A MULTI-CRITERIA EVALUATION METHODOLOGY FOR AN ECONOMICALLY AND ENVIRONMENTALLY SUSTAINABLE COFFEE INDUSTRY

by

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The Calf Path – Sam Walter Fosse (1858-1911)

One day, through the primeval wood, a calf walked home – as good calves should,
But made a trail all bent askew, a crooked trail, as all calves do.

That trail was taken up next day, by a dog that passed that way.
And then a wise bellwether sheep pursued the trail o'er vale and steep,
And drew the flock behind him, too, as good bellwethers always do.

And from that day, o'er hill and glade, through those old woods a path was made,
And many men wound in and out, and dodged, and turned, and bent about,
And utter words of righteous wrath, because 'twas such a crooked path.
But still they followed (do not laugh), the first migrations of the calf.

Each day a hundred thousand rout, trailed that zigzag calf about.
And o'er his crooked journey went, the traffic of a continent.
A hundred thousand men were led by one calf near two centuries dead.

A moral lesson this might teach, were I ordained and called to preach;
For men are prone to go it blind along the calf paths of the mind.
They work away from sun to sun to do what other men have done.
They follow in the beaten track and out and in and forth and back.
And still their devious course pursue, to keep the path that others do,
But how the wise old wood gods laugh, who saw the first primeval calf.
Ah! Many things this tale might teach – but I am not ordained to preach.

**

This thesis is dedicated to my Dad,
for showing me how to find my own path.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

LC50	Concentration of a substance resulting in lethality for 50% of a population
ff	Fanega - volume of coffee cherries to produce 46 kg of dry coffee
CRC	Costa Rican colon (~425 CRC = 1 $US in 2004)
ff/ha	fanegas per hectaure
kwh	kilowatt hours
Q_c	heat required to produce 1 kg of dry coffee beans
m_w	weight of water (1000 g)
m_c	weight of coffee (1000 g)
C_w	specific heat of water (4.2 J/g$\cdot$ C^o)
C_c	specific heat of coffee (based on wood) (1.6 J/g$\cdot$ C^o)
L_w	latent heat of water converted to steam (2.26 KJ/g)
T	temp at which water turns to steam (100 C^o)
T_a	ambient temperature (20 C^o)
CSI	Composite Sustainability Indicator
n	number of different criteria
w_i	weight assigned to objective *i*
c_i^n	measured value of sub-criterion n for c_i
w_i^n	relative weight assigned to sub-criterion n
FV	future value of money ($)
i	interest rate (%)
n_{yr}	number of years in the future
PVR	Present value of revenues ($)
PVF	Present value of fixed costs ($)
PVV	Present value of variable costs ($)
NPV_{score}	Net present value of system being analyzed
NPV_{max}	NPV for the most profitable system available to local conditions
NPV_{min}	NPV for the least profitable system
ER_{score}	Economic performance - score between 0 and 100 measured in CSI units
w_{NPV}	Weighting factor assigned to the NPV_{score}

w_{ER}	Weighting factor assigned to ER_{score}
A	Soil erosion rate (tonnes/ha/year) calculated using equation $A = R*K*LS*P*C$
R	Rainfall factor
K	Soil erodibility
LS	Slope factor
P	Factor relating to conservation practices
C	Factor relating to amount of soil cover vs bare soil exposed. Calculated using equation $C = PLU * CC * SC * SR$
PLU	Prior land use (can influence baseline levels of factors such as organic matter, fertility, compaction, or soil contamination) (unitless)
CC	Crop cover (percentage)
SC	Surface cover (percentage)
SR	Surface roughness (unitless)
Pr (AP)	Present return for the profit stream from alternative products and /or reduced operating costs ($)
Pr ([EC])	Present return from the avoided environmental costs and taxes during the lifetime of the investment ($)
Pr ([LC])	Present return from the avoided legal costs ($)
C&I	Capital equipment and installation costs ($)
Pc (O&M)	Present cost operating and maintenance costs during the lifetime of the investment ($)
S	Subsidy or Foreign Aid provided for "sustainable innovation/technology" ($)

Abbreviations

ABCR	Asociacion del beneficiadores de Costa Rica
APOT	Asociacion de productores organico de Turrialba
BOD	Biological oxygen demand
CATIE	Centro agronómico tropical de investición y ensenanza
CEGESTI	Center for Technology and Industrial Information Management (CEGESTI

CICAFE	Centro de Investigaciones en Café
COD	Chemical oxygen demand
CP	Cleaner production
EAIS	Environmental accounting information system.
EMS	Environmental Management Systems
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIS	Geographical information systems
HRT	Hydraulic retention time
IBS	Integrated bio-industrial systems
ICA	International Coffee Agreement
ICAFE	Instituto del café de Costa Rica
ICO	International Coffee Organization
IMF	International Monetary Fund
LCA	Life Cycle Assessment
MAG	Ministry of Agriculture and Livestock (Costa Rica)
MAUT	Multi-attribute utility theory
MCA	Multi-criteria analysis
MCE	Multi-criteria evaluation
NCPC	National cleaner production centre
NGO	Non government organization
OCs	Organochlorines
OHSA	Occupational Health and Saftery Act
PSR	Pressure-state-response
TNC	Transnational corporations
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
USAID	United States Agency for International Development
WCED	World Commission on Environment and Development
WHO	World Health Organization List of Symbols

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ABSTRACT

This study examined the current coffee production and processing system in Costa Rica in order to maximize its sustainability through cost and risk reductions and identification of new opportunities. A two-year field investigation was carried out, assessing resource, energy and water uses, characterizing by-products, and evaluating training, management and industry structure, with the aim of identifying opportunities for the implementation of cleaner production and industrial ecology strategies. It was observed that the application of industrial ecology and cleaner production strategies have been implemented in piecemeal and have not been widely accepted by the industry at large. The coffee production system in Costa Rica does not encourage the practice of environmentally sustainable methods within production or processing, and does not encourage the exploration of niche markets that rewards higher-valued coffee in terms of quality or socio-environmental consciousness. Changes in industry throughput, operational design, and management attitudes are needed to ensure sustainability within the industry. A number of opportunities for maximizing the sustainability of the coffee industry exist through: (a) strategic application of cleaner production, (b) effective use of resources, (c) alternative use of by-products, (d) efficient operational design, (e) training, (f) application of environmental management systems, (g) changes to industry structure, (h) a thorough understanding of stakeholder concerns, and (i) understanding the perceived barriers to sustainability.

In order to address the broader issues of sustainability of agro-industrial systems, various types of sustainability were highlighted and current sustainability frameworks were evaluated. A multi-criteria sustainability evaluation methodology was developed to take into consideration the various types of sustainability within industrial systems. The developed composite sustainability index (CSI) model is a management tool primarily focused on the requirements of managers and farmers of industrial systems. To induce a change towards more sustainable production, the stakeholders have to be first aware of the factors that should be considered and then how these factors can be influenced by their decisions and practices. The CSI proposed here integrated all factors: environmental (both biophysical and chemical), economical, social and institutional. Using this methodology, the sustainability of three different coffee production systems were then evaluated to determine the usefulness of the methodology as a tool for industry stakeholders to better understand (and therefore implement) holistic sustainability strategies.

CONTRIBUTIONS TO KNOWLEDGE

This study has provided an analysis of the present condition of the Costa Rican coffee industry and outlines technical and management opportunities to improve sustainability within the whole system. The following are the major contributions of the study:

1. A new integrated bio-system, that incorporates the various by-products from coffee production and processing into a cyclic system to maximize the usefulness of the various material and energy flows, was developed.

2. The importance of including institutional considerations in the decision making process of technology transfer projects was illustrated.

3. A Composite Sustainability Indicator (CSI) methodology was developed to assist the industry incorporate the concerns and issues of industry stakeholders. The CSI permits the integration of both qualitative and quantitative measures into an empirical evaluation that provides a simply numerical score.

4. A procedures of weighting and aggregating the indicators in a realistically simple manner, without undermining the end goal of providing the user with a realistic evaluation of the system's sustainability, was developed.

5. Direct comparison of the sustainability of two different systems and the changes in the same system over time were demonstrated, using the CSI.

1 INTRODUCTION

1.1 Industrial Ecology

In nature, the world's ecosystems have evolved to include a complex set of links that minimizes energy usage and allow all by-products to be completely utilized within the system (Tibbs, 1993). However, most industrial processes are linear systems that do not mimic the workings of a natural ecosystem. Discharges and wastes from industries are not used within their systems of production and as a result contribute to the degradation of surface and ground waters and the reduction in the productivity of surrounding ecosystems. To bridge the gap between human design and ecologically sustainable systems in nature, the concept of 'industrial ecology' emerged (Allenby and Graedel, 1998). Frosch and Gallopoulos (1989) suggested that companies could cut costs and reduce pollution by turning the waste of one process or industry (outputs) into another process or industry's raw material (inputs). Although, industrial ecology has been intuitively evident for many years, Erkman (1997) considered the article by Frosch and Gallopoulos (1989) to be the beginning of industrial ecology as a specific field of study.

There have been, nonetheless, many definitions of Industrial Ecology. Allenby (1993) defined industrial ecology as the management of the earth's resources in a way that to approaches and maintains a global carrying capacity for our species, which is both desirable and sustainable over time, given continued evolution of technology and quality of life. It is also necessary to take into consideration the existing (objectives) and desirable (normatives) patterns (Allenby, 1992).

Ehrenfeld (1997) on the other hand called industrial ecology "a largely analytical framework" that serves mostly to identify and enumerate the myriad flows of materials and technological artifacts within a web of producers and consumers. Tibbs (1993) believed that it fell somewhere between being a new field of study and merely a tool to be used. He stated that industrial ecology involves designing industrial infrastructures as if they were a series of interlocking man-made ecosystems interfacing with the natural global ecosystem. Industrial ecology should take the pattern of the natural environments as a model for solving environmental problems, creating a new paradigm for the industrial system as a process.

The common thread in all of these definitions is the essence that a man-made process should be designed to mimic a natural ecosystem, thus industrial ecology takes the pattern of the natural environments, creating a new model for the industrial systems as processes. This includes maximizing the resource and energy efficiencies, the elimination of toxic or dangerous materials from the process, and the reduction of emissions (Sanchez, 2003).

1.1.1 Cleaner Production

The concept of *cleaner production* (CP) was first introduced by the United Nations Environment Programme in 1989 (Sanchez, 2003). It represents the more efficient use of natural resources and thereby minimizes waste and pollution. The focus is on minimizing the cause or sources of pollution and wastes within the production process, rather than the implementation of end-of-pipe treatments (UNEP, 2002). Cleaner production is the first steps in the application of an industrial ecology framework in an industrial setting.

With the goal to avoid generating pollution in the first place, cleaner production frequently cut costs, reduces risks and identifies new opportunities (UNEP, 2002). A cleaner production assessment examines production processes and takes a life cycle approach to products and services. Costa Rica's UNIDO Cleaner Production Centre (Musmanni, 2003) describes cleaner production:

(a) for production processes, cleaner production includes the efficient use of raw materials and energy, the elimination of toxic or dangerous materials, and the reduction of emissions and wastes at the source,
(b) for products, the strategy focuses on reducing impacts along the entire life cycle of the products and services, from design to use and ultimate disposal, and

(c) for services, the strategy focuses on incorporating environmental concerns into designing and delivering services.

1.1.2 Eco-Efficiency

The term eco-efficiency can be used to describe an approach that focuses on the economic benefits that result from the more efficient use of resources and the prevention of emissions. Industry Canada (2003) suggests that eco-efficiency is the art of doing more with less, and maximizing value and efficiency within the industrial process. It can also be viewed as the physical manifestation of industrial ecology/cleaner production concepts within the industrial setting. DeSimone and Popoff (1997) discussed how eco-efficiency promotes pollution prevention strategies by linking environmental excellence to bottom-line benefits in business. Fussler and James (1996) stated that the aim of cleaner production is to implement operational processes that improve resource and energy efficiency and which have a positive economic benefit.

In general, eco-efficiency explores business opportunities that also result in environmental improvements. In practice, eco-efficiency has three core objectives: (a) increasing product or service value (where possible), (b) optimizing the use of resources, and (c) reducing environmental impacts (Industry Canada, 2003). These objectives are particularly applicable to developing countries. By focusing on integrating efficiency and innovation into industrial process in these countries, these regions have the opportunity to 'leap frog' over older ideas prevalent in industrialized countries that have left their industries encumbered with costly pollution control techniques. By learning from the mistakes of developed industrialized countries, developing nations can develop as the models of industrial innovators. The United Nations Industrial Development Organization (UNIDO) has established a number of cleaner production centers throughout the developing world with the specific aim to aid in this transition as cleaner production and eco-efficiency are considered complementary business strategies that promote sustainable development (NCPC, 2003).

To minimize the wastes generated from production processes, cleaner production offers preventative strategies to increase resource efficiency primarily through methods that reduce the amount of resources used, and increase their productivity. Another strategy that achieves waste minimization is to make use of the wastes by turning them into by-products of economic value. This is the aim of integrated bio-industrial systems.

1.1.3 Integrated Bio-Industrial Systems (IBS)

Integrated bio-industrial systems (IBS) are similar to industrial ecosystems in terms of promoting an industrial symbiosis to achieve environmental goals. The application of integrated bio-industrial systems relates almost exclusively to organic wastes produced in agricultural, fisheries or forest industries. IBS's normally begin with a main industry of focus, with interconnections made with other biological systems in an attempt to minimize emissions. The conversion of by-products into value-added products is intended to create a more ecologically sound and healthy environment, while providing viable income-generating activities and employment (Foo, 2001). Compared to the field of industrial ecology, the development of an IBS places more emphasis on improving socio-economic development when designing cyclical production and consumption systems.

One of the first large scale examples of an integrated bio-system was developed in Suva, Fiji, with the use of brewery wastes (Pauli, 1998). The author describes the system where the spent grains and liquids from a local brewery were used as the growth substrate and irrigation water for a mushroom cultivation operation. This newly created industry provided additional employment for the local population and the residue for these mushrooms was fed to livestock. In turn, the animal wastes are fed into a biodigester, where the methane is captured producing electricity for a local school. The remaining slurry is decomposed using vermi-composting and is used as manure on farm fields. This system successfully resulted in little to no waste being generated at each level of production. Since then, there have been many similar projects implemented in countries around the world. However, the idea of integrated bio-industrial systems has been implemented at the local farm level for years.

1.2 Application to Sustainable Development

Since The World Commission on Environment and Development (WCED) in Rio de Janeiro in 1992, it has been increasingly accepted that resource and environmental considerations must be integrated into the industrial planning and decision-making process of both government and industry if the goal of sustainable development is to be met (WEC-FAO, 1999). Industrial ecology provides a framework for these considerations; it allows for a steady reduction in the energy and resource required for future growth while increasing the efficiency of resource (including natural resources) use, reducing waste, and promoting resource recovery (Schwarz and Steininger, 1997). Ultimately, the only way a sustainable future is possible if a natural design is followed, through dependence on renewable energies, the minimization of waste in its present form and the elimination of all processes and materials that contribute non-reusable or non-biodegradable materials to the environment.

There is no sector in the economy where the opportunity to convert industrial by-products into multiple use products of economic value could be as rapidly achieved than in the agro-industrial sector, specifically that found within developing countries (Code, 2001). If agro-industrial management were to opt for an innovative approach towards handling their operations by-products, the outcome could champion the economic development so sought by developing nations today. With no increase in material resource input, the productive output could be increased dramatically (Rodriguez et al., 1998).

Cash crop operations have a core business. The tendency is to focus solely on a small portion of the resource - that part considered being of immediate commercial value – while discarding the rest. Their operations do not permit for the complete exploitation of the resource potential. Particularly in developing countries, lower operating costs and the abundance of cheap resources and human labour exacerbates this issue – resource and energy inefficiencies have been considered just a part of doing business (ABCR, 2003; and Musmanni, 2003). Pauli (1998) discussed the possibility developing these operations into bio-refineries, in a way similar to the complete exploitation of petrochemical compounds, by using the various agricultural by-products as feedstock for chemical manufacturing. However, there will be many steps in between present monoculture industrial practices and the ultimate goal of a complete bio-refinery operation at every facility or plantation. In between, there could be gradual implementation of low and medium-tech, positive return solutions that demonstrate the socio-economic and environmental benefits of producing value-added materials out of economically benign (or costly – in the case of wastes that need to be treated) products.

Developing countries in particular have been looking to increased productivity as a means to improve economic development, including the development of pest-resistant strains, improved pest control, and higher yielding plants. However, even with these implementations, it is unlikely that there is no longer the opportunity for the doubling and tripling of productivity that is ideally needed to meet their economic needs. The first Green Revolution has reached the stage where the only way for cash crops to double or triple their revenues is by cashing in on the total biomass that they produce (Pauli, 1998; and Rodriguez et al., 1998). Coffee plantations market only a small percentage of the total biomass produced (i.e, the seed of the fruits), palm oil plantations capitalize on only 11% of the biomass produced and sugar represents only about 15% of the cane crop (Pauli, 1998). The coconut oil industry marginalizes over 75% of the coconut's biomass (Code, 2001). Applications to agro-industrial operations could be one of the best platforms for socially equitable economic expansion, by evolving present day cash crops to a major source of wealth generation through the diversification of presently non-, or under-utilized raw materials.

The possibilities have taken hold in the minds of some more innovation producers and government officials. There are positive examples of some sugar cane producers in Brazil using the biomass of sugar cane, bagasse, as feed stock for the manufacture of fiber board and paper (NCPC, 2003), or in Costa Rica where some producers have it pelletized and used as a highly efficient energy source (ABCR, 2003). The palm oil industry of Costa Rica has also actively been seeking the assistance of the UNIDO Cleaner Production office in San Jose in order to develop alternatives for a number of their present waste streams (Musmanni, 2003). These forward-looking groups realize that biomass residues should not be treated as a waste, or even as a secondary product, for which one should just 'find' a use. This material should be treated as a raw resource in its own right, with a mind set of how to best extract value from its use.

1.3 Coffee Industry

The coffee industry uses only a small part of the total resource extracted from coffee plantations. Typically, the coffee processing facilities (or *beneficios* as they are know in Central America) that transform the coffee cherry to the dry, green coffee beans ready for export operate in the standard linear fashion noted in most man-made processes. In its present form the coffee industry is environmentally nor economically sustainable (ABCR, 2003). Deforestation associated with the drive for higher yields contribute to biodiversity loss, soil health degradation and erosion. Erosion and agrochemical inputs degrade the health of the soil that provides the basis for agricultural growth. It also contributes to the sedimentation and eutrophication of the waterways that provide, (a) clean water for human consumption, (b) habitat for species and (c) employment to fishermen and others who depend on nearby rivers, estuaries and coastal regions for their livelihood. Pesticides have been linked to elevated cancer rates, acute pesticide poisonings, the development of chemical resistant pests, and the evolution of secondary pests into problem infestations (Forastieri, 1999; Robinson and Mansingh, 1997; and Rice and Ward, 1997). It is also being linked to the degradation of the marine and aquatic environment (Robinson and Mansingh, 1997; and Bargh and Baru, 1982)

When coffee is processed, only about 20 % of the natural resource taken from the farm is converted into a useful product, the remainder of that resource is either sent to waste treatment facilities or, in some lesser developed settings, is discharged in local waterways. This contributes to the environmental degradation of the region because of the deposited effluent high BOD, COD and suspended solids (Adams and Dougan, 1981; Gautho et al., 1991; Segura and Reynolds, 1993; and ICAFE, 2003c).

Like any other industrial model, the coffee industry process is typically linear, with material and energy inputs, internal processes and material and energy outputs. The coffee bean defines the economics of production within the coffee industry since the price of coffee is the main reason for maintaining or increasing production. The few pollution abatement programs that have been rigorously initiated in some of the more developed settings have been viewed as the cost of doing business (ABCR, 2003; and Adams and Ghaly, 2005). There have been ongoing discussions about improving the efficiency of the industry and reducing the negative outputs in terms of chemical and biological pollutants, but the main driving factor has been regulatory compliance, not resource (or economic) efficiencies (ICAFE, 2003b. This has limited innovation with the industry, as managers will only do enough to avoid fines. Environmental improvements have been largely limited to the implementation of environmental management systems (EMSs) and the availability of economical waste treatment technologies (Adams and Ghaly, 2005).

