continuous application of an integrated, preventive, environmental strategy applied to processes, products and services to increase overall efficiency and reduce risks to humans and the environment (UNEP, 2000).

Eco-efficiency can be described as follows:

> Eco-efficiency is achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle to a level at least in line with the earth's estimated carrying capacity (Verfaillie and Bidwell, 2000).

Because the FPI is potentially a major contributor to the CF and hence to the LCA of fish products, the application of CP in this sector can significantly affect these environmental measures. CP can be applied from product and process design through distribution to disposal in a proactive manner rather than as an 'end-of-pipe' application (i.e. it can also be applied through the supply chain approach). The application of a CP assessment follows a very similar series of phases as does the LCA such that information gleaned for one form of assessment could be used for the other. The CP assessment phases are planning and organization; pre-assessment; assessment; evaluation and feasibility study; and implementation and continuation (UNEP, 1996); and thus very similar to the LCA (see Section 1.2.3). The contribution of CP (and eco-efficiency) to the SD agenda could evolve in such a way that the three concepts may become inseparable in time and CP will contribute to the TBL through protecting the environment, process worker and consumer, improving process efficiency and increasing profitability and competitiveness (UNEP, 2000).

1.8 CONCLUSION: SUSTAINABILITY IN THE FISH-PROCESSING INDUSTRY

The foregoing has set the scene for the following chapters, some of which describe specific processes and some look at generic practices. A common SD theme will be applied throughout using the concepts described above although not all analyses will apply equally to all areas of the FPI. The four main areas in the FPI, which can make an SD impact, are listed below.

Energy consumption: For driving machinery, producing ice, cooling and freezing and heat for steam generation, canning, smoking and drying/dehydration. Reduced energy consumption will conserve fossil fuels and reduce GHG emissions. Efforts must be made to convert wastes to energy where appropriate to substitute for conventional energy sources. Energy for transportation will not be included in depth in our discussion as this forms part of the general debate about all forms of transport but should be recognized in any full LCA for fish products. The contribution of the FPI to supplying its energy needs from within is included where appropriate.

Water consumption: For transporting fish around the plant, thawing, washing and cleaning the raw material and product and cleaning the plant and equipment. The substitution of sea water for freshwater, metering and control of water use and the reuse of waste water (where appropriate and safe) are possible measures to reduce the 'water footprint' of the process.

Effluent control: Discharges from the FPI are often dilute and in large volume but contain polluting organic matter such as oils and protein in solution or as suspended solids. Effective capture of the effluent will lead to less pollution and opportunities for developing valuable by-products. For example, modern membrane systems can handle large volumes of dilute effluent, require infrequent downtime for cleaning, concentrate the solubles and suspended solids for by-products and produce 'cleaner' water which may find other uses in the plant.

By-product development: The proportion of the fish for DHC might only be about 45% of the caught weight so there is scope for the use of the rest of the raw material as added-value by-products. Fishmeal and oils are obvious examples of this principle although these products have now developed their own fishery with attendant problems. The oils and proteins in the effluent (or derived from offals) are potentially valuable as the basis for biodiesel (oils) and enzymes (proteins). Whilst the importance of developing fish products for DHC must never be lost the potential for by-products must be explored.

It is our hope that the discerning reader will take the ideas and tools herein and apply them to their own sector, or at the very least, feel that there is a systematic approach, which they can follow. The chapters look at examples of the FPI from across the world and, again, it is our hope that the concepts can be exported to other regions and cultures. There is not one fishery, processing sector or continent of production and consumption or trading arrangement on Earth that is not under pressure if sustainability is to be achieved. An optimist would see these pressures as drivers for the application of human ingenuity, technology and economic activity tempered by environmental concern and social justice to achieve the TBL for fisheries.

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