There has been similar linear thinking with regard to farming techniques. Traditional plantations with a diversity of edible and income-producing shade trees and ground cover were able to provide some stability to farmers when coffee prices dropped (Rice and Ward, 1997; and Campos, 2003). However, since the green revolution of past decades however these plantations have been increasing technified and have developed into energy and chemically intensive, monoculture crops plantations designed to increase yield in a time of high pricing and high demand. The significant increases in energy and agrochemical costs were offset by the increased yields and little considerations was given to increased economic risk associated with mono-crop cultivation (Rice and Ward, 1997; and Segura and Reynolds, 1993).

However, the coffee industry is now in the midst of a potential disaster. The world price has bottomed out at the lowest levels in years, while production costs, prices for agrochemicals and fuel continue to increase (ICO, 2004). As a result, farms and plantations are being abandoned, as producers cannot cover costs and have no other resources to fall back on (Danse, 2003; Schram, 2003; APOT, 2003; and Talbot, 1997).

Now, more than ever, the by-products of the processing, the possible economic outputs, and the reduction in energy and chemical intensity need to be looked at as a path to a sustainable industry. This is no longer for environmental reasons only, but as the economic solution to an industry in crisis. Any waste diverted to a value added process or an increase in operational efficiency is an economic plus. Any reduction in the quantity of pesticide used is a reduction in the harmful chemical affecting non-targeted species and a reduction in expenditures by the farmer, both financially and in health risks. Any move away from monoculture production is a move towards sustainable farming practices, self-sufficiency and reduced economic risk. Instead of being in the coffee bean producing business, the frame of reference needs to be one of complete exploitation of all available coffee resources.

The UNIDO Cleaner Production Center in Costa Rica has offered significant advice to ICAFE and the Ministry of Health and Environment on how to best address the pollution issues (NCPC, 2003). Some of the ideas have been implemented, but unfortunately, as often is the case, the government approach to controlling pollution within the coffee industry has been largely reductionist, treating each waste stream and material stream as separate instead of looking at the operation/industry as a whole (Adams and Ghaly, 2005c). For example, the use of anaerobic digesters is the only wastewater treatment technology that financial organizations will approve loans for (ABCR, 2003), and thus far the government has refused support opportunities for farming operations at the composting sites (such as flower or mushroom cultivation) in order to improve the return on investment for operations (Cutie, 2003). There is a significant excess of coffee pulp compost in Costa Rica because; (a) at present there is not sufficient demand to overcome the cost to transport large volumes of the compost from the four centralized locations presently operating in the Central Valley region (Ramirez, 2003; and Marcos, 2003), and (b) the composting process is presently unsuccessful in ensuring the elimination of broca eggs, a significant pest that can be transported regionally within coffee pulp and compost.

1.4 Research Needs

The mindset needs to change from one of linear production to one of cyclic production that includes the minimization and effective utilization of process wastes. While presently biomass wastes are often used as fuels, the chemical and nutritional composition of these wastes should be investigated to determine possible opportunities to convert them into valued added products or to use them in alternative processes that can take advantage of a cascading effect. Although the nutrient content of these wastes is substantial it is in a form in that is unavailable as a food source. Natural processes such as microbial degradation and fungi cultivation can be used to liberate these nutrients into a useable form (Pandey et al., 2000; Rodriguez et al., 1998; Wang, 1998; Roussos et al, 1995; and Martinez-Carrera et al., 1992).

There are obstacles to this change of mindset and those obstacles may vary from industry to industry and from region to region. When considering the opportunities to apply sustainability strategies, oftentimes the focus has been on the more traditional industrialized settings involving heavy industry or manufacturing. It has drawn on ideals that have been (at least in the recent past) more suited to industrialized nations. For example, the application of ISO14001, Life Cycle Assessment (LCA) tools, computer models and 'Best Management Practices' have a limited starting platform within some developing regions. There is a lack of consideration with regards to social and cultural consideration found within the support systems presently available to aid with the implementation of environmental / efficiency improvements. Within Central America, there is also an apparent lack of a comprehensive database with regards to available knowledge for industries that wish to pursue alternative ways of doing business. Within Costa Rican coffee industry, the gap between researchers and end users is quite apparent. These observations will be further discussed in Chapter 5.

These observations have resulted in the idea of developing an evaluation methodology that incorporated industrial ecology based ideas to aid industries within developing countries transform their linear processes to manmade ecosystems. The concepts outlined in this research can help provide a framework for improving the overall sustainability of agro-industrial activity. There is a need for the development of an evaluation system that can be used to assist in the development of sustainable solutions. The application of this methodology was developed with the holistic systems approach in mind, through the integration of the networks of producers, suppliers and recyclers, and the material and energy flows found within the system, comparable to the symbiotic relationship found in biological food webs. This is while considering the social and cultural conditions that provide the backdrop for the operational setting and the environmental and health impacts along with the economic sustainability of the system.

Before a broader systems view of possibly developing interconnections between external industries and processes can be established, it is important to first optimize the efficiency with which resources are traditionally being used in each individual process. For the purpose of this research, evaluation model development and testing was based on data obtained through a case study of the coffee industry of Central America. This case study focused primarily on improving the environmental performance and resource efficiency of the industry, with inclusion of the social and cultural considerations, which could result in obstacles that had not been previously included. Although some connections with other industry sectors was sought to achieve this objective, emphasis was placed on optimizing the efficiency of material use within the individual systems of production where possible.

2 OBJECTIVES

The aim of this study was to develop a multi-criteria evaluation methodology that would enable stakeholders to evaluate the sustainability of agro-industrial systems and processes, and to aid in the decision of implementing sustainable technical innovations. The specific objective were:

1. To determine the needs and challenges faced by the coffee industry, using Costa Rica as a case study, with the aim of:
   (a) developing a strategy to aid the industry evolve through the incorporation of industrial ecology ideals into operational and organization structures,
   (b) evaluating the economic and social climate, and
   (c) investigating the material and energy throughputs found in coffee production.
2. To evaluate parameters that influence the implementation of environmental innovation and lead to environmental sustainability within the coffee industry.
3. To identify barriers to sustainability.
4. To develop a multi-criteria evaluation methodology, that could be used to evaluate industrial operations in terms of resource and energy utilization inefficiencies, based on the guiding principals of industrial ecology and integrated bio-systems, specifically:
   (a) the consideration of social conditions, cultural attitudes, and health and safety issues within the objective functions of the model, and
   (b) the integration of industry by-products back into the system - as raw materials for new industries and new products.
5. To offer suggestions/solutions to industries on how to:
   (a) maximize efficiency/efficacy of resource use, and
   (b) minimize energy use, waste production and negative environmental impacts.

3 SCOPE

For the purpose of this research, the coffee industry will be used as a case study. This was done for two purposes: (a) to demonstrate the applicability of these ideas to industries within the developing world and (b) to offer solutions to an industry presently experiencing severe economic crisis. The aim is to do a complete evaluation of the processing aspects of coffee and to develop a multi-criteria based decision making model that allows the industry to analyze present systems in terms of material and energy throughput while considering the social, health and ecological impacts, and to help determine what opportunities are present for the implementation of industrial ecology concepts into industrial systems and processes. The study will be carried in three separate but interrelated stages.

During the first stage a review of applications of cleaner production and industrial ecology concepts in developed and developing countries was completed. A research survey was conducted with stakeholders in the coffee industry during a five-month period of research at the Centro Agronómico Tropical de Investigación y Ensenanza (CATIE) in Costa Rica to gain a better understanding of concerns, ideas and issues, existing life cycle, typical operational practices and waste disposal/treatments.

The social, economic health and environmental issues and opportunities for waste utilization were identified during a second, four-month period of research with CATIE and an analyses of material and energy streams was performed. The impacts of present operational practices in the coffee industry, the quantification of those impacts, and the justification of implementing cleaner production strategies were investigated. An analyses of the waste-streams from the standpoint of viewing it as potential feedstock for new industrial development was performed. A determination of design factors (i.e. what is feasible within the economic, cultural and social climates of the industry) was conducted.

The third stage involved the development of an evaluation methodology that could aid the coffee industry with the reduction of non-useable materials, implementation of renewable energy sources and the integration of remaining processing wastes into industrial clusters that utilizes these resources to produce value added products in a way that approaches a closed-loop system. The applicability of the model to industrial processes in both developed and developing countries was addressed. Suggestions to maximize efficiency and minimize energy use, waste production and environmental impacts are provided.

4 LITERATURE REVIEW

4.1 History of Coffee Industry

Coffee was known in the Middle East at least by the 900 AD and gradually increased in popularity until it became a common drink amongst Arabic nations by the 15th century (Pendergast, 1999). Since that time, the world has progressively become more enamored with the "nectar of all men"(ICoffee, 1999). Countries that had access to fruit guarded it with ferocity, even passing laws that declared a death penalty for exporting seedlings and ripe coffee cherries. It appeared in Vienna and Venice around 1600 after the retreating Turkish army left behind 500 sacks of coffee. By 1650 coffee houses were well established in London and similar patterns of coffee houses arose in the American colonies. Tea remained the favourite of the Americans until the Boston Tea party in 1773 when American merchants destroyed British tea shipments in protest of British taxation leading up to the American Revolution. This caused a rapid decline in the popularity of tea, and coffee gained prominence (Pendergast, 1999).

Since its humble beginning, coffee has come to be a source of substantial income to countries blessed with the favourable conditions. Coffee has been the base for the economic and social development of many regions. The need for cheap and abundant labour was the primary impetus for the abolition of slavery in Latin America in the 1800s (Pendergast, 1999), as producers lobbied for the mass influx of European workers that could provide labour more cheaply than owned slaves. Coffee and the finances surrounding its production played a key role in the political evolution of major producing countries like India, Kenya, Guatemala and Brazil (Pendergast, 1999; and Paiva, 2000), leading to stability for some like Costa Rica (Winson, 1989) and turmoil for others such as Guatemala (Paige, 1997) as players vied for control and position within the coffee trade.

4.1.1 Commodity Statistics

Coffee is of vital a importance to many countries as a source of both employment and foreign exchange earnings. Coffee, after oil, is the largest valued commodity in international trade, with the annual value of export revenues in recent years exceeding $10 billion, while annual retail sales of coffee are estimated at 50$ billion (ICO, 2004). Moreover, it is a highly labour intensive industry, employing an estimated 100 million people in over 60 countries. The dependence on coffee is greatest in Africa, where there are 25 coffee exporting countries in which smallholders account for the majority of the production (ICO, 2004).

4.1.2 Types of Coffee and Locations

There are at least 50 different types of coffee trees, but only two major types are commercially important: *Coffea Arabica* and *Coffea Robusta.*

Coffea Arabica (or simply *arabica*) is the coffee tree originally found in Ethiopia, and spread to Indonesia (Java and Sumatra), India, Arabia, the West Indies and Latin America. It is grown at high altitude and is the slowest growing of the major varieties. It remains the premium coffee. A sub-species of *Arabica* is *Coffea Liberica*, a large plant, very hardy and disease resistant that can be grown right down at sea level in the most difficult areas. It is produced mainly in Liberia, parts of Indonesia (Java), Malaysia and the Philippines. The yield is low and the flavour is the poorest of the three varieties. Little is exported and it is useful mainly for blending. It represents less than 1 % of the international coffee market.

Coffea Robusta (or simply *robusta*) came to the world when the coffee plantations of India and the Middle East were being devastated by disease. A scientist (Emile Laurant) discovered this coffee tree growing in the wilds of the Belgium Congo (Pendergrast, 1999). It had many advantages including resistance to disease and more rapid maturation; producing fruit in two to three years. *Robusta* has become increasingly popular and is used extensively for instant coffee (Pendergrast, 1999; ICO, 2004; and Adams and Dougan, 1981), but connoisseurs do not find it to have the flavour and aroma of *Arabica.*

Presently, *arabica* represents ~ 70% of world production and is grown primarily in Central and South America. *Robusta* is grown primarily in the African nations. Asian producers offer some *arabica*; regions such as Sumatra and Java are well known for their top-grade *arabica*. However, Vietnam and the Indonesian archipelago are known primarily as *robusta* producers. Table 4.1 presents the annual production of the world's coffee producers. Table 4.2 presents total world production since 1990.

3.1.3 Early Socioeconomic Impacts

Many researchers have discussed at length, the important role that coffee has played in the economics and social development in developing countries (Paige, 1997; Winson, 1989; and Pendergast, 1999). In his speech at the World Coffee Conference in May, 2000, Paula Paiva (Vice-President of the Inter-American Development Bank) reiterated this sentiment in the Latin American context. He reported that the coffee sector was the catalyst for the economic and social modernization of producing countries, providing hard currency and capital accumulation for coffee growers, employment for immigrant labour, and having major impacts on the gross domestic product. It also led to foreign investment in infrastructure throughout the region (Paiva, 2000).

Coffee production also stimulated the insertion of Latin American economies in the world trade markets (Paige, 1997). The income generated by coffee production and exports created domestic demand in the industrial sector of many countries, allowing for gradual diversification of their economies (Talbot, 1995; and Pendergast, 1999).

The coffee influence on Africa and India came largely after the WWII. The European colonists who owned most of the coffee plantations were losing power over the local populations and the native peoples were looking to share the wealth that the British and French had developed (Pendergast, 1999). Coffee played a major role in the independence movements in Kenya, Uganda, the Ivory Coast, Angola and the Belgian Congo. By 1954, Africans were dominating the coffee industry. At the same time, rising coffee prices lead the United States to begin looking for alternative sources of coffee in an attempt to reduce their dependence on Latin America (Brazil in particular). As a result,

Table 4.1. Total coffee production of exporting members during the period of 1996/97 to 2001/2002 (ICO, 2004).

Country	Type	1996	1997	1998	1999	2000	2001
Bolivia	(A)	133	153	150	184	173	190
Brazil	(A/R)	27 664	22 758	34 550	32 345	32 004	28 137
Burundi	(A/R)	401	297	356	501	337	313
Ecuador	(A/R)	1 993	1 191	1 206	1 245	901	1 062
Indonesia	(R/A)	8 299	7 759	8 458	5 432	6 727	6 250
Madagascar	(R/A)	849	623	992	460	333	1 070
Malawi	(A)	49	61	64	59	63	64
Papua New Guinea	(A/R)	1 089	1 076	1 351	1 387	1 041	1 150
Paraguay	(A)	40	34	34	28	31	35
Peru	(A)	1 806	1 922	2 022	2 663	2 596	2 700
Rwanda	(A)	293	194	222	308	273	300
Zimbabwe	(A)	174	130	147	122	93	125
1 April		*42 790*	*36 198*	*49 552*	*44 734*	*44 572*	*41 396*
Congo, Rep. of	(R)	14	3	3	3	3	5
Cuba	(A)	366	300	280	318	300	300
Dominican Republic	(A)	519	941	422	694	680	900
Haiti	(A)	429	435	442	402	418	450
Philippines	(R/A)	890	935	685	739	775	759
Tanzania	(A/R)	765	624	739	837	827	925
Zambia	(A)	33	40	56	56	84	55
1 July		*3 016*	*3 278*	*2 627*	*3 049*	*3 087*	*3 394*
Benin	(R)	0	0	0	0	0	1
Cameroon	(R/A)	1 432	889	1 114	1 370	1 438	1 380
Central African Rep.	(R)	208	115	214	241	116	220
Colombia	(A)	10 876	12 211	11 024	9 398	10 532	11 500
Congo, Dem.Rep. of	(R/A)	794	800	644	457	414	870
Costa Rica	(A)	2 126	2 500	2 350	2 404	2 246	2 623
Côte d'Ivoire	(R)	4 528	3 682	2 042	5 899	3 974	4 100
El Salvador	(A)	2 534	2 175	2 056	2 835	1 717	1 630
Equatorial Guinea	(R)	1	2	1	0	0	3
Ethiopia	(A)	3 270	2 916	2 745	3 505	2 768	3 917
Gabon	(R)	2	3	4	2	0	3
Ghana	(R)	32	28	45	45	38	50
Guatemala	(A/R)	4 524	4 219	4 893	5 201	4 700	3 900
Guinea	(R)	148	172	140	112	114	125
Honduras	(A)	2 004	2 564	2 195	2 985	2 667	2 300
India	(A/R)	3 469	4 729	4 372	5 457	4 853	5 293
Jamaica	(A)	54	46	29	39	37	42
Kenya	(A)	1 246	882	1 173	1 502	988	917
Liberia	(R)	5	5	5	5	5	5
Mexico	(A)	5 324	5 045	5 051	6 442	5 125	5 500
Nicaragua	(A)	793	1 084	1 073	1 532	1 610	1 040
Nigeria	(R)	46	45	46	57	45	55
Panama	(A)	211	218	192	167	170	160
Sierra Leone	(R)	41	50	24	76	28	45
Sri Lanka	(R/A)	37	58	35	38	43	40
Thailand	(R)	1 403	1 293	916	1 271	1 692	1 243
Togo	(R)	290	222	321	263	334	285
Trinidad and Tobago	(R)	18	20	17	16	14	15
Uganda	(R/A)	4 297	2 552	3 298	3 097	3 205	3 250
Venezuela	(A)	1 200	986	991	717	1 075	1 085
Vietnam	(R)	5 705	6 915	6 972	11 648	14 775	12 600
1 October		*56 618*	*56 426*	*53 982*	*66 781*	*64 723*	*64 197*
TOTALS (000) bags*		102 495	95 966	106 246	114 619	112 442	109 112

A – *Arabica*
R - *Robusta*
* A bag of coffee is equivalent to 60 kg

Table 4.2. Total world coffee production during the period of 1989/1990 to 2003/2004 (ICO, 2004).

Crop Year	Total World Production (1000 bags)*
1989/90	93 321
1990/91	101 552
1991/92	88 913
1992/93	90 366
1993/94	95 154
1994/95	85 250
1995/96	102 445
1996/97	96 129
1997/98	106 123
1998/99	114 523
1999/00	112 336
2000/01	109 275
2001/02	119 444
2002/03	101 382

* A bag of coffee is equivalent to 60 kg

African coffee that had accounted for only 4.8 % of US Coffee import in 1951, claimed 11.4% four years later (ICO, 2004; and Pendergast, 1999).

There is minimal information on what role, if any that coffee played in the early stages of modern development in Asia. The origins of coffee in this region were on the island of Java (now part of Indonesia), where *arabica* coffee was initially cultivated for colonial use in the mid-1700s (ICO, 2004; and Pendergast, 1999). Since then, Indonesia has become the world's largest producer of *robusta* coffee, but coffee has historically accounted for less than 8% of total exports and presently only represents 2.5% (Talbot, 1995). It would seem unlikely that the cultivation of coffee had a significant effect on the early socioeconomic develop of the region, one that was already known for its riches in spices, exotic timbers and minerals (Pendergast, 1999).

3.1.4 Present Socioeconomic Situation

The coffee sector has an excess of supply over demand, which has lead to the lowest prices in thirty years, with many producers now failing to cover production costs (ICO, 2004; and Diaz, 2002). Table 4.2 shows the steady growth over the last 13 years and the sharp decline in 2002-2003 as producers abandon their farms (Alfaro, 2003) Table 4.3 shows the importance that coffee plays for many of the worlds poorest countries accounting for up to 50% or more of some countries exports (Talbot, 1995)

The coffee commodity chain is a relatively simple one with minimal side branches beyond the transportation and packaging of the beans. The coffee tree is planted and tended, and then the coffee cherry is harvested and brought to the processor by the grower. Some small farmers will de-pulp the cherry themselves, but the coffee industry is moving towards centralized processing facilities that are also coordinated with the exporters. Virtually no value-added processing is performed in producing (or peripheral) countries; it is the green coffee bean that is exported to the core countries where the final products are prepared for retail (Talbot, 1997). Figure 4.1 outlines the typical coffee chain from grower to retailer to the consumer.

In recent years, plummeting prices have resulted in widespread poverty and emigration to urban areas throughout coffee producing nations around the world. In many cases, prices being received at the farm have fallen below the cost of non-labour inputs. By contrast, incomes in the importing coffee chains are holding up; the transnational corporations (TNCs) that have situated themselves in a monopoly control position of the processed product have not passed on the plummeting prices to the consumer. Trading companies, roaster and retailers have remained profitable throughout the past four decades of falling prices (Fitter and Kaplinsky, 2001; and Talbot, 1997). Some companies, such as Nestle and General Foods have sustained profit margins well above food industry averages (Talbot, 1997). Figure 4.2 reflects the distribution of coffee proceeds, from which it is evident that a growing share of the total incomes in the coffee chain is going to the importing, high-income countries. One of aspects that should be noted is that the margins that formerly went to intermediaries in the producing countries, such as marketing

Table 4.3. Dependence of major producing countries on coffee exports (Talbot, 1995).

Country	Coffee as % of Country's Exports	Market Share as % of Total Exports
Uganda	96.1	2.9
Burundi	82.9	0.9
Rwanda	80.1	0.9
Ethiopia	61.5	2.9
El Salvador	59.6	3.6
Tanzania	35.7	1.1
Guatemala	32.4	3.6
Madagascar	31.9	1.0
Colombia	30.5	17.8
Nicaragua	30.4	0.8
Kenya	23.8	2.6
Honduras	21.2	2.1
Costa Rica	20.7	2.9
Ivory Coast	18.8	5.6
Zaire	15.2	2.0
Ecuador	7.3	1.8
Brazil	5.9	21.9
Indonesia	2.5	5.6
Mexico	2.4	5.8
India	1.4	2.0

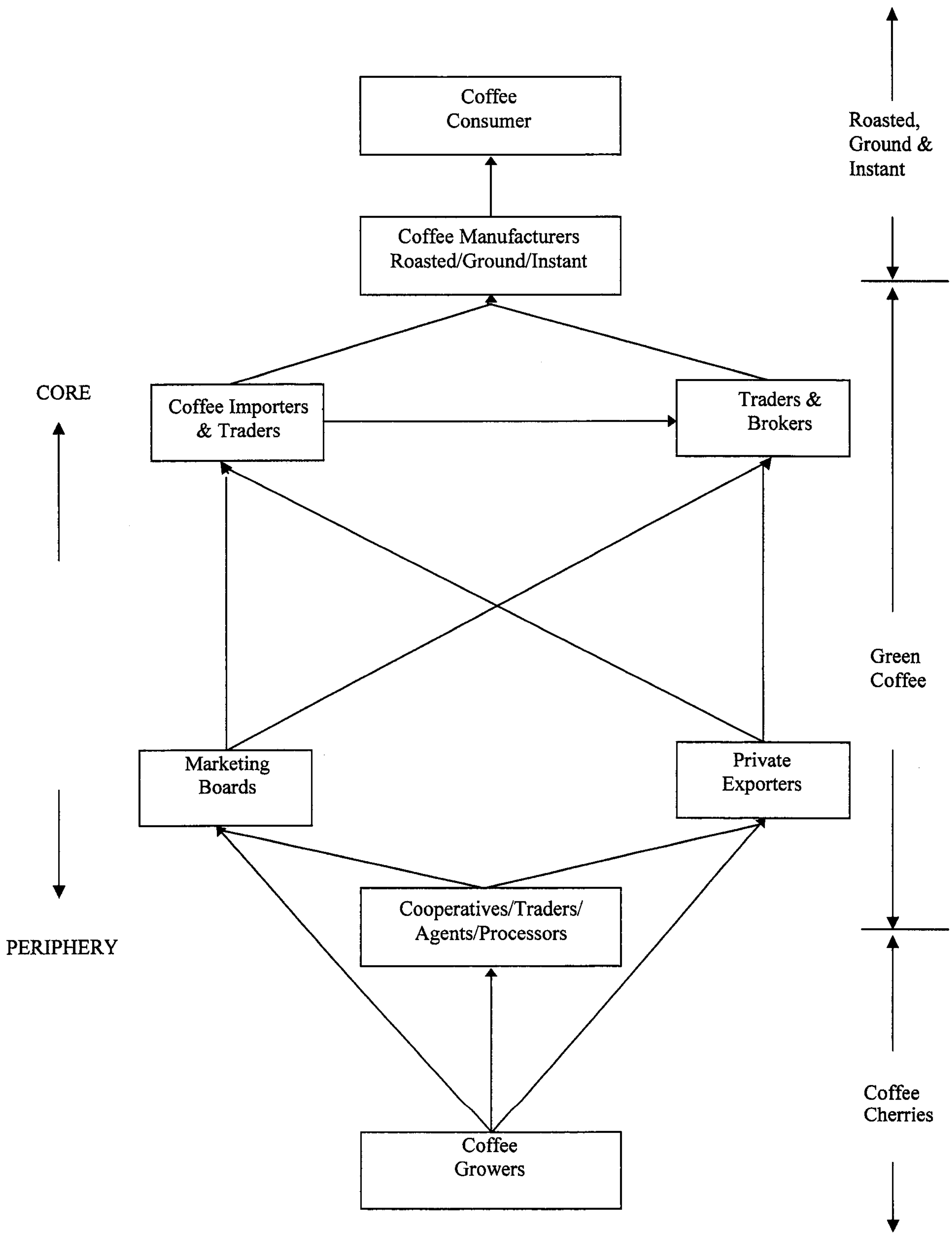


Figure 4.1. Coffee commodity chain (Talbot, 1997; and Diaz, 2002).

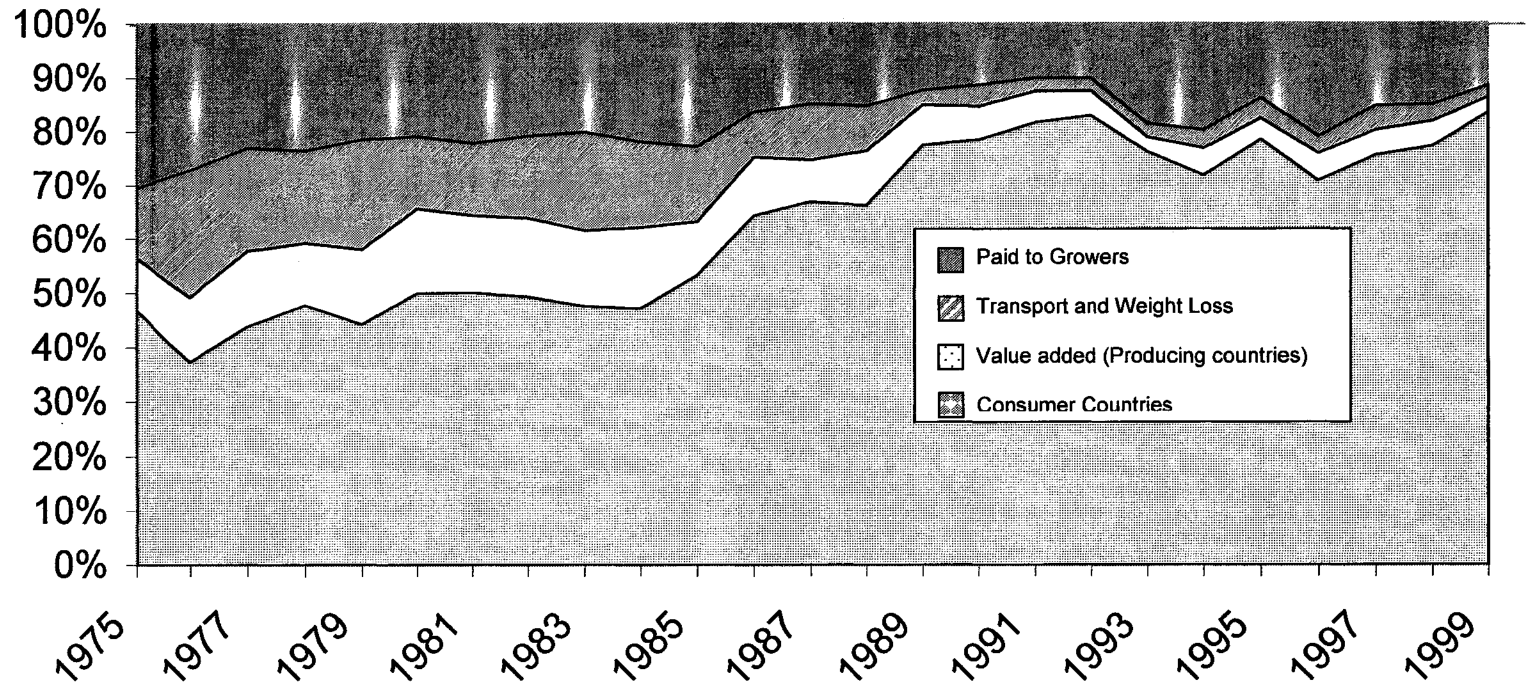


Figure: 4.2. Distribution of coffee proceeds (Fitter and Kaplinsky, 2001; and Talbot, 1997).

boards, have been eroded. This is largely due to pressures coming from multilateral agencies such as the World Bank to eliminate what were seen as parasitic intermediaries. However, instead of their share having gone to growers, it has been almost entirely consumed by the higher-income core countries (Talbot, 1997; and Fitter and Kaplinsky, 2001). By having the abolition of marketing boards imposed by these agencies, the producers of the seventy percent of global coffee grown on farms of less than five hectares are losing the bargaining power that they had in the past (Fitter and Kaplinsky, 2001).

4.1.5 Fair Trade

The 'Fair Trade' social justice movement being initiated by NGOs like Transfair and companies like Café Direct are hoping to aid in this crisis through the education of core-country consumers about the ethics of coffee consumption (Transfair, 2002). They hope to see that their members receive a minimal price for their coffee, which reflects true production costs and a small profit to allow small coffee farmers to survive. The aim is to appeal directly to the conscience of consumers, invoking them to pay a higher price for their coffee. The current pricing is between ~0.77$/kg for *robustas* and 1.65$/kg for *arabicas*; FairTrade guarantees a minimum price of 2.33$/kg and 2.77$/kg respectively. If the market value increases beyond this the farmer is paid a 10% premium (Transfair, 2002). This plan has been particularly successful in Europe with Fair Trade accounting for 1.6% in overall sales and up to 3% in countries like Switzerland and the Netherlands (FLO, 2002; and Rice, 2001)

Rice (2001) indicated that fair trade pricing is a conditional situation that promotes tolerance and assists in the move towards gender equality. Among other criteria to be meet, the producer group must consist of small farmers who depend on family labour to produce their coffee. The group must also be politically independent, be open to the acceptance of new members and do not practice discrimination on the basis of sex, religion, politics or race. It also must be organized and operated along democratic lines. As a result, Fair Trade promotes sustainable living conditions for these small producers, and it also brings social awareness to regions that may only be in the early stages of social development, particularly in the areas of the democratic decision-making process and women's rights.

4.1.6 International Coffee Agreements.

The International Coffee Agreement (ICA) was first initiated in 1963. Its aim was to halt a steady decline in worldwide coffee prices through the establishment of an export quota system. The fact that exporters supported this measure is not surprising, but most major importers were also signatories of the original agreement. Much of the literature explains this seemingly contradictory action as politically motivated as developed countries recognized the strategic importance of the African and Latin American regions and considered it necessary to stabilize the coffee industry in order to promote economic and political stability in these areas (Talbot, 1995; and Akiyama and Varangis, 1990).

In order to enforce export quotas, the International Coffee Organization issued export stamps on a quarterly basis to each exporting member. Importing members agreed to only buy coffee covered by these stamps. While it was obvious that exporting members could sell unlimited quantities to non-member importing countries, this typically occurred at significantly discounted prices as compared to that paid by importing members, which kept this activity in check to some extent. The overall effect was one of stability within the industry (Akiyama and Varangis, 1990).

Over time, these ongoing ICAs have had a stabilizing effect on the world coffee prices. The quotas reduced real export revenues for most small exporting countries, but large producers gained. However, most small countries gained in risk reduction however. (Akiyama and Varangis, 1990). In times when there has been a brief suspension in quotas typically due adverse weather conditions in Brazil or unstable politic conditions in another major producer, the quota system has worked as a buffer, allowing withheld product to enter the marketplace and assist in meeting demand. During the 1980-89 seasons for example, the ICA had an important influence in stabilizing pricing despite wild fluctuations in production. However, with the suspension of quotas in 1989 due to disagreements between members (primarily core-country members) prices dropped 40%.

Another ICA was signed in 1993, but due to the fact that the US and Vietnam (both one of the largest importers and producers, respectively) refused to sign it was believed unlikely that the agreement could be enforced to a point that it would be effective in raising prices (Fitter and Kaplinsky, 2001; ICO, 2002). As previously noted, prices were temporarily raised due to a Brazilian frost in 1994, but by the end of the 1999 prices had fallen to their 1990 level and have not recovered (Figure 4.3).

In response to this crisis the ICO signed a new International Coffee Agreement in 2001 in an attempt to raise coffee prices through quota regulation. Their plan is to destroy up to 15 million bags of coffee, retain 20% of global exports for three years, bring an end to World Bank fund coffee expansion programs, promote labour and environmental standards that will draw premium pricing and assist coffee farmers to diversify. However, the US and Vietnam are still noticeably absent from this agreement and many do not believe it will be successful without their participation (Fitter and Kaplinsky, 2001).

4.2 Coffee Cycle

4.2.1 Coffee Cherry

At the center of each coffee cherry there are two beans with flat surfaces facing each other (Figure 4.4). Each bean is completely surrounded by a delicate spermoderm tissue know as silver skin that is held in place by a fibrous membrane called the hull. Parchment is the term used to refer to the hull and silver skin collectively. A 0.5–2.0 mm thick layer of mucilage surrounds this hull (Bressani, 1979b).

The epicarp and the underlying flesh constitute the pulp that is removed during the first stage of processing. This pulp represents 40-43% of the fresh cherry weight (Gautho et al., 1991; and Mburu and Mwaura, 1996). The mucilage surrounding the bean is a colloidal system, lyophillic and represents ~ 5% of the dry weight of the coffee berry (Elias, 1979). Chemically, it contains water, pectins, sugars and organic acids. This fraction has neither tannins nor caffeine, but does contain pectin-degrading enzymes that come into play during processing of the coffee cherries to produce the green coffee

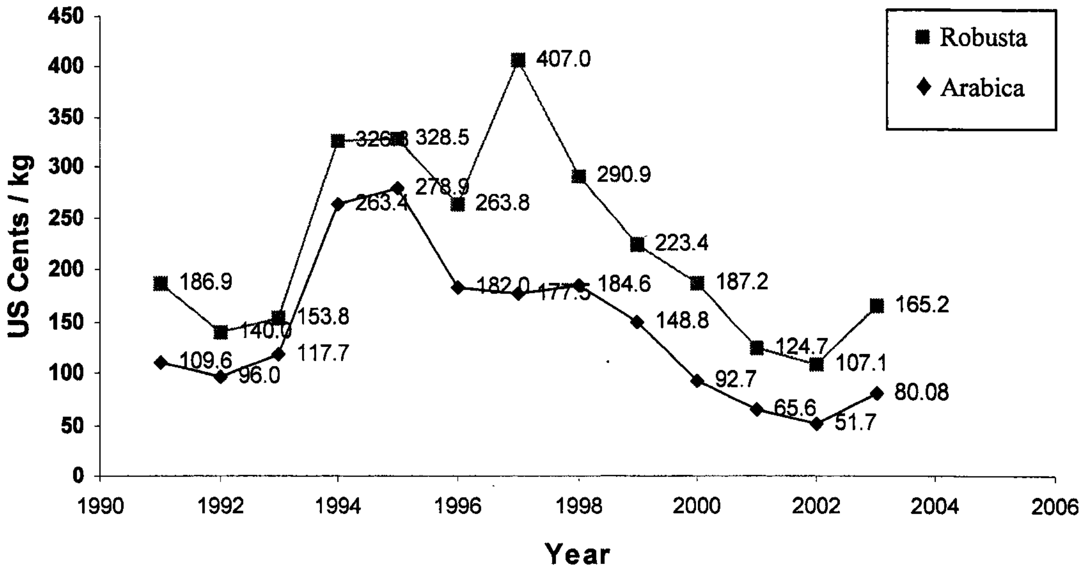


Figure 4.3. Mean annual coffee prices for the period of 1991-2003 (ICO, 2004).

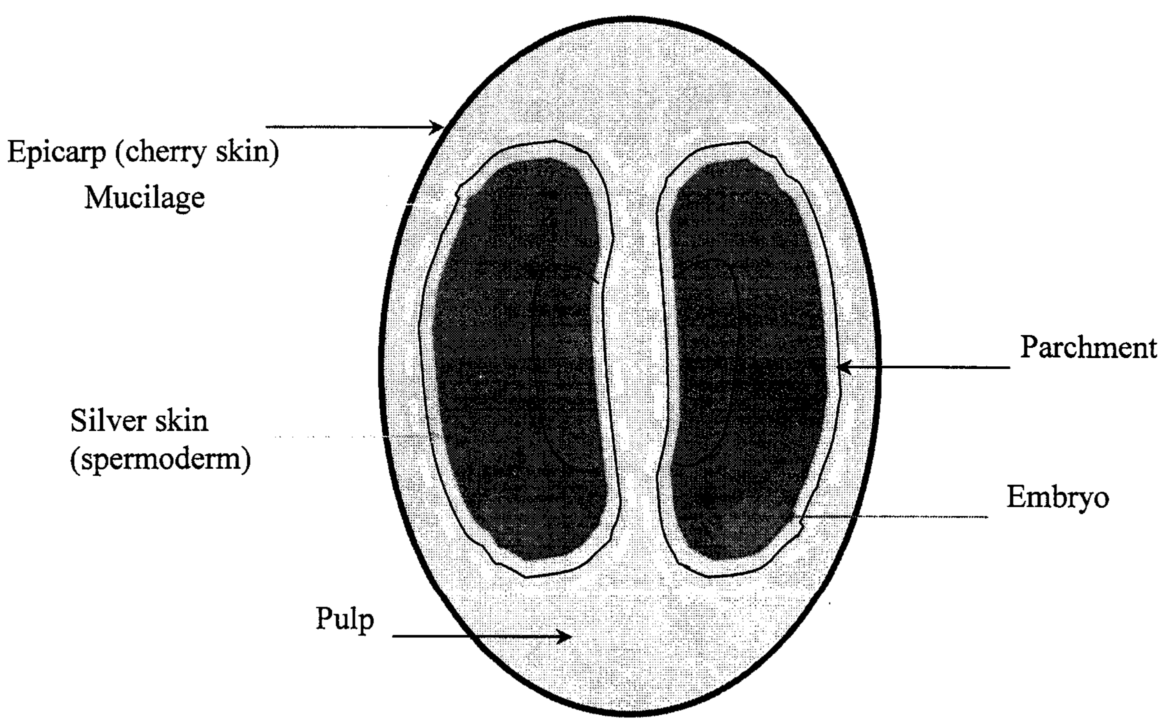


Figure 4.4. Longitudinal cross-section of a typical coffee cherry.

beans. The coffee parchment is primarily cellulose with a high crude fiber content (Elias, 1979). It has virtually no available nutritional value in natural form (Bressani, 1979b; Adams and Dougan, 1981; and Saenger et al., 2001).

4.2.2 Coffee Production

There are essentially two extremes of production systems for coffee; at opposite ends of the spectrum are traditional shade grown coffee at one end and sun grown coffee at the other. During his analysis of coffee production systems in El Salvador, Gobbi (2000) suggested five different production systems. These systems are varying hybrids of the two core methodologies that fall somewhere in between on the production spectrum. Four of these systems will be discussed below and include: shade coffee, technified shade coffee, sun coffee and organic coffee. The fifth system discussed by Gobbi (2000) is a subsystem of the technified shade coffee characterized by the number of strata used in the technified shade coffee production.

4.2.2.1 Shade Coffee Production. Shade coffee production was the methodology traditionally used in Latin America, the Caribbean and most parts of Africa, until the early 80s (Rice and Ward, 1997; Gobbi, 2000; and Moguel and Toledo, 1999) when, through the direction of USAID, shade plantations began to be replaced by sun coffee plantations (Talbot, 1995; and Rice and Ward, 1997). Traditional coffee plantations were intensively shaded, with the coffee bushes planted as part of the undergrowth of the forest. In addition to the natural overgrowth, the farmers would also replace original shade trees with value-added plant and timber species. Coffee farmers produced products such as bananas, plantains, citrus, medicinal herbs and extracts and timber; either for personal use or as additional cash crops that could be sold in times of lean coffee revenues (Pauli, 1998; Gobbi, 2000; and Babbar and Zak, 1995).

Due to the structural and floristic complexity of the shade trees, shade coffee plantations contain very high biodiversity (Gobbi, 2000; and Rice and Ward, 1997). This biodiversity allows the coffee to be grown with very little application of agrochemicals. Shade trees fix nitrogen in the soil (Babbar and Zak, 1995), thus reducing the need for chemical fertilizers. An integrated pest management system is inherent with this type of production (Rice and Ward, 1997). Birds and carnivorous insects that inhabit the trees eat the herbivore insects that attack the coffee. The presences of coffee-friendly herbivore insects (i.e. those that do not feed on coffee leaves) are also known to attack a variety of fungi that are harmful to coffee, and the canopy provides environmental services such as moisture and temperature control (Rice and Ward, 1997). As well, the lack of a mono-crop reduces the likelihood of a significant pest infestation to begin with.

4.2.2.2 <u>Technified-Shade Production</u>. This traditional production method is now being lost. The initial transition is to what is now called "Technified-Shade" plantations. (Gobbi, 2000). These plantations were originally initiated at the direction of the USAID, with the aim of increasing the yield of coffee plantations in order to meet an ever-growing consumer demand (Talbot, 1995; and Rice and Ward, 1997). The traditional shade cover was reduced to include only a limited number of species of shade trees and the use of agro-chemicals (typically supplied by US based TNCs) was heavily advocated (Rice and Ward, 1997). Additionally, any focus on additional value-added products being produced along side the coffee dwindled, leaving farmers dependant on their coffee crops alone. This transition is continuing and is leading to what is known as sun-grown coffee.

4.2.2.3 <u>Sun Coffee Production</u>. Sun coffee plantations are characterized by hedgerows of coffee trees planted very close together with little to no shade cover and an absence of any ground covering between the rows (Diaz, 2002; and Rice and Ward, 1997). Traditional varieties of coffee are being replaced by newer varieties that respond well to chemical fertilizers (Gobbi, 2000; and Rice and Ward, 1997). Aside from increased yields, USAID also promoted the idea to open up the coffee to the sun to deter the spread of fungal diseases, unfortunately this move has had little impact (Rice and Ward, 1997).

Rice and Ward (1997) stated that the transformation from shade coffee to sun coffee has closely resembled the 'green-revolution' associated with corn, wheat and rice production in the 1950s, particularly in eastern African countries and Latin America. The transition to sun coffee production has been increasing rapidly in the last 10 year. Of the 2.9 million hectares of coffee planted in Central America in the 1990s, 40% was sun coffee (Rice and Ward, 1997). Two relatively new strains of *C. Arabica*, (Catuai and Caturra), grow three times faster when exposed to sun and cultivated in high intensities. Unfortunately, instead of being resistant to fungal disease and "responding well" to chemical fertilizers, these varieties are virtually dependent on agro-chemicals for both their growth and protection from pests (Harner, 1997). Table 4.4 compares and contrasts the major parameters of sun-coffee cultivation vs traditional shade coffee.

There have been numerous studies investigating the environmental impacts associated with this transition. Nitrates provided by fertilizers are an often-cited source of water pollution (Boyce et al., 1994). Robinson and Mansingh (1997) found levels of organochlorine pesticides (used to combat coffee berry borer) in the water and fauna of the major rivers and coastal waters of the Blue Mountain Coffee area of Jamaica. Rice and Ward (1997) noted much-reduced biodiversity in sun-coffee plantations. They also noted significantly higher soil-erosion rates in plantation that had been transformed in Nicaragua and Jamaica. The same study demonstrated higher levels of soil moisture and organic material. Nutrient recycling is also affected by changes in plantation operations. Babbar and Zak (1995) reported that sun coffee loses almost three times more soil nitrogen through leaching than shade coffee plantations. In general, shade coffee systems were more conservative recyclers of nitrogen.

4.2.2.4 Organic Coffee Production. Organically grown coffee is essentially traditional shade grown coffee; the only difference being the actual certification that a plantation must undergo in order to be able to market its coffee as "organically grown" (Gobbi,2000; and Aronson, 2002). Quite often small coffee plantations are organic by default where (a) the farmer simply has continued to follow the same historical cultivation methods he has been accustomed to or (b) through necessity as the farmer cannot afford to purchase agro-chemicals and fertilizers (Gobbi, 2000; and Aronson, 2002).

Table 4.4. Sun and Traditional Coffee Production (Rice and Ward, 1997; Gobbi, 2001; and Diaz, 2002).

Production Charateristics	Sun Coffee	Traditional Coffee
Average yield per hectare	28-32 bags*	13 – 20 bags
Density (# trees per hectare)	3000-7000	1000-2000
Plantation longevity (years)	12-15	30
Years until first harvest	4 to 6	3
Shade Trees	None to limited	90%
Shade Tree Species (#s)	Short (5–8 m) selected leguminous species (heavily pruned)	Tall (25m) natural forest trees, interspersed with economical species such as banana, indigo and mahogany (growers choice)
Bio-Diversity (% of virgin forest)	10%	90%
Agrochemical use	high	None to low
Labour requirements	Year-round maintenance with higher demands at harvest	Seasonal for harvest and pruning

*one bag is a standard measurement equivalent to 60kg of green coffee

Rice (2001) suggested that governments and NGOs involved in the certification of organic coffee should develop a system that allows these 'accidental' organic farmers to capitalize on the organic movement. At present, organic certification is an expensive proposition as it is the farmer's responsibility to pay for certification officials to inspect his plantation. This is acceptable to a farmer with larger holdings, but for smaller farmers with less than 2 hectares of coffee cultivation, the cost of certification becomes prohibitive. Allowing these smaller farmers access to the organic market can provide an increased level of income and sustainability. At present the demand for organic coffee is greater than supply and the "converted" are willing to pay a premium for it.

It should also be noted that many organic certification organizations recognize the environmental importance of shade cover to issues such as biodiversity and will only certify farms with extensive multi-species shade, even if the technified-shade or sun-coffee plantations are grown using organic methods (Rice, 2001). Organizations that provide organic certification are realizing that the lack of agro-chemical input is not the final accomplishment and are increasingly supportive of programs aimed at improving socio-economic and environmental condition of coffee plantations that are outside of the tradition "organic" line of site (Rice, 2001). In reality, the same priorities and philosophies govern the organic movement, as that of the fair-trade movement, i.e. equity in all its forms: social, economic and environmental.

4.2.3 Processing

Both small-scale farms and large estates produce coffee. Typically, the processing facilities that handle this coffee are located in rural areas. In much of the world the processing is done on the farm, but the facilities used can range from full-scale automated operations to small-scale manual processes. However, in Costa Rica and El Salvador, the processing is done in centralized facilities called *beneficios* that service many farms in the region. These can be operated as co-operatives by the growers or as stand-alone businesses that purchase coffee from the farmers directly or through intermediary agents. Processing facilities do not operate all year round; they are directly linked to coffee harvest as the cherries need to be processed shortly after harvest to avoid degradation of the bean quality (Diaz, 2002; and Rice and Ward, 1997). In Latin America, the harvest typically runs from November to March, with some regional variation. In Africa, harvesting is done during two seasons: May to July and October to January. Regardless of the region, processing mills operate 5-6 months per year at the most (Rice and Ward, 1997; Zugasti, 2000; and Varangis et al., 2003).

There are two types of coffee processing: dry processing and wet processing. Wet processing, which is of greater environmental concern due to the abundant waste products associated with it, accounts for up to 50% of the world's annual production (Gautho et al., 1991; Adams and Dougan, 1981; and Rice and Ward, 1997). All *arabica* coffee, with the exception of Brazilian *arabica*, is produced using the wet processing method.

3.2.3.1 Wet Processing. After harvesting, the coffee berries are transported to the coffee mill and fed into a hopper. The cherries are normally transported to the depulper by water. The water serves two purposes: (a) removes green or spoiled berries and foreign material that rises to the surface; and (b) acts as a transport mechanism (Bressani, 1979b; and Gautho, 1995). Once in the depulper, the skin and flesh of the coffee is removed, leaving beans surrounded by a mucilaginous layer of 0.5-2.0 mm thickness. The pulp is discarded as waste and the remaining bean is placed in fermentation tanks.

Once in the tank the mucilage is allowed to ferment for 12 to 48 hours (depending on the condition of the cherry) and is digested through a combination of microbial activity and the work of endogenous enzymes contained within the mucilage (Adams & Dougan, 1980; Gautho, 1995). The clean, parchment covered beans are sent to the dryers, whereas the water and mucilage are discharged as wastewater.

The parchment-co vered beans are then dried to ~12% moisture (sun dried or using mechanical drying machines). The parchment and silver skin are then removed. This can be done mechanically by hulling machines or by manually shaking the beans in large screened boxes that allow the parchment to be separated from the beans. Parchment is then discarded and is typically burned as fuel, used either in the mill or sold to locals. Figure 4.5 shows the typical process. It should, however, be noted that while all wet processing has the same steps, the mechanisms and level of automation within this system can vary substantially from operation to operation.

Wet processing has increasingly been facing the following major problems:

1. **Inadequate water supply** – a minimum of 22500 L is required to process one tonne of coffee. If water minimization technologies and practices have not been implemented, the processing of one tonne of coffee can require up to 90000 L of water.

2. **Waste disposal** – 22500 L of wastewater is produced with an average of 80 kg BOD for every tonne of coffee processed (Gautho, 1995; Bressani, 1979a; and Adams and Dougan, 1981). It should be noted that the overall load of 80 kg BOD per tonne of dry coffee remains constant even if water minimization practices are used. In addition, two tons of pulp is produced for every tonne of coffee. Pulp is typically discarded in heaps around the factory, where it attracts flies and rodents, and produces an offensive smell as it ferments. Leachate from the pulp piles (also high in BOD) has been known to seep into local waterways, providing another water pollution source. (Figure 4.6). Wastewaters are sometimes contained in ill-operated stabilization ponds that become breeding sites for mosquitos, emit offensive odours and cause other nuisances (Gautho et al., 1991; Gautho, 1995; and Adams and Dougan, 1981). Unfortunately, topography and cost of land in coffee growing areas can make waste treatment methods difficult to implement (Gautho, 1995).

3. **Energy** – a rotating drier drum requires 10 000 GJ of heat energy to dry 1 tonne of processed coffee. Energy is also required to operate the pulping machines and the conveyor systems throughout the mills. These mills are typically located in rural

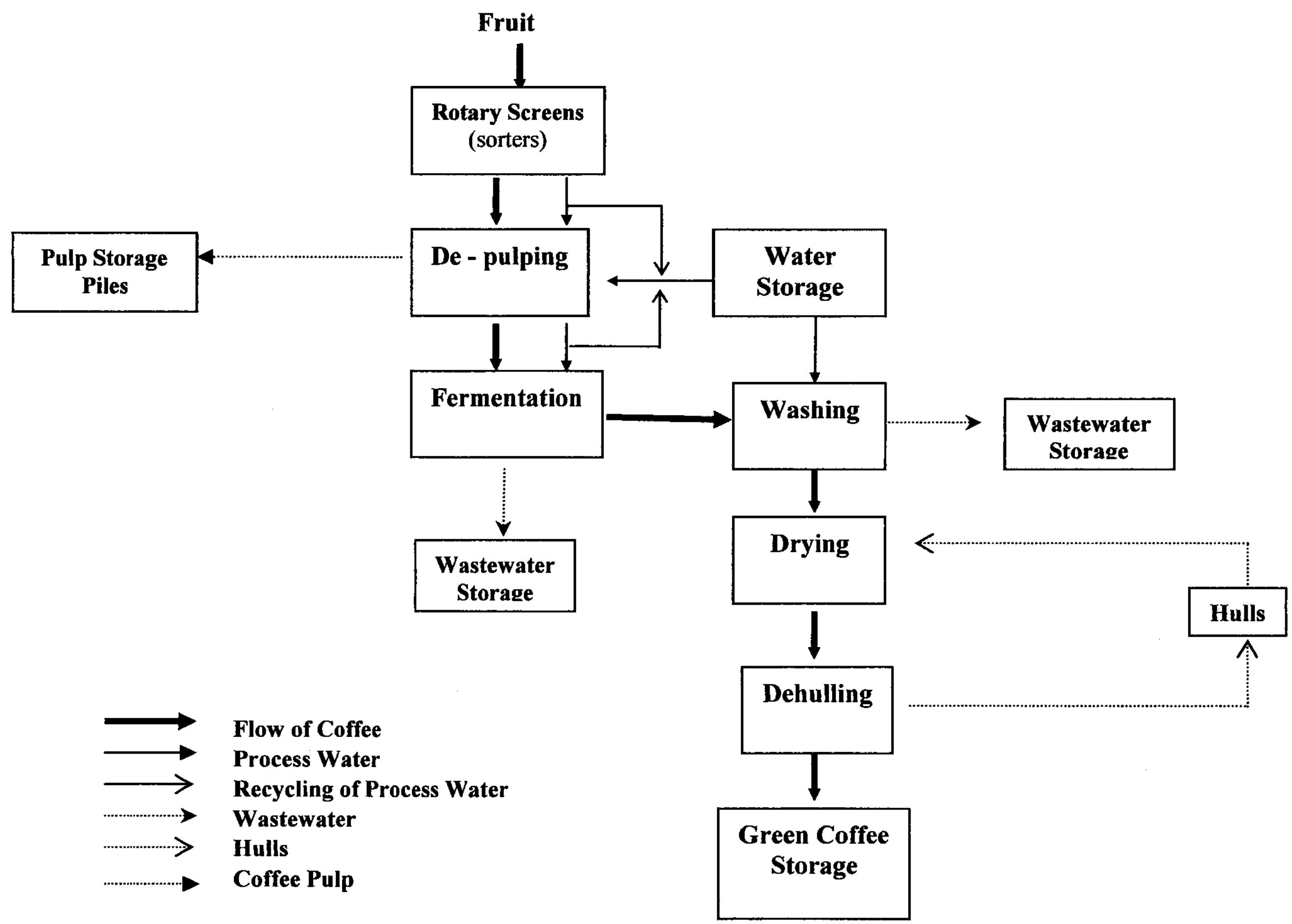


Figure 4.5. Wet Processing Method.

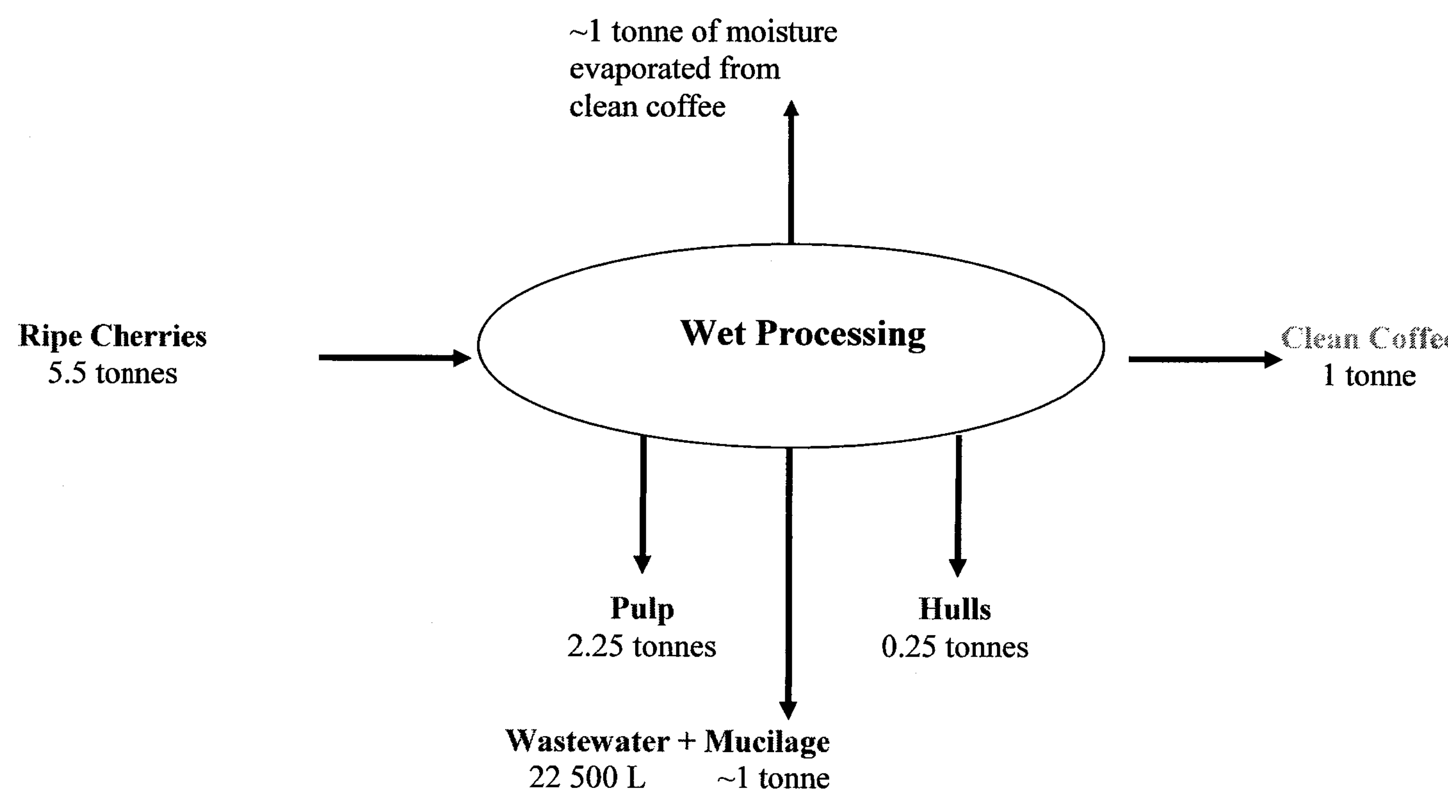


Figure 4.6. Mass Balance of Typical Wet Coffee Processing (modified from Bressani, 1979a and Gautho, 1991)

areas where reliable energy is often hard to come by and many mills have installed costly diesel generators to carry the energy load during problem periods (Gautho et al., 1991).

4.2.3.2 Dry Processing. In the dry process, the cherries are left on the trees until the end of the season and all berries have ripened. The intact cherries are all picked at once and are dried in the sun intact. The removal and separation of the beans from the pulp is done in a single mechanical de-hulling operation. The waste associated with this is the dried cherry flesh. Due to its high cellulose composition it is typically used as fuel.

This is a relatively simple process and the environmental impacts associated with it are significantly less than that of the wet process. However, the quality of the coffee is considered to be much lower and receives a significantly lower price than wet processed coffee (ICO, 2004). All *robustas* and Brazilian *arabicas* are processed this way and will typically find their way into lower priced blends and/or instant coffee.

4.2.4 Wastes from Wet Processing of Coffee

Coffee pulp, mucilage and wastewater, and coffee parchment represents a 80% of the biomass of the coffee cherry and presently the bulk of it is discarded as unwanted waste product. Figure 4.6 demonstrates the mass balance. Despite ongoing research into possible uses of these products there is still very little progress beyond the pilot-study, demonstration phase. Any treatment of by-products is still almost wholly focused on environmental controls initiated as a result of government legislations. Sanchez et al (1999) stated that there is an urgent need for efficient technologies to transform coffee by-products in useful products, for both economic and environmental reasons.

4.2.4.1 Coffee Pulp. According to Elias (1979), coffee pulp is made up of a number of constituents including organic components, mineral matter, carbohydrate fractions, and amino acids. There have been numerous studies completed since his data was published, but his values are generally accepted as the standard and are most often quoted (Cléves ,1995; Mburu and Mwaura, 1996; and Diaz, 2002).

Bressani (1979a), Adams and Dougan (1980) and Mburu and Mwaura (1996) have all indicated that the level of tannin and caffeine hinder the applicability of coffee pulp as livestock feed. Similarly, it was found that the high potassium content also impaired the use of coffee pulp as animal feed (Bressani, 1979a). The data indicates that coffee pulp contains similar levels of essential and non-essential amino acids to products such as soybean and cottonseed meal, and has higher concentrations than corn (Elias, 1979). In particular is the relatively high level of lysine. However, Elias (1979) noted that it is deficient in sulfur containing amino acids. It appears that there has been little other research into the amino acid potential of coffee pulp. There is the belief that these amino acids may not be biologically available due to the high tannin content which is know to react with protein (Elias, 1979).

4.2.4.2 Wastewater. The effluent emanating from processing units is high in both suspended and dissolved solids consisting of pectins, proteins and sugars. Table 4.5 outlines the typical pollution load that the International Coffee Organization has cited as the average found in the total combined effluent (ICO, 2004). It also presents the data broken down by wastewater stream. Approximately 50 million bags of coffee wet are processed each year around the world and yields 2.25 million tonnes of BOD that are discharged annually to the rivers and waterways of some of the worlds poorest nations.

4.2.4.3 Parchment. Coffee parchment has been compared to corncobs and cottonseed hulls (Elias, 1979) and contains high levels of lignin and hemicellulose (Bressani, 1979b; Adams and Dougan, 1981; and Saenger et al., 2001).

4.2.5 Current Treatments of Coffee Wastes

According to the review by Gautho (1995), there are a number of waste treatment options, but very few have been adopted. In Central America, the use of ponds (both aerobic and anaerobic) is the main waste treatment method. These are reported to be in poor operating condition and are breeding sites for mosquitoes. Ponds and lagoons can

Table 4.5. Pollution loading for coffee effluent.

Parameter	Total Mean	Pulping Waters	Fermentation & Washing
Total Suspended Solids	7.0 - 10.9 g/L[a]	13.2 g/L[b]	2.9 g/L[b]
		6.2-11.0 g/L[c1]	1.95-4.8 g/L[c1]
		3.6-5.0 g/L[c2]	2.2-4.6 g/L[c2]
Biological Oxygen Demand (BOD)	10.0 - 13.0 g/L[a]	1.8-2.9 g/L[b]	1.3-2.2 g/L[b]
		1.8-9.0 g/L[c1]	1.2-3.0 g/L[c1]
		0.9-2.4 g/L[c2]	1.4-3.9 g/L[c2]
Chemical Oxygen Demand (COD)	18.0 - 23.0 g/L[a]	13.9-28.0 g/L[b]	3.0-10.0 g/L[b]
		2.95-14.6 g/L[c1]	1.65-2.8 g/L[c1]
		1.4-3.9 g/L[c2]	0.85-1.75 g/L[c2]
BOD: COD ratio	0.5 – 0.6[a]		
N: COD ratio	0.08[a]		
P: COD ratio	0.02[a]		

a - ICO (2004)
b – Adams and Dougan (1981)
c – Gautho et al. (1991)
1 – with recirculation
2 – without recirculation

be effective if properly maintained, for example they reported a 70 to 90 % reduction in BOD with a retention time of 10 days. In many African countries, producing wet processed coffee, soak pits are used.

The water is discharged into large in-ground pits and the water is then disposed of on land. However, it has been often noted that these pits are not properly operated and the wastewater does eventually return to local waterways. India has recommended that large pulping mills use an anaerobic lagoon followed by an aeration stage, but it is unclear how widespread this practice has become (Gautho, 1995). Gautho (1995) concluded that the anaerobic digestion of coffee wastewater is the most cost effective waste treatment option for processing mills and noted a biogas yield of 0.46 m^3/kg per COD removed.

National coffee industries in India and Costa Rica have conducted extensive research in the development of water usage minimization through process modifications and utilizing re-circulation techniques and new pulping machines (ICAFE, 2003c). However, this does not minimize the total load of BOD, COD or suspended solids being discharged to surrounding waterways. Ananda-Alwar et al. (1990) noted that a typically recommended treatment is anaerobic digestion of this effluent followed by aerobic treatment. In 2003 the Asociacion de Beneficadores del Costa Rica (ABCR) reported that 12 of the ~ 100 operational mills utilized anaerobic digestors, but did not indicate the effectiveness of these operations (ABCR, 2003).

Treatment of wastewater by conventional means is technically feasible (Gautho et al., 1991; and Adams and Dougan, 1981). Biological filters, anaerobic digestions, activated sludge (aerobic treatment) all demonstrated reliable removal of BOD, COD and suspended solids from coffee wastewater. The minimal adoption of these practices is probably due to economical limitations. The authors noted that where simple treatments such as stabilization ponds have been implemented, poor operations limit their effectiveness.

Gautho et al. (1991) reported that the use of land-based treatment such as land disposal, anaerobic lagoons and stabilization ponds run the risk of accumulation of the toxic pesticides used during cultivation. Copper, organophosphates and DDT were found at elevated levels in the residual sludge of lagoons and in soils receiving wastewater runoff. Land disposal by irrigation was reported to be suitable for coffee trees as an organic fertilizer, but its effective depends on the physical characteristics of the soil. Application of liquid wastes at rates higher than the soils capacity to handle will result in waterlogging, anaerobiosis, and inhibition of plant growth. This has been demonstrated to be successful with some small family based operations. Finally, the author's reported that pulp compost contains 3.5% nitrogen and is use as a soil conditioner in small farms, but is not widely used by larger facilities due to the high transportation cost of a large volume. It was noted by both Diaz (2002) and Gautho (1995) that pulp applied directly without composting can increase soil acidity and promote infestations of coffee berry borer and other herbivore pests.

Costa Rica is probably the only nation that has aggressively approached the problem of pollution associate with coffee wet-processing. Presently, all mills are required by law to treat all wastewater and compost all coffee pulp (White, 2002). However, this still does not address the possibility of value-added products being produced from by-products.

3.3 Impacts of the Coffee Industry on the Ecosystem

The way coffee is grown and processed has profound environmental importance both locally and internationally. According to Mattsson (1999) and Diaz (2002), the environmental problems associated with coffee are traditionally classified by impact categories. These are organized into three main groups: depletion (extraction from the environment); pollution (emissions to environment) and damage or degradation (changes to the structure of the environment). There are aspects related to the coffee sector that fall into at least one of these three categories: deforestation, biodiversity loss, agrochemical use, pollution, soil quality and erosion, aquatic degradation, human health and environmental costs.

3.3.1 Deforestation

Deforestation is a serious trend throughout the coffee-producing lands, particularly those of Latin America (Brown et al, 1995). Traditional coffee plantations are a major component of the overall forested and protected areas of Central America. In El Salvador (for example), the area of dense forest that makes up shade coffee plantations is more than 10 times as large as the entire system of protected areas (Varangis et al., 2003). Coffee can be grown under conditions that resemble a natural forest. The transition from shade coffee to "technified-shade" and sun plantations results in the removal of this forest structure (Gobbi, 2000). Traditional shade cover is reduced to include only a limited number of species of shade trees. Modern coffee plantations are characterized by hedgerows of coffee trees planted very close together with little to no shade cover and an absence of any ground covering between the rows (Diaz, 2002; and Rice and Ward, 1997). Since 1990, approximately 1.2 million hectares of sun coffee have been planted in Central America, thus eliminating vast areas of forested areas (Rice and Ward, 1997).

Seven of the ten countries in the world with the highest deforestation rates are in Latin America and the Caribbean; these seven countries include Jamaica, Haiti, Costa Rica, Paraguay, Ecuador, Guatemala and Mexico (Brown et al, 1995; and Current, 1995). In a number of areas, tropical forest ecosystems have disappeared or are on a path to elimination in the near-future. By the late 1980s, only an estimated one-fourth of the primary moist tropical forest in Colombia remained. While deforestation as a general problem is a concern, Lation American tropical forests are particularly critical (Current et al, 1995). They protect atmospheric dynamics, water quality, and wildlife species. They are also of economical importance as reservoirs of germplasm that has multiple applications for food, medicine, and industrial products (Rice and Ward, 1997).

4.3.2 Bio-diversity loss

Closely linked with deforestation is the associated loss of biodiversity. Biodiversity loss is a concern due to the unprecedented rates of losses that have resulted from human activity. The stability and continuity of the affected ecosystems are threatened. This in turn threatens the indirect benefits these ecosystems provide to humans in terms of the quality and quantity of goods and services (Nunes et al., 2001).

Shade coffee provides essential habitat for diverse communities of other tropical forest species at levels similar to natural forests (Current et al., 1995; Gobbi, 2000; and Varangis et al., 2003). Perfecto and Snelling (1995) reported that local species diversity of beetles, ants, wasps and spiders on a single tree species (*Erythrina poeppigiana*) in shade coffee plantations in Costa Rica approximated that the arthropod diversity levels on single tree species sampled in undisturbed tropical forest.

Neotropical migratory birds that winter in northern Latin America constitute 60 to 80 percent of the bird species that inhabit forests throughout the U.S. and Canada. Birds numbering in the hundreds of millions and representing more than 120 species migrate annually through or to the part of the lower Central American area consisting of Costa Rica and Panama (Rice and Ward, 1997). Traditional shade coffee production has been shown to be highly beneficial to biodiversity conservation in tropical forest ecosystems.

Technified or sun coffee has been found to contain up to 90% fewer bird species. This not only affects the tropical regions but will also impact the bird populations of North America.

Traditional coffee is often integral in agro-forestry systems in which tree species are cultivated together with the coffee and other agricultural commodities. Where geographic and market conditions are favorable, economic returns can be achieved through sustained-yield timber production in association with coffee. For example, research in Costa Rica has shown that timber from the precious hardwood species *Cordia alliadora* can occur with no significant damage to growing coffee crops (Somarriba, 1990). Talbot (1995) stated that agro-forestry systems, including those involving coffee, have potential to enhance the economic and ecological stability of poor rural areas in northern Latin America. According to Pratt and Harner (1997) and Charveriat (2001), the USAID promoted transition to sun coffee diminishes these opportunities and leaves poverty stricken farmers dependant on the whims of the developed world for income (commodity pricing of coffee) and plantation productivity (purchased agrochemical inputs).

4.3.3 Agrochemical Use

Traditional shade coffee systems typically rely on much lower chemical inputs than industrial plantations. This is because planting coffee among natural vegetation, or among trees planted for shade, fruit or timber, can reduce susceptibility to pests. Moreover, because many traditional methods have been passed down to today's farmers by previous generations (before synthetic pesticides and fertilizers were widely used in agriculture), human-land use equilibrium has evolved in coffee production.

With the transition from traditional coffee to "technified" coffee, agrochemical use dramatically increased (Varganis, 2003; Gobbi, 2000, Pratt and Harner, 1997; Rice and Ward, 1997; and Segura and Reynolds, 1993). Unfortunately pesticides are not specific in their biocidal action and others besides the intended species will be eliminated from the system (Schmidt-Bleek and Marshal, 1993). As such, use of insecticides for example, can result in a significant reduction in the number and variety of benign or beneficial insects as well as the natural predators of the target pests (Pimentel and Greiner, 1997).

Pollinators such as honeybees are also affected by the use of agrochemicals. As their numbers drop, this can affect not only the levels of agricultural productivity on site, but also the general biological productivity of the surrounding plant life (Wilson and Tisdell, 2001). Herbicides can limit soil fertility by killing seedlings and non-target species (Pimentel and Greiner, 1997).

In searching sustainable solutions, Staver et al, (2001) investigated the use of the higher levels of biodiversity found in shade-coffee plantations as an integrated pest management system. Present pesticide use is on a pest by pest basis and the authors believed that the use of a diverse mixture of carefully selected shade tree and ground covering weeds can provide the proper conditions to promote the development of beneficial organisms that will aid in the overall control of pest infestations, both insect and fungi. (Staver et al, 2001).

4.3.4 Pollution

During the 80s, the importation and use of agrochemicals in the Central American region reached an annual average of 53.6×10^6 kg. In Costa Rica, as much as 4 kg of pesticide per capita was used annually during the last decade, eight times the 0.5 kg estimated for the whole world population and twice the average use of the total Central American region. The infiltration of agrochemicals into the surface water table and the runoff of agrochemically contaminated soils and water are a source of pollution resulting from coffee production. Aguilar and Klocker (2000) reported the application of over 213 tonnes/yr of fungicide in the Tarcoles River Basin, the main watershed of San Jose. Segura and Reynolds (1993) have noted that synthetic fertilizer inputs in coffee have contributed to nitrate contamination of drinking water aquifers in Costa Rica. Carlson and Wetzstein (1993) noted the existence of pyrethroid compounds (insectide) in ground and surface water in areas of intensive agriculture. Other forms of pollution from coffee production result from the untreated discharges of organic wastes from the processing facilities to the surrounding waterways. The spread of agrochemicals through airborn dusts and soil erosion to surrounding fields and terrestrial ecosystems can affect local biological productivity.

4.3.5 Soil Quality and Erosion

In general, soils in humid tropics (including the coffee regions of Costa Rica) are prone to infertility and compaction due to: (a) the rapid decomposition of organic matter indicative of these types of climates and (b) the high leaching potential (Kral, 1989; and Sheng, 1986). Therefore, in order to maintain proper soil structure and reasonable productivity, 4-5 tonnes/ha of organic biomass must be returned to these soils on an annual basis (Lal, 1995; and Roose, 1996). In natural ecosystems, this biomass recycling occurs through the regular deposition of fodder from animals and plants. In mono-crop agricultural setting, this is not the case and as such it needs to be incorporated into a management strategy aimed at maintaining soil productivity.

The elimination of shade cover and transistion to sun coffee cropping systems can cause significant impacts on various soil quality parameters. Research in Nicaragua in the late 1980s documented that significantly higher erosion rates, relative to traditional systems, occurred on renovated coffee plantations where shade had been reduced (Rice and Ward, 1997). Similar findings have been noted throughout coffee producing areas (Varangis et al., 2003; and Segura and Reynolds, 1993). Shade coffee systems demonstrate higher levels of soil moisture and organic material (Gobbi, 2000; and Muschler, 2003).

Robinson and Mansingh (1997) reported that typically coffee plantations are found on slope ranging from 10 to 75° and that sun and "technified-shade plantations are prone to higher rates of erosion than those found in traditional plantations. The annual erosion rate in some areas of the Blue Mountain coffee range in Jamaica, for example, is estimated to be thousands of tonnes/ha and could be as high as 13000 tonnes/ha in a newly cultivated area.

Babbar and Zak (1995) stated that elimination of shade cover and mono-cultural practices have been shown to cause reduced levels of soil moisture and detritus (nutrient-rich organic material that natural recycles back into the soil). Technified coffee loses as much as three times the amount of nitrogen through leaching as traditional farms; typically shade coffee plantations are more conservative nutrient recyclers than the un-shaded farms. An additional issue arising from use of pesticides is the elimination of insects and micro-organisms that play vital roles in the enhancement of soil productivity and plant nutrition (Babbar and Zak, 1995; and Rica and Ward, 1996).

Rubin and Hyman (2000) discussed the impact that soil erosion has had on Costa Rica, both on-site and off-site. Particularly with off-site impacts, they noted the inability of most models to estimate off-site costs as they do not predict where the eroded soil will finally be deposited. They do suggest the significance of costs related to sediment-related damage to hydropower facilities, flood-damage, costs related to dredging of navigable waterways and increased water treatment costs. Solorzano et al. (1991) reported 287,000$/year was spent on erosion related maintenance at the Carchi Dam and reservoir in Costa Rica.

4.3.6 Aquatic Degradation

Aquatic degradation results from two aspect of the coffee industry: (a) run-off from plantations washing nitrates, pesticides and sediments into the waterways and (b) effluents from the processing facilities (or *beneficios*) (Segura and Reynolds, 1993; Gautho, 1995; Rice and Ward, 1997; Varangis et al., 2003; and Barbier et al., 2003).

Coffee *beneficios* exist in a wide range of sizes. In Guatemala, for instance, where a total of some 4000 processing facilities are estimated to dot the landscape, the National Association of Coffee Growers divides them into micro-facilities (those with a capacity to process 500 to 5000 pounds of harvested coffee per day), medium facilities (5000 to 50,000 pounds per day), and large (greater than 50,000 pounds per day). The 100 *beneficios* belonging to this last category (3% of all Guatemala's *beneficios*) process 60% of the coffee produced annually (Rice and Ward, 1997). To place this in perspective, each of these large *beneficios* discharges into the regions waterways the equivalent of the daily raw sewage dumped by a town of 35,000 people.

Elevated BOD and COD resulting from the discharge of organic pollutants from *beneficios* to waterways rob aquatic plants and wildlife of essential dissolved oxygen. Costa Rican health officials have expressed concerns over harms to marine life along parts of the Pacific Coast, where rivers contaminated by coffee processing wastes flow into the ocean. According to the Costa Rican government, coffee processing residues account for two-thirds of the total BOD in the country's rivers (Segura and Renyolds, 1993). In 1992, Costa Rica instituted a plan to upgrade the nation's coffee processing systems, with the objective of cutting organic pollutant discharges to surface waters by 80 percent within five years. As of 2000, every processing mill in Costa Rica has implemented a waste treatment plan in accordance with this initiative, although the efficiency of these plans is debated by some (ABCR, 2003; Marcos, 2003 and Alfaro, 2003). However, Costa Rica's plan is a unique case and most other Central American countries do not enforce the implementation of such systems (White, 2002; and Barbier, et al., 2003). For example, in the 2002/03 coffee production season an estimated 440,000 metric tonnes of organic matter (coffee pulp and mucilage) was discharged to Honduran waterways without control or treatment. There was a subsequent loss of plant and fish life due to eutrification and anoxic conditions (Barbier et al., 2003).

In a study conducted by the Bureau of Water Resources of Papua New Guinea (Bargh and Baru, 1982), it was noted that coffee processing wastes were discharged directly to the Ramu River. In samples collected and tested at graduated distances away from the point source, dissolved oxygen was not detected. The researchers suggested that the high BOD/COD loading from the coffee discharge had rendered that area of the river anoxic. It was also indicated that most small waterways receiving coffee effluent directly had been rendered anoxic during the coffee harvesting season and had a detrimental effect on the flora and fauna of these water bodies.

The magnitude of damage caused by agrochemical use in the coffee industry was the center of study by Robinson and Mansingh (1997), who determined that organochlorines (OCs) used to combat the coffee berry borer in the Jamican Blue Mountain regions are making their way into the flora and fauna of the receiving waterways in concentrations high enough to be of concern. Bioaccumulation of pesticide residues in mussels and oysters were reported to be at least five-times and in some cases as high as ninty-three times that of the concentrations found in the associated sediments. When comparing the concentrations of the OCs with lethal concentrations (LC50s) for shrimp, salmon larvae and striped bass, it was reported that there may be links between the pesticide-use in the coffee fields of Jamaica and the dwindling stocks of the shrimp and fish populations in the coastal regions receiving the pesticide residuals. This kind of impact on the aquatic environment can have an indirect effect on the well-being of the people who depend on these resources for food and livelihood.

4.3.7 Human Health

The transition from traditional coffee to "technified" coffee is agrochemically intensive (Gobbi, 2000; Pratt and Harner, 1997; and Rice and Ward, 1997). The users are often illiterate or minimally educated farm workers who have little understanding of how and in what quantities to apply these chemicals (Rojas et al., 1999; and Perfecto and Velasquez, 1992). As well, coffee workers historically unaccustomed to technified coffee production systems encounter an array of chemicals that are supposed to be applied with protective gear such as masks, long-sleeved shirts, long pants and boots. This protective clothing is frequently unused in the heat and humidity of tropical environments (Rice and Ward, 1997; and Rojas et al., 1999). Misuse of pesticides and chronic exposure can cause severe health effects in animals and humans (Schmidt-Bleek and Marchal, 1993).

Popper et al. (1996) found that there was widespread misunderstanding and misuse of pesticides among rural smallholding farmers in Guatemala. While interviewing over 200 farmers and their wives they noted an obvious lack of knowledge of the proper use and potential hazards to human and environmental health. They reported that very little protective gear was used and most farmers did not understand that dermal contact was dangerous. Highly toxic insecticides were used for all forms of pest control including fungi control and domestic pests, such as head lice on children. It was also found that there was a common belief that lemonade and coffee are effective medicines for pesticide poisoning.

The magnitude of health damage caused by agrochemical exposure would vary according to the type of crop cultivated, the type of agrochemical used, the mode of application/exposure, the individual susceptibility and the climatic conditions (Margni et al., 2002; and Wilson and Tisdell, 2001). Some of the widely used substances are highly toxic according to the hazard classification of the World Health Organization (WHO) and many are banned or severely restricted in industrialized countries. For example, DDT is still readily found in many African and Northern Latin American countries (Rice and Ward, 1997; and Wilson and Tisdell, 2001).

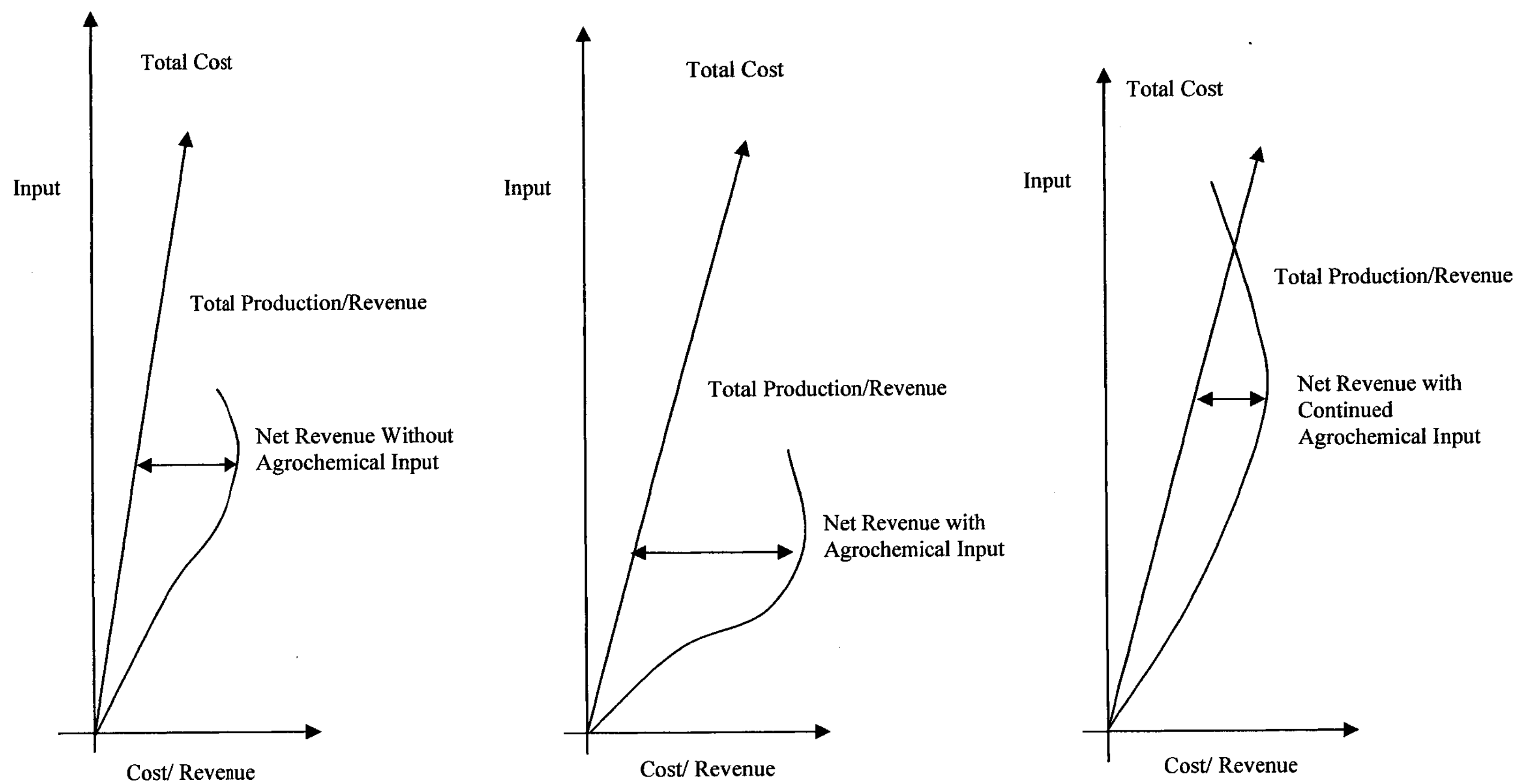
One investigation by the International Labour Organization revealed that during 1986, a total of 1,880 acute poisoning, dermal and eye injuries due to pesticide exposure, were reported to the National Social Security Institute of Costa Rica (Forastieri, 1999). The annual pesticide poisoning rate for the total wage earning population for the period of 1980-86 was 5.3 per 1000 workers, 97 % of these occurred among young adults aged 20 to 29 years (23 per 1000). Female agricultural workers showed a higher incidence rate (25 per 100) than male workers in all age groups (Forastieri, 1999).

Although a significant amount of the literature focuses on the pesticide inputs to coffee production, increased nitrogen fertilizer application has also gone hand in hand with the widespread implementation of technified-coffee and the removal of shade cover from Central American coffee plantations. Segura and Reynolds (1993) reported that heavy synthetic fertilizer inputs in coffee have contributed to nitrate contamination of drinking water aquifers in Costa Rica, with the documented groundwater pollution in some cases exceeding World Health Organization limits. In high concentrations, nitrates can cause infant methemoglobinemia (blue-baby syndrome), a potentially fatal condition that impedes oxygen transport in infants' bloodstreams. Other human health concerns surrounding nitrate contamination of groundwater include suspected links between nitrates and certain cancers, birth defects, hypertension, and developmental problems in children (Segura and Reynolds, 1993; Wilson and Tisdell, 2001; and Varangis et al., 2003).

The use of pesticides not only affects the users (mainly farm workers) but also affects the health of those living in and around farming areas. The FAO estimated approximately 3 million poisoning and approximately 200,000 deaths each year from pesticide exposure with the greatest percentage in developing countries (Wilson and Tisdell, 2001). Furthermore, there is evidence that suggests chronic exposure can result in immune dysfunction. Fiore et al. (1986) showed that women who chronically ingested water contaminated with low levels of aldicarb reported evidence that of significantly reduced immune response. Wesseling et al (1999) identified several hypotheses for associations between pesticide use and cancer rates in Costa Rica, and has recommended further study.

4.3.8 Environmental Costs

According to Wilson and Tisdell (2001), there are significant financial costs associated with the use of pesticide simply from an agricultural productivity standpoint. Figure 4.7 shows the relationship between chemical inputs and revenue over time. The first graph (a) shows cost of production and output before chemical use. Graph (b) shows higher return with chemical input, but the cost of production is also significantly higher. Finally in graph (c), the pollution level resulting from the chemical use is impacting on the productivity of the system in terms of declining soil fertility and the proliferation of pests due to pesticide resistance and the loss of beneficial predators (linked with decline in biodiversity). As a result more and more chemical inputs are required in order to maintain high productivity and the overall cost of production rises. Gradually the productivity will decline regardless of chemical input and will become unsustainable. At this point, it is not unusually to see farmers walk away from their farms (Aguilar, 2004; Russillo, 2004; and ICAFE, 2003c).



(a) No Pollution

(b) Pollution has not yet surpassed assimilative capacity of local environment

(c) Chemical pollution has surpassed assimilative capacity of local environment and is affecting crop yields

Figure 4.7. Cost and revenue relationship before and after agrochemical use (Wilson and Tisdell, 2001).

Costa Rica has only recently introduced insecticides into their regime due to the arrival of the Coffee berry borer at the end of 2001 (Ramirez, 2004). However anecdotal evidence provided to the author by extension officers suggests that the findings by Wilson and Tisdell (2001) are similar to the reality in other regions that have been battling the berry borer infestation for a longer period.

4.4 Social Impacts of the Coffee Industry

4.4.1 Agricultural Hazards

The bulk of the literature concerning agricultural safety focused on farmers in highly mechanized settings, where heavy equipment is the norm (Pratt, 1990). This is typically not the case for coffee farmers in developing countries as a greater share of the work is performed manually (Gobbi, 2000). Rojas et al. (1999)indicated that one of the most significant factors in the safety of coffee farmers and workers is the amount of exposure to agro-chemical, but other factors such as malnutrition, dehydration and exposure to tropical diseases and parasites need to be considered as well.

Perfecto and Velasquez (1992) reported that even in the United States casual farm workers were excluded from the Occupational Health and Safety Act, which governs health and safety standards in the workplace, from the Fair Labour Standards Act which governs minimum wages and child labour, and from the National Labour Relations Act, which guarantees the right to join a union and bargain collectively. The exclusion of farm workers from the Occupational Health and Saftery Act (OHSA) regulations has particular relevance to the pesticide issue. Any other worker, guaranteed under the OHSA, has the right to petition their employer for the removal of or protection from, hazardous/toxic chemicals in the workplace. Not being covered by OHSA, farm workers do not have this right and are forced to petition the Environmental Protection Agency (EPA), which is the agency in charge of regulating pesticides. Unfortunately, such petitions offer very few legal options, typically leaving farm workers in the position of being forced to accept hazardous conditions of work if they wish to stay employed. Guidelines to proper pesticide use have only been developed for 12 of the estimated 35,000 different chemical formulations available and are generally not adhered to in the first place.

Farm workers in developing nations have even fewer rights or precedents when dealing with health hazards relating to pesticide use. Track records in developing countries have not been good and worker and labourers in these parts of the world are often seen as expendable (Wilson and Tisdell, 2001). This is particularly true of the large farms (called fincas in Latin America) that are typically owned either by members of the "coffee elite" or foreign investors (Varangis, et al., 2003). Wilson and Tisdell (2001) reported that attempts in Latin America to organize and assert their rights for safe working environments were met with reprimands and dismissal because replacement workers were easy to find. Often these workers were migrant workers who may not be in the country legally (Talbot, 1997; and Collins, 1995).

4.4.2 Farmers/Workers Well-being

Ong et al. (1993) noted that the principles of occupational health may be the same in the developed and developing countries, but there can be a wide diversity in practice. The exposure to chemicals at the workplace in developing countries is usually of a different nature, and the level of exposure is generally of a higher magnitude. Wasserman (1997) reported that the leading occupational diseases in developing countries are also very different to those reported in industrialized nations. The author suggested that for hazard evaluation in developing countries, more factors need to be considered.

Ong et al. (1993) suggested that problems are usually more complicated as most workplaces are subjected to many factors that are typical of small-scale industries similar to those outlined by Pratt (1990). Low capital investment and declining economic return as seen in the coffee industry, often culminates in cutbacks on necessary expenses, especially on occupational and environmental health activities. Thus, the health, safety and welfare of the workers are usually overlooked. This situation helps only to promote greater risks to the workers. Furthermore, many workers in the developing countries suffer from poor nutrition, endemic diseases, and other debilitating conditions (Ong et al, 1993; and

Wasserman, 1997). For these reasons, it is possible that currently recommended occupational exposure limits could allow injury to workers in the developing nations. Both Pratt (1990) and Rojas et al. (1999) state that when carrying out health assessment, careful attention must be paid to cultural practices, genetic components, working conditions, and other predisposing factors

Wasserman (1997) noted the scarcity of studies examining the possible health and safety issues in industries such as manufacturing, processing and non-traditional agriculture (of the type characterized by the Green Revolution). It was suggested that this was due to the fact that most of these industries and services lack occupational and environmental regulation. The author highlighted the urgent need of in-depth epidemiological studies to better determine the health and safety effects associated with exposure to industrial and agricultural wastes, agrochemicals and other occupational hazards.

The International Labour Organization reported that developing countries consume more than 20% of the world production of agrochemicals and are responsible for approximately 70% of the total number of cases of acute poisoning occurring in the world, which corresponds to more than 1.1 million cases annually. In Central America alone 27,745, cases of acute poisoning have been registered between 1980 and 1987; more than 2000 cases per year (Forastieri, 1999).

Forastieri (1999) reported that in Central America, more than half (56.5%) of victims of pesticide poisoning were agricultural workers with an average annual rate of 9.2 per 100,000. All work-related fatalities autopsied occurred in the agricultural sector (1.8 per 100,000 agricultural workers), 90% of the occupational poisoning occurred among agricultural field workers, 87% during the application of the pesticides and 13% during mixing, carrying of containers or cleaning equipment.

Rojas et al. (1999) surveyed peasant farmers in the Andres Blano municipality of rural Venezula and found that a good percentage (45.5%) of farmers had indicated that they had exhibited symptoms of pesticide poisoning at one time or another. The other disturbing figure noted in the study is that only 37.9% of the farmers surveyed had received any direction for use and application of pesticides, and only 7 % wore any protective gear beyond safety boots and long sleeves during application. It was noted that farmers often returned from the fields wetted down with pesticide residue after application.

Regardless of the present state of occupational health and safety regulations in any given country, in addition to the humanitarian reasons outlining the importance of worker safety are the economic motivations, as unhealthy workers cost money. Reduction in productivity, down-time and long term health care effect financial well-being of the worker, the employer and the national economy even if the short-term thought process leads to other conclusions (Ong et al., 1993; and Pratt, 1993). Particularly in farming operations accidents and ill-health can impact time-sensitive operations like harvesting or processing, resulting in lower quantity or quality yields. Wilson and Tisdell (2001) noted the cost associated with pesticide related illnesses in terms of the amount of external labour that needed to be hired to replace that of the ill workers as well as the cost of care of these individuals.

In the last twenty to thirty years there has been a shift in the agricultural labour force of developing nations (Collins, 1995). In some cases, past and ongoing conflicts have taken men away from the family farm, leaving the woman with her tradition chores (such as preparing meals, gathering firewood and collecting water) and placing the new role of farm operator firmly on her shoulders (Rodriguez et al., 1998). In other circumstances, the level of poverty has forced women out of the home to seek alternative ways of bringing income into the household (Razavi, 1999).

It has been noted that in areas where institutional and technical intervention to poverty alleviation has been initiated, women have been the more active participants. An example is the "Village Bank" micro-credit program in Bangladesh, which was established to assist poor families purchase small livestock animals. About 95% of the borrowers were women (Rodriguez et al., 1998).

There has been growing employment of women in agriculture and agri-businesses, particularly in the production of fruits and vegetables and other crops that require careful handling. Agribusinesses are increasingly employing female workers for the jobs previously done by men. At the same time, agribusiness are subcontracting out their production (including coffee) out to smaller farms that are dependent on family labour, in order to cut wage costs, enhance control over labour and transfer production risks to the small farmer. This small farmer is often a woman (Collins, 1995).

Role of women is particularly impacted by the mechanization and industrialization of agriculture. The displacement of women from the family farm (that was used primarily to produce food for the home) has had severe effects on poor households, lowering the overall income and worsening access to food. Food that was once produced now must be purchased with wages or income form export-driven agriculture (Conway, 2001).

It is apparent that any strategy aimed at improving the social, economic and environmental condition of developing nations is going to have to consider the impacts it will have on the lives of women and understand the level of influence (albeit underlying) the women hold in these societies (Collins, 1995). Improvements in overall natural resource efficiency that result in improved economic conditions, employment opportunities, improved social conditions in the region and a reduction in negative health effects associated with agro-industrial pollution will have a significant impact on the quality of life for women of developing countries. They will also be more likely to embrace changes that they perceive as being beneficial to the well-being of their community in general (Ravazi, 1999; Rodriguez et al., 1998; and Collins, 1995).

4.5 Sustainable Development

4.5.1 Definition

The original definition of sustainable development was put forth by the UN's World Commission on Environment and Development in 1987 as development that meets the needs of the current generations without compromising the ability of future generations to meet their own needs (WCED, 1987). Since that time there has been numerous variations of the definition of the term "sustainable development" put forth by governments, industry and academia. According to Hall (2000), the concept of sustainable development implies, first, the integration of environmental issues with the imperatives of economic development in order to meet the immediate needs of populations today without undermining the aspirations of future generations. However, the definition of the term "sustainable development" has been expanded to include the ideas of fairness and interdependence, not only between generations but also between the countries and peoples of the globe (Brown et al., 1995). Social, cultural, economic and natural environments, whose harmonious development is essential to the welfare of humanity and of nature, are also included in the concept of sustainable development (NRTEE, 1993).

In the extensive discussion on and use of the concept of sustainable development since it was first introduced, Reed (1997) and Elkington (1997) reported on the growing recognition of the three essential aspects: (a) social, (b) economic and, (c) environmental. Toman (1994) highlighted other issues that included the requirements for intergenerational equity and the degree of substitutability between natural capital and other forms of capital. The author supported the 'stewardship' perspective of sustainable development and suggested the obligation to maintain the present context of human life, rather than the individual. The aim would, therefore, be to safeguard the large-scale ecological processes that support all facets of human life from biological survival to cultural existence in perpetuity.

4.5.2 Assessing Sustainability

Sustainability has become a central issue in the agricultural sector for researchers, producers and policy-makers. An increasing body of literature has been developed on methods for the evaluation of sustainability, with special attention given to the environmental aspects (Piorr, 2003; Conway, 2001; and Brown et al, 2000). However, Falconer and Hodge (2001) reported on the lack of tools to support the design of policy schemes that would ensure the implementation of sustainability in an efficient way. Pacini et al. (2004) suggest two reasons for this: (a) the complexity of the ecological and production processes evoked by the concept of sustainability, and (b) the necessary multi-objective approach of policy decision-making. Falconer and Hodge (2001) and Hardaker (1997) note that sustainability implies multiple objectives, and policy makers are often faced with the problem of how to best allocate their limited funds over these objectives

A number of studies in the literature address the evaluation of sustainability from a farm-level perspective and note that many of the environmental impacts associated with agricultural production are location-specific and are intrinsically connected with the production decisions (Jansen et al., 1995; Hardaker, 1997; Marchettini et al., 2003; Piorr, 2003; and Pacini et al., 2003). Jansen et al. (1995) applied mathematical programming techniques, such as linear programming (LP), in farm-level studies and Falconer and Hodge (2001) and De Koeijer et al. (2002) reported that this kind of approach was well suited for economically based ecological (or environmental) analyses. However, Pacini et al. (2004) reports that many of the studies involved with ecological-economic modeling advocate a systems approach that lacks a holistic interpretation of the farm agro-ecosystem. The number of environmental impacts that are actually modeled is often limited (e.g., only total pesticide use and nitrogen losses) and includes only those parameters that can be seen to have a quantifiable economic effect. The authors suggested that omissions of information on many environmental aspects can lead to serious misjudgments in the multi-objective policy-making process and conflicts between different government programs or regulations.

Assessing sustainability in the corporate and industrial sector has been the focus of a wide range of studies including sustainability of industrial processes in a generic form (Yang et al., 2003; Sonnemann et al, 2000; Kasemir et al., 1999; Culuba, 1999; and Ehrenfeld, 1997), to more specific systems such as the coffee industry (de Groot, 2002; Aguilar and Klocker, 2000; and Harner, 1997), domestic wastewater systems (Balkema, 2001), national economies (Hall, 2000; Vargus et al., 2000), food production (Mattsson, 1999; and Cowell, 1995), and demolition and construction (Klang et al, 2003). Throughout most literature, researchers acknowledge the three 'pillars of sustainability': environmental, economic and social (Elkington, 1997).

4.5.2.1 Environmental Sustainability. Reed (1997) reported that it is generally accepted that an environmentally sustainable system must maintain: (a) a stable resource base, (b) avoid overexploitation of renewable resources systems or environmental sink functions and (c) deplete nonrenewable resources only to the extent that can be covered by investments made in adequate substitutes. This includes maintenance of biodiversity, atmospheric stability, and other ecosystem functions not ordinarily classified as economic resources.

Pearce (1995) and Pauli (1998) believe that environmental sustainability is the crux of sustainable development as without a healthy, productive natural ecosystem there will be no agricultural, economic or social sustainability. Hawken (1993), Pauli (1998), Pearce et al. (1994) suggested that most other authors of sustainable development accept this as fact at 'some level'. UN (2001) and Hawken (1993) stated that the quality of the following factors is the support structures of human society and the natural world: (a) the air people breathe, (b) the water they drink, (c) the soil that grows food, (d) the natural resources that are extracted, and (e) the natural systems that regulate nutrient, climate and hydrological flows. Harris (2001) supported this notion and added that the protection of the environment from continuing degradation, depletion and pollution needs to be incorporated in any sustainability plan.

4.5.2.2 Economic Sustainability. In the literature, the definition of economic sustainability is not straightforward. Zugasti (2000) and Ruttan (1997) reported a number of attitude that cause divergence from a singular description. These included: (a) conflicts among different social groups when realizing what is profitable economically for one group is not profitable for another; (b) the problem of reducing and interpreting any economic action in monetary terms when addressing social groups that do not function according to monetary logic; and (c) different trains of thought with regards to the relative importance of economic in relationship to other social and environmental factors. Zugasti

(2000) and Pretty (1995) noted that these factors add a sense of relativity to economic sustainability and prevent a straightforward measurement or definition. Pretty (1995) stated that sustainability, economic or otherwise, is a social construct and is a changing perspective depending on the position in society of the individual or group defining it. The author believes that any sustainability strategy needs to incorporate this. Elkington (1997) and Labuschagne et al. (2005) point out that an economically sustainable system must be able to produce goods and services on a continuing basis, to maintain manageable levels of government and external debt, and to avoid extreme sectoral imbalances that damage agricultural or industrial production.

In terms of implementation, Bradbury and Rayner (2002), Hall (2000), Pauli (1998) and Pearce et al.(1994) noted that the belief that sustainable economic development comes from increased productivity (higher yields, more mechanization). However, Hall (2000), Brown et al. (2000) and Pauli (1998) suggested that in developing countries where lack of capital, political will and reliable energy sources make it very difficult for these societies to develop economically through the traditional routes, it is more likely that sustainable economic development will come from increased efficiency in the use of natural resources and development of value added products from these resources. Pauli (1998) suggested that this route would likely be much more economically sustainable as it turns away from foreign dependence (fossil fuels), environmentally degrading activities (pollution and depletion) and economic instability developed through dependence on a limited number of resources for the bulk of the country's gross domestic product (GDP).

While the United Nations addresses the problem through a call for market liberalization and the abolition of trade-tariffs (UN, 2001), Hawken (1993) and Reed (1997) indicated that the likelihood of this happening in the near future was minimal. Reed (1997), Hall (2000) and Harris (2001) contested the benefit of such a development and noted the disastrous effect that market liberalization had on some of the world's poorer countries. The authors indicated that that increased national wealth has not appeared to be contributing to the prosperity of all, but instead increased the income discrepancy between the wealthy and the impoverished.

4.5.2.3 Social Sustainability. Elkington (1997), Kasemir et al. (1999) and Lasbuschagne et al. (2005) reported that economic and environmental indicators represent only two of the three aspects necessary in determining sustainability. Indicators that reflect social aspects such as longevity, literacy, crime rates, family stability and the working conditions of the poor need to be considered as well (NRTEE, 1993). Reed (1997) suggested that a socially sustainable system must achieve fairness in distribution and opportunity for social services such as health care and security in old age, gender equity and empowerment, political accountability and participation, and sustainable population rate. Labuschagne et al. (2005) stated that the social dimension of any sustainability evaluation model should be concerned with the impact that the system being evaluated has on the social system within which it operates as well as its relationship with its direct stakeholders.

4.6 Sustainability Models

Hall (2000) notes that the Agenda 21 endorsed in Rio suggested that methods for monitoring trends of sustainable development needed to be developed, and particularly emphasized the need to integrate environmental accounting with traditional economic calculation methods. Vargas et al. (2000) and Rees and Wackernagel (1995) postulated that this may be one reason why the main focus of the scientific debate on sustainability in the last decade has been at the macro-level. The objective had been to describe how entire communities, or even nations, are developing towards or away from sustainability. Pacini et al. (2003) and Marchettini et al. (2003) indicated that it is important to also develop models to evaluate sustainability and sustainable development on a smaller scale, such as in industries, production chains and/or operations and smaller community projects. Klang et al. (2003) agreed and notes that it is not always obvious how individuals in their respective situations make progress towards sustainability if it is only approached at the macro-level. Hall (2000) and Kasemir (1999) suggested setting up targets in a limited system can be a more efficient way to implement sustainable development programs, and contribute to fulfilling sustainability goals at the macro-level

Hodge et al. (1999) suggest that in order to do so, appropriate indicators and models need to be developed in order for the evaluations of sustainability to be feasible.

4.6.1 Model Indicators

Hall (2000) and Harris (2001) suggested that sustainable development requires a fundamental rethinking of major elements of classical economic theory. Although the authors suggested that some environmental sustainability principles can be expressed in standard economic terms, in order to consider the full implications of sustainable development, one must look beyond these attempted formulations and consider the social, cultural and ecological contexts of human activity. Therefore, to capture these other contexts, indicators beyond those used in standard economic accounting methodologies need to be created (Harris, 2001; Brown et al., 2000; Elkington, 1997; and Rees and Wackernagel, 1995).

Ecological/environmental indicators such as energy and resource-use efficiencies, biodiversity, contaminant levels in various medium, emission levels, water usage, or levels of dissolved oxygen in water bodies (Pacini et al., 2004; Marchettini et al., 2003; Laloe et al., 2001; Gobbi, 2000; and Jansen et al., 1995) are some examples. As well, biophysical indicators such as soil erosion, soil fertility, slope, organic content of soil, annual rainfall, temperature (Aguilar and Klocker, 2000; Vargas et al., 2000; Gobbi, 2000; Rice and Ward; 1996; and Segura and Reynolds, 1993) must also be considered. Some suggest that more consideration need to be paid to direct measures of education levels, working conditions, access to health care and social services, and gender equality instead of assuming proportional linkages between these factors and GDP (Kroeger and Montayne, 2000; and Hall, 2000) or net income (Jansen et al., 1995; and Harris, 2001).

There is no consistency in defining an indicator in reported literature. Gallopin (1997) surveyed a wide range of literature and reported that an indicator has been identified in different sources as ''a variable", "a parameter", " a measure, "a statistical measure", "a proxy", "a value", "a measuring instrument", "a fraction", "an index", "piece of information", "a single quantity", "an empirical model", or "a sign''. Woodhouse et al.

(2000) noted that many authors define indicators as quantitative measures. However, this criterion of quantification is not universally accepted, since some authors, such as Ducey and Larson (1999) regard qualitative indicators as valid and, in fact, indispensable tools. Rather than provide a definition for a sustainability indicator, the authors identified the uses and desirable properties of indicators and have identified the major functions of indicators as: (a) to assess conditions and change, (b) to compare across place and situations, (c) to assess conditions and trends in relation to goals and targets, (d) to provide early warning information, and, (e) to anticipate future conditions and trends. Woodhouse et al. (2000) reported the necessity of threshold levels for indicators, drawing the role of indicators back to one of more quantitative measure that qualitative evaluation. The authors also noted the discord that arises in trying to assign threshold values and when determining if the passing of one threshold level is sufficient to class a system as unsustainable or if several indicator thresholds need to be passed before a system is unsustainable.

Van Pelt et al. (1995) suggested that sustainability research should focus on specific industry sectors and geographical regions, with the understanding that models must be able to deal with indicators that are fuzzy, qualitative or incomplete. Hall (2000) and Kroeger and Montayne (2000) noted that this is in contrast to organizations such as the World Bank and the IMF that generally still prefer a much more macro level approach, using broad-scale aggregate data such as GDP to provide an indicator of development, while the more qualitative indicators such as quality of life and distribution of wealth are largely ignored.

Nambier et al. (2001) believe that the choice of indicators can skew the overall sustainability picture into one direction or another. For this reason the authors reported that models should include indicators that provide accurate measures of all aspects of sustainability and suggested that indicators that provide information on the following should be considered: (a) social and policy relevance (economic viability, social structure, etc.), (b) analytical soundness and measurability, (c) suitable for different scales (e.g.

farm, district, country, etc...), (d) encompass ecosystem processes, (e) sensitive to variations in management, climate and culture, (f) accessible to many users.

Many researchers (Yang et al., 2003; Marchettini, et al, 2003; Mendoza et al., 2003; Balkema et al, 2001; and Janssen, 2001) tried to include similar principles, but thus far it is felt that most fall short of truly encompassing all aspects of sustainability. Janssen (2001) suggested that this is done by design. However, according to Kratena (2004) this does not improve the reliability of the outcome from an overall sustainability perspective.

Laloe et al. (2001) tried to demonstrate the importance of well-defined indicators in the development of any sustainability model. The authors postulated that the clarity of the indicators and their purpose would be necessary for the objective of the model to be clearly understood. Data collection revolved around the measure (or value - in the case of qualitative indicators) of these indicators and their efficacy lay in the ability to obtain a true measure of reality and, therefore, progress toward the model's overall objective.

Kratena (2004) reported that the most significant problem with determining sustainability was the inability to assign values to indicators of sustainability and environmental accounting. Mendoza and Prabhu (2003) suggested that models to date largely ignore interactions and relationships that individual sustainability indicators have, thus possibly compromising the evalution outcome. The authors believe that linkages and relationships between individual indicators needs to be carefully studied and sustainability assessments addressed from a holistic point of view. They report on a graphical methodology to examine the linkages between various indicators by using arrow diagrams to indicate which indicators are related and in what direction the relationship occurs. An analysis of the number of indicators that have a relationship with a particular indicator both directly and indirectly (secondary connection via another indicator) is conducted in order to establish the level of importance and influence each indicator has in terms of legitimately offering an indication of true sustainability levels.

4.6.2 Quantitative Models

4.6.2.1 Economic Models. Munda (1997) and Harris (2001) noted two major approaches to the economics of sustainability: neoclassical environmental economics and ecological economics. The authors reported that neoclassical environmental economics essentially sees all of nature as exploitable resources that can have an economic value assigned to them. Therefore sustainability within this framework is defined as a system that generates more economic value than the combined 'depreciation' of natural and human-made capital.

Desvousges et al. (1993) and Munda (1997) suggested that ecological economics differs from environmental economics in that it acknowledges that some aspects of the natural system cannot be assigned a predetermined monetary value. These aspects, therefore must be treated as qualitative, taking intrinsic social and ecological values in account as factors for consideration, not as numerical constraints to be used as quantitative data points. For this reason, ecological economics are typically more holistic in nature.

Pacini et al. (2003) and Pacini et al. (2004) suggest that environmental sustainability models used by scientists lack a close link to actual management decision making about sustainability issues and as such make them little more than academic exercises. Pacini et al. (2003) reported on the use of a sustainability analysis using what they call an integrated environmental – economic accounting framework that is used to evaluate the environmental and financial sustainability of different farming systems in Italy. The environmental performance was measured through the application of an Environmental Accounting Information System (EAIS) which incorporated a variety of environmental indicators such as nitrogen loss, nutrient balances, water use, soil erosion and organic content and attempt to relate these to the economic well-being and long term sustainability of a system with well defined boundaries. The EAIS indicators were measured and sustainability was assessed by comparing the values of the indicators with threshold levels established by regulations or found in literature.

Pressure-state-response (PSR) sustainability models have been generally applied to environmental problems from an economical point of view, often used in measuring agricultural sustainability (Suvedi et al., 2003). Pressure refers to any human activity that causes a change in the quality of the environment or a change in the quality or quantity of natural resources (Woodhouse et al., 2000; and Rigby et al., 2001). Hence in this model, pressure is always negative. Society's 'response' to this pressure has typically played out in the marketplace, or the government arena in the forms of new taxes, polluter pays policies, or new environmental or worker health and safety legislation (Rigby et al., 2001).

Woodhouse et al. (2000) reported problems with the PSR model. These are: (a) the necessity for having an obvious 'response' to a specific pressure, and (b) the difficulty in including non-environmental variables. Suvedi et al. (2003) reported that the use of arbitrarily set target indicator points in this model make the overall analysis complex and open to subjective errors. Rigby et al. (2001) acknowledged that it takes no account of social and economic dimensions of sustainability. Presently, it is this kind of model that is being used to evaluate and promote sustainability in the coffee industry of Costa Rica (de Groot, 2002).

The United Nations Commission for Sustainable Development has tried to improve upon the PSR model by using – the 'Driving Force' – State – Response model – that was modified to better include economic, social and institutional aspects of sustainable development. They shifted from solely considering environmental indicators to environmental indicators plus societal indicators and also allowed for the inclusion of both positive and negative 'driving forces' (Woodhouse, 2000).

Emergy analysis evolved as an alternate modeling technique to the Pressure (or Driving force) – State – Response approach often used in measuring agricultural sustainability. PSR models are heavily promoted by economists in the areas of land-use and agricultural sustainability (Woodhouse et al., 2000; Rigby et al., 2001 and Suvedi et al., 2003). Yang et al. (2003) discussed a model that attempts to evaluate sustainability through the comparison of human and natural systems based on a common value: the quantity of solar energy directly and indirectly required for the production of an item. Yang et al. (2003) and Brown et al. (2000) refer to this quantity as emergy.

Marchettini et al. (2003) stated emergy represents the memory of all the energy, matter and time that the biosphere used until a product is made available. Brown et al. (2000) reported that the emergy concept is the basis of a system of indicators that attempts to evaluate the efficiency, the environmental stress and the sustainable use of the resources, involved in a single process or in systems at various scale. Emergy tries to use solar equivalents in an attempt to encompass all the inputs (erosion, agrochemical use, water availability, etc…) with the same unit (Suvedi et al., 2003). For example, Marchettini et al. (2003) applied emergy analysis to determine which of four wine production methods were more sustainable, but was only useful in providing comparisons. No absolute sustainability could was determined.

Kersten et al. (2000) and Jansen et al. (1995) outline that many biophysical or land-use models evaluate sustainable development as optimizing net farm income over time. This approach links net income with social sustainability in terms of nutrition, levels of education and gender equality, and ecological sustainability through assumptions of productivity loss in the face of unsustainable land use.. However some researchers note the invalidity of these assumptions, citing the failure to consider the impacts of food security for farmers in the face of export-driven agriculture and reliance on global pricing schemes (Vargas et al., 2000; Reed, 1997; and Razavi, 1999).

The evaluation model proposed by Labuschagne et al. (2005) incorporates a variety of aspects from four different models that were assessed for 'suitability' through the use of four criteria. These criteria were to determine which presently existing frameworks were included. The criteria are: (a) The framework includes a set of measurable indicators, (b) The framework tries to address all three dimensions of sustainability – economic, social and environmental, (c) The framework has a broad focus, i.e. at a national, regional or company level. Product focused or site-specific frameworks were not considered, and (d)

The framework was not based on another closely related framework; it was original in its methodologies. Based on these criteria, four frameworks were included: (a) The Global Reporting Initiative, (b) United Nations Commission on Sustainable Development framework, (c) Sustainability Metrics of the Institution of Chemical Engineers, and (d) Wuppertal Sustainability Indicators. By absorbing some of these frameworks' particulars and the addition of new ideas, the authors developed a socio-economic evaluation model to be used for assessing sustainability within the processing industries of South Africa. The major focus of the model, as can be ascertained by the indicators being used for assessment, is one of a socio-economic viewpoint with emphasis on the social aspects. Only four of the nineteen indicators are related to ecological or environmental issues, eleven indicators focus on social issues, with the remaining four focusing on broad economical factors. The model is not completed however, the determination of how to measure many of the proposed indicators being left for future work.

4.6.2.2 Material Based Models. Jansen et al. (1995) proposed the use of linear programming to assess the sustainability of land use. The authors noted that mathematical programming is frequently applied in farm planning. It allows the determination of an optimal allocation of land, labour and capital, given a set of goals (e.g. maximization of income and leisure and minimization of risk) and constraints (e.g. labour and land). However, the authors also noted the limits to linear programming in sustainability models. Von Wiren-Lehr (2001) supported the view of a 'goal-oriented' mathematical sustainability model as well, but commented that the validity of the output information can also be dependent on the goals of the model user, raising opportunity for conflict between users with different definitions of sustainability.

Jansen et al. (1995) developed the model presently in use by the Costa Rican Ministry of Agriculture and Livestock (MAG) for the purpose of model sustainability land use. It uses a system that limits the time horizon of analysis to a subjective ten years. The model was based on the assumption that the use of the resource would not have an effect within this time frame and externalities are not included in modeling.

Munda (1997) stated that mathematical programming approaches typically use input–output relations derived from separate biophysical simulation models. The ensuing model can only deal with discrete input–output relations: a specific level of input always results in a specific level of output. The author suggested that one of the benefits of input-output analysis is that it enables a detailed view of smaller systems and the corresponding indicators, such as production chains. The problem definition can be examined on sector level, whereby all production sectors and final demand categories are a part of the analysis. Thus the numerous relations between production and consumption units can be represented.

Munda (1997) and Tellarini and Caporali (2000) reported that the basic idea of input-output analysis is to determine both the direct and the indirect demand effects. Conventional environmental economics and sustainability analyses mainly examine direct material inputs and pollution aspects, i.e. the resource use and/or pollution per unit output in a certain sector. Indirect material requirements and pollution effects, which arise during the production process due to multiple transactions, are ignored. These indirect effects also become visible by input-output analysis.

Tellarini and Caporali (2000) reported that in addition to the monetary flows normally focused on by input-output analysis it is also possible to illustrate material flows within an economic area as well as between economy and environment. The authors suggested that applying an environmentally extended input-output model enables a comprehensive sector analysis with respect to financial flows on the one hand and resource flows on the other hand. The authors also argued, that dynamics of ecological and social processes need to be fully integrated in the model, resulting in a continuous input-output relationship that can account for changing conditions over time. However, the indicators of such ecological or social components are generally evaluated in terms of material or monetary scales.

Kratena (2004) used a mathematical model that sets up a linear, input–output model of the relevant ecosystem flows that determine the carbon cycle in the global ecosystem. The author reported that introducing energy as the value added component in the ecosystem allows for the calculation of ecosystem prices expressed in 'energy values'. Like most other economic based models, the attempt is made to link the ecosystem with the economy in order to calculate prices of economic activities and of ecosystem activities. In analogy to the 'Ecological Footprint' (Rees and Wackernagel, 1995), where sustainability is characterized by the appropriate amount of productive land that is needed to absorb anthropogenic emissions, this model attempts to equate the 'energy prices' to the amount of carbon sinks needed for emission absorption, instead of equating the 'prices' to dollar values.

Bontkes and van Keulen (2003) argued that sustainability and decision support systems require non-linear dynamic models that allow for simulation of the more qualitative aspects of the process and can be developed in the face of uncertainty with regards to available data sets. The authors suggested that an important difference between system (or holistic) models and approaches based on mathematical programming refers to the integration of ecological and socio-economic aspects. They indicated that strict mathematical models can be too limited to provide holistic evaluation of a systems' sustainability. The authors provided an econometric approach to sustainability evaluations based on statistical analyses of historical data, thus providing a fairly accurate description of the behavior of the system in the past and an estimate of the future situation if present behaviors are maintained. They noted that the disadvantage, however, is that it does not always provide insight in the processes that play a role in system evolution and that it is not very suitable to deal with new or external phenomena. As well, large sets of data are required, preferably time series, which are rarely available in developing countries.

Varma et al. (2000) report on the use of Geographical Information Systems (GIS) models in the evaluation of sustainable land use. Similar to the model by Bontkes and Keulen (2003), GIS models present an assessment based on predictions that arise from historical data and require large spatial and temporal data sets often unavailable. GIS is useful as a tool, but can be limited in overall sustainability evaluations due to the absence of economic or social data resulting form changes in the land-use patterns. GIS models are typically aimed at biophysical sustainability through a spatial and temporal analysis of biophysical changes to the landscape such as: (a) the number of acreas of natural forest, (b) rate of agricultural development, (c) changes in soil quantity or quality, (d) biodiversity indexes, or (e) changes to water sheds (Varma et al, 2000; Yeh, 2000; Lotov et al., 2000; and Rafea, 2000). As such, GIS is evolving as a tool to be used in concert with other modeling methodologies (Yeh, 2000).

Galka (2004) and Musmanni (2003) noted that the framework for Cleaner Production (CP) is normally associated strictly with the sustainability of industrial processes. However, there have been some developments in the application of cleaner production techniques in agricultural settings in developing countries. Musmanni (2003) indicated that CP aims at sustainability through the reduction of pollution being discharged from a process by providing a system model that promotes the maximizing of resource and energy efficiencies and improving the efficacy of material use. End of pipe treatments are not considered a part of the 'cleaner production' model.

Ehrenheld (1997) and Musmanni (2003) reported that while economic considerations are included in the application of cleaner production models they are not the emphasis. It is believed that economic benefits will be the result of more efficiency within the operation by cutting costs, reducing risks and identifying new opportunities. The cleaner production model advocated by the UNEP (2002) does not include social considerations. However, Grutter and Egler (2004) argued that in order to optimize the benefits of CP, CP must be a component in a more comprehensive model. The authors suggested that if left as a stand-alone tool, CP will fail to support sustainable industrial development.

Life Cycle Analysis (LCA) examines the impact a product has on the environment from the beginning to the end of its lifetime. The aim is to highlight problems and deficiencies and thereby increase resource and energy-use efficiency. The boundaries of an LCA encompass the extraction of the raw materials used in the manufacturing or producing of the product, the production process, its intended use in the market and its disposal. For these reasons, it is commonly referred to as "cradle-to-grave" analysis (Culaba and

Purvis, 1999; Mattsson, 1999; and Elkington, 1997). This 'cradle to grave' analysis incorporates all stages of a life cycle of a product. The UNEP (1999) outlined the following stages of an LCA:

1. Inventory phase - a detailed description of raw materials and energy inputs used at all points and the emissions, effluents and solid waste outputs.
2. Impact assessment phase - relating material and energy inputs and outputs to real world environmental problems.
3. Improvement phase - using information collected in the other phases to improve overall environmental importance.

Klang (2003), Sonneman (2000) and Mattson (1999) suggested that LCAs can be considered environmental models, as minimizing environmental impact is the main aim of such analysis. However, Mattson (1999) pointed out that the UNEP model does not address the economic or social aspects of a product and should be considered a tool to assist with the sustainability assessment, but not a stand-alone format.

Despite this handicap, Sonneman (2000) and Klang (2003) stated that LCA is a versatile tool that can be used by companies in the development of business strategies and purchasing decisions in order to improve product and process design and also to convey environmental aspects about a product. Furthermore, it can be used to provide environmental data for the public or government or even to formulate environmental legislation (UNEP, 1999). The key components of LCA are:

1. A technique for assessing the environmental aspects and potential impacts associated with a product.
2. To study the environmental aspects and potential impacts throughout a products life.
3. To be used to study the environmental impact of either a product or the function the product is designed to perform.

Life Cycle Assessment (or Analysis) has successfully been applied to a wide variety of systems. Mattsson (1999) reported the application of LCA in the sustainability evaluation of specific agricultural systems in Sweden. Culaba and Purvis (1999) reported the use of LCA in the evaluation of the environmental impact associated with generic manufacturing processes. For the purposes of their work, the authors used procedures within the LCA to highlight inefficiencies and optimize the reuse and recycling of by-products and unused material during the various stages of processing of products. This was to avoid wastage and prevent depletion of natural resources. Sonneman (2000) noted that boundaries can be set based on geographical considerations, logistical factors, or economic constraints - as the broader the boundary, the more extensive (and more expensive) the evaluation can be.

De Groot (2002) proposed the use of a modified life cycle assessment to promote sustainability within the Costa Rican coffee industry. The author developed a quantitative evaluation model for usage within some of the coffee cooperatives in Costa Rica that attempted to include all three aspects of sustainability. This was based on an input-output model that quantitatively evaluates of the various indicators with regards to a predetermined target value for each indicator. The model presupposes that what constitutes sustainability within the system is already known and is closely related to other models where sustainability is measured by the resulting economic output. He based sustainability on the proper application of ISO 14000 EMS standards and adherence to present regulations making the assumption that these regulations are sufficient thus placing the burden of sustainability on information external to the system (i.e. government enforced wastewater guidelines).

4.6.3 Qualitative Models

The sustainability model being developed in concert between the Rain Forest Alliance (Russillo, 2004) and the National Cleaner Production Centres of Central America (Aguilar, 2004) for use in the evaluation and policy development of the coffee industry in Central American has a basis for qualitative analysis. The two groups aim to combine the concepts of LCA and cleaner production ideals to produce a holistic model aimed at securing the sustainability and well-being of the industry in general. However, according to Rainforest Alliance (2004a and b), the initial framework being proposed is largely qualitative in nature, where indicators values will be assessed based on the perception of what are 'good practices' according to the field personnel doing the evaluation. No quantitative scales are provided for the evaluator and little quantifiable data had been integrated into the model thus far (Russillo, 2004; and Aguilar, 2004).

Ramanathan (2002) discussed the application of analytical hierarchy process (AHP) in a multi-criteria model aimed at the determination of which environmental technologies should be implemented in industrial settings of developing countries. Both qualitative and quantitative scales were used. According to the author, AHP permits the inclusion of a variety, often conflicting criteria to be used in the formulation of an optimal solution. In this instance, the criteria of consideration were: (a) profitability, (b) compatibility with other development agendas, (c) capacity building opportunities (i.e. training opportunities for workers), and (d) barriers. Three difference technologies aimed at reducing greenhouse gas emission were evaluated, considering the preferences of a variety of stakeholders. The model was quite simplified, but demonstrates the applicability of AHP when indicator scales are quantitative in nature.

However, according to Barzalai (2003), AHP models often use qualitative scales to determine indicator values that cannot be mathematically combined with values obtained from quantities scales. An example of a qualitative scale would be (often used in the evaluation of the various criteria in government tender documents): excellent = 10, very good = 8, satisfactory = 5, and poor = 2. This kind of measurement is considered weak measurement and as such does not permit the application of mathematical functions. Often AHP models incorporate the use of expert knowledge, but can lead to inconclusive results as the values used in the models are based on individual interpretation of these qualitatively defined scale. Without a predetermined quantitative scale or a comparative analysis where an indicator's value is based on a comparison to at least two others, these models become completely qualitative in nature. In the case of a sustainability analysis, this wholly qualitative nature would cause difficulty in using the output in the development of policy or sustainability solutions (Barzalai, 2003).

4.6.4 Systems (Holistic) Models

Ducey and Larson (1999) reported that it is appropriate to use expert judgment when dealing with the qualitative concerns of sustainability evaluation. Judgments about the adequacy of the planning and industrial infrastructure, financial stability, ability to absorb risks, likelihood of cultural or social acceptance of new technologies or management ideals all require some integration of knowledge not available as a single, measurable criteria. However, the authors do not attempt to combine qualitative and quantitative measurements mathematically within their model.

Phillis and Andriantiatsaholiniaina (2001) reported on the use of fuzzy logic in the evaluation of sustainability. The model allows for the input of a wide variety of indicator values covering economic, social and environmental aspects and uses a feedback loop to make the system dynamic. The output of the model is a percentage value of sustainability, i.e. the system being evaluated is X % sustainable. Ducey and Larson (1999) point out that numbers evolving from evaluation models must have real life measures that can be readily understood by users and/or policy makers. Without a quantitative scale available for comparison, a model evaluation of 25% sustainability for example, becomes completely qualitative and completely open to subjective viewpoints. 25% sustainability must be linked with something concrete such as: (a) the number of remaining years at a certain level of agricultural productivity, or (b) the number of years until resource depletion.

Klang et al. (2003) suggested that achieving environmental sustainability is closely linked to the manner in which waste products of society are handled. Visions of what constitutes an ecologically sustainable system for waste treatment have been suggested by following a plan of 'industrial ecology', where wastes are reintroduced as alternative, value-added products. There is a volume of literature on the application of the concept of industrial ecology to environmental sustainability (Korhonen, 2004; Allen, 2001; Erkman, 1997; Ayers, 1994; and Cote and Hall, 1994). The underlining theory throughout this literature is that only by mimicking human processes (industrial, agricultural, urban planning, etc...) after natural ecosystems that true sustainability is attainable. Isenmann (2003) and

Korhonen (2004) stated that the idea of using nature as model is more than rhetoric or a theoretical idea, and that industrial ecology research should be advanced and turned into practice by incorporating the industrial ecology concept into applicable, usable models.

Mendoza and Prabhu (2003) discussed the methodologies of determine the criteria and indicators to be used in sustainability evaluation models. Mendoza and Prahhu (2003) discussed the use of the method of multi-criteria analysis to estimate the relative importance of each criteria and indicator, the performance relative to the desired condition and assessed the indicators combined effect or impact. The author described the use a panel of stakeholders to offer opinion on the preference and weighting that the various indicators should receive, but did not outline how to measure the criteria/indicator values. As long as quantitative scales are used in the criteria/indicator evaluation, the problems outlined by Barzalai (2003) could be avoided.

Hall (2000) and Kroeger and Montanye (2000) reported the danger of models that assume direct linkages between financial increase with positive social development. The authors highlight a variety of situations where gross household income was increased but quality of life was dramatically degraded. This is due to issues such as: (a) increased risk through dependence on foreign resources and global pricing schemes, (b) increased child labour in order to maintain household operations, (c) increased food expenditures as food once grown now had to be purchased, (d) and increased exposure to agrochemicals. Razavi (1999) suggests negative impacts on women in areas of mechanized agriculture, as they are required to increase their daily workload to secure income. Sustainable land use models such as the one presently employed by the Costa Rican government are based on the neoclassical economic theory that, according to Hall (2000) and Kroeger and Montanye (2000), has exacerbated the social and ecological degradation of the world's most impoverished regions.

Sonneman et al (2000) developed a system for evaluating damage resulting from industrial processes. Their methodology uses a matrix system that uses chemical process 'eco-vectors' that contain all the environmental loads of the individual process and make some attempt to evaluate the synergetic damages resulting from outputs of various processes being received in the environment. They demonstrate the usefulness of the evaluation in site and industry specific circumstances and could be expanded to provide a sustainability evaluation of similar sites and industrial processes.

Culaba and Purvis (1999) integrated qualitative and quantitative measures through the use of an expert systems model. The model evaluates sustainability of a system through the use of IF-THEN statements where the logic function IF is related to a particular predetermined sustainability parameter. The THEN statement indicates what the outcome is, either sustainable or unsustainable based, based on an AND operation of the various input IF statements. This model is largely limited to environmental evaluations due to the use of an LCA framework, but the authors suggest that it would be possible to apply this format to a broader spectrum of criteria that could provide a more holistic evaluation of the system in question.

5 FIELDWORK

5.1 Background

In its present form the Central American coffee industry is not sustainable, neither environmentally nor economically (Charveriat, 2001; ABCR, 2003; and Adams and Ghaly, 2005). Deforestation associated with the drive for higher yields contribute to biodiversity loss, degradation of soil fertility and erosion. Erosion and agrochemical inputs degraded the health of the soil that provides the basis for agricultural growth. They also contributed to the sedimentation and eutrophication of the waterways that provide: (a) clean water for human consumption, (b) species habitat and (c) employment to fishermen and others dependent on nearby rivers, estuaries and coastal regions for their livelihood. Pesticides have been linked to elevated cancer rates, acute pesticide poisonings, the development of chemical resistant pests, the evolution of secondary pests into problem infestations (Pratt, 1990; Popper, 1996; and Forastieri, 1999), and the degradation of the marine and aquatic environment (Robertson and Mansingh, 1997).

During the processing of coffee cherries, only approximately 18% of the natural resource taken from the farm, is converted into a useful product (Figure 5.1). The remainder of that resource is either directed to waste treatment facilities or in some lesser-developed settings is discharged into waterways. Depositing effluents with high BOD and suspended solids to waterways contributes to the environmental degradation of the region (Barbier et al., 2003). Therefore, redesigning the system using an industrial ecology approach would help eliminate the need for costly waste treatment systems, reduces environmental impact, and perhaps most importantly, provides an additional economic return to the producer.

Like any other industrial model, the coffee industry has material and energy inputs, internal processes and material and energy outputs. Unfortunately, the process is typically linear (Figure 5.2), the only consistent 'closed-loop' in the system is the removal of old coffee trees and their use as firewood within the drying portion of the processing

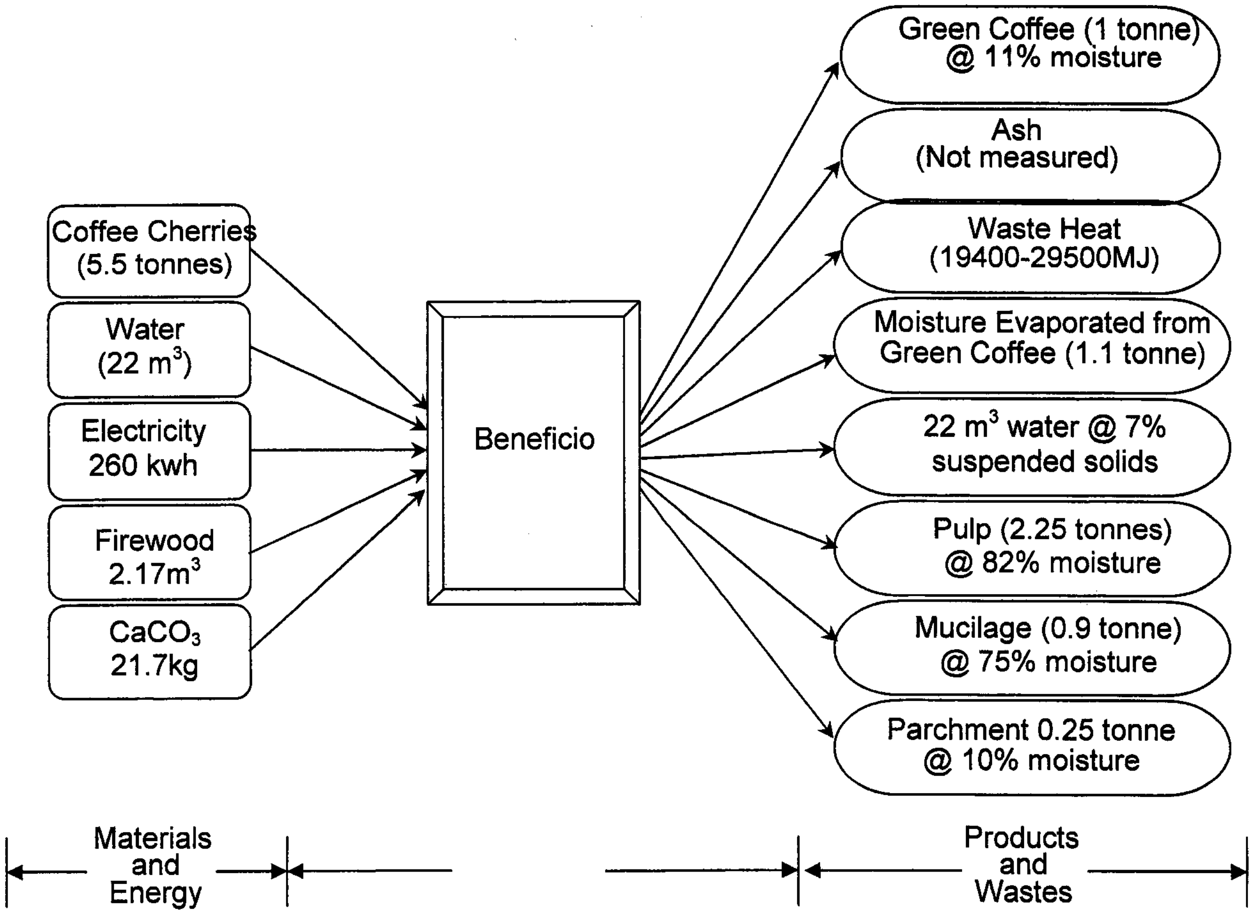


Figure 5.1. Material and energy balance in Costa Rican coffee industry.

operation. The coffee bean defines the economics of production within the coffee industry, as the price of coffee is the main reason for maintaining or increasing production. The Associacion de Beneficiadores del Café de Costa Rica indicated that the few pollution abatement programs that were rigorously initiated have been viewed as the cost of doing business (ABCR, 2003). Although, there have been ongoing discussions about improving the efficiency of the industry and reducing the negative outputs in terms of chemical and biological pollutants, the driving factor has been regulatory compliance, not resource management efficiencies (Kopper, 2003). This has limited innovation with the industry as managers typically only do enough to avoid fines. Therefore, environmental improvements have been largely limited to the implementation of environmental management systems (EMSs) and economical waste treatment technologies (Danse, 2003).

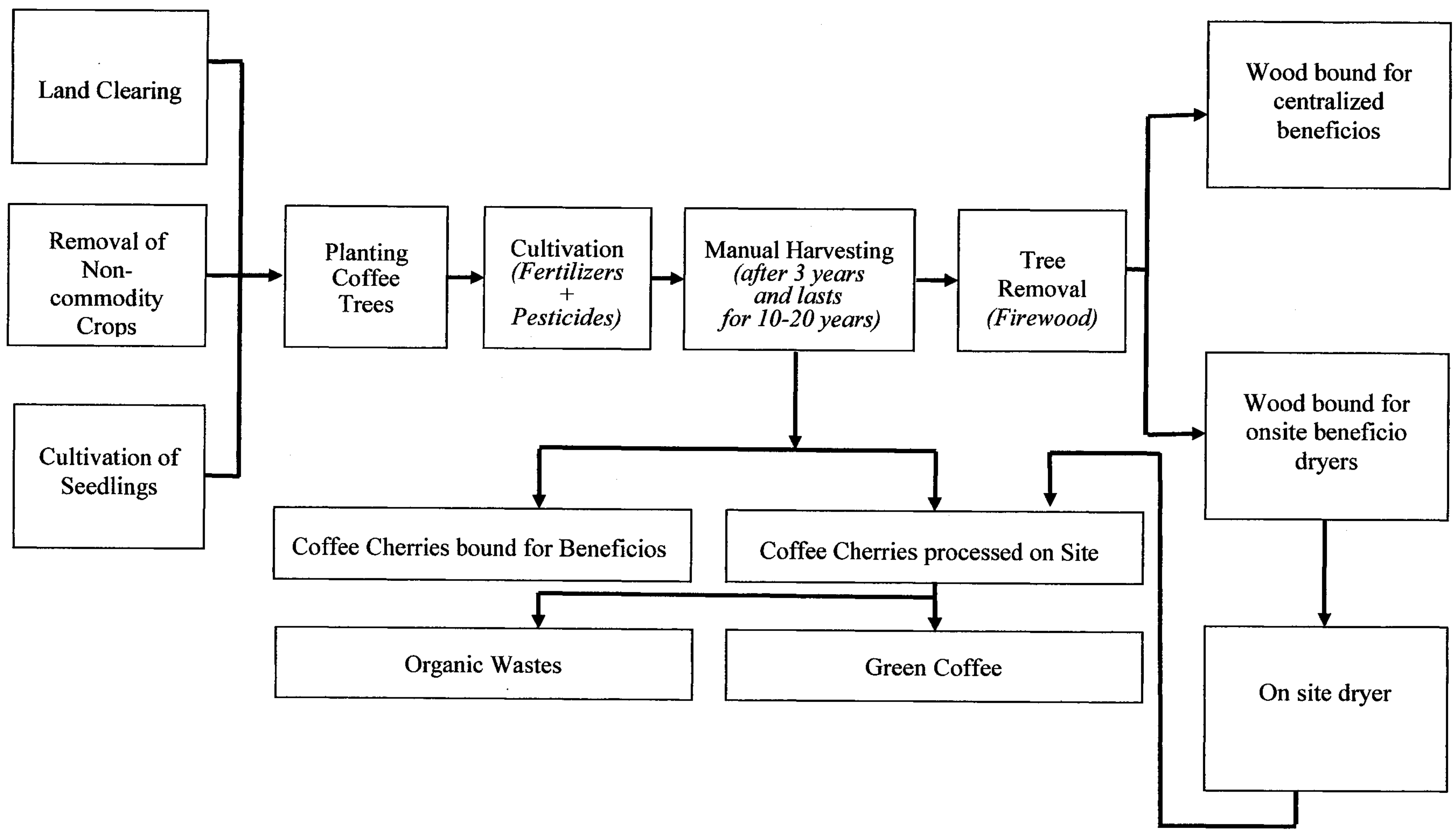


Figure 5.2. Production model for Costa Rican coffee.

There has been similar linear thinking with regards to farming techniques. In the past, traditional plantations with a diversity of edible and income-producing shade trees and ground cover were able to provide some stability to the farmer when coffee prices dropped. However, since the green revolution of past decades many of these plantations have been increasingly technified and developed into energy and chemically intensive, monoculture crops plantations, designed to increase yield in a time of high pricing and high demand. The significant increases in energy and agrochemical costs were offset by these increased yields, but little thought was given to increased economic or environmental risk associated with mono-crop cultivation as coffee was the product and everything else was insignificant (Rice and Ward, 1997).

Currently, the coffee industry is now in the midst of a potential economic and social crisis. The world price has bottomed out at some of the lowest levels in years, while production costs, and agrochemical and fuel prices, continue to increase. As a result, farms and plantations are being abandoned because producers cannot cover costs and have no other resources to fall back on during the time of crisis (Charveriat, 2001; Campos, 2003; and Transfair, 2002). Farmers are adding to urban congestion as they come to the cities to find work and children are being taken out of school, as farmers can no longer afford to send them (Charveriat, 2001). This has been particularly hard on the significant portion of small coffee households run by women, who are also the primary caregivers for their families and have limited options for other forms of work. Now, more than ever, the by-products of coffee processing need to be looked at as possible economic outputs, and the reduction in energy and chemical intensity must be considered as a path to a socially, environmentally and economically sustainable industry. Converting waste to value added products is an economic plus and reducing commercial fertilizer and pesticide uses will result in reductions in: (a) the harmful chemicals affecting non-targeted species, (b) production costs and (c) health risks. Any move away from monoculture production is a move towards sustainable farming practices, self-sufficiency and reduced economic risk.

5.2 Methodology

For the purpose of the field evaluation, the methodology was broken down into two categories: (a) the resource use assessment that focused on the technical evaluation of opportunities for the implementation of cleaner production and industrial ecology strategies to improve the sustainability of the coffee industry, in both the production and processing phases, and (b) the assessment of social conditions, cultural attitudes and institutional issues that need to be addressed to facilitate the implementations of sustainable technologies and practices.

5.2.1 Resource Use Assessment

The methodology for the resource use assessment was adapted from the Cleaner Production Assessment in Industries developed by the United Nations Environmental Programme Production and Consumption Branch (UNEP, 2002). It consisted of six phases as outlined in Figure 5.3. They are: (a) planning and organization, (b) pre – assessment, (c) assessment, (d) feasibility analysis, (e) implementation and continuation, and (f) project results assessment.

5.2.1.1 Planning and Organization. Before commencing the each phase of field, communications were established with the research facility Centro Agronomico Tropical de Investigación y Ensenanza (CATIE) in Turrialba, Costa Rica. Prior to each period, a group of coffee researchers expressed interest in supporting the field portion of this work and as such: (a) offered access to their research literature collection, personnel and field stations, (b) provided lodging, office space, and computing resources, and (c) assisted with establishing contacts with many within the coffee industry.

An extensive review of literature relating to industrial ecology, cleaner production, industrial development in developing countries, coffee production, coffee by-products, sustainable agriculture, decision modeling and general information on the coffee industry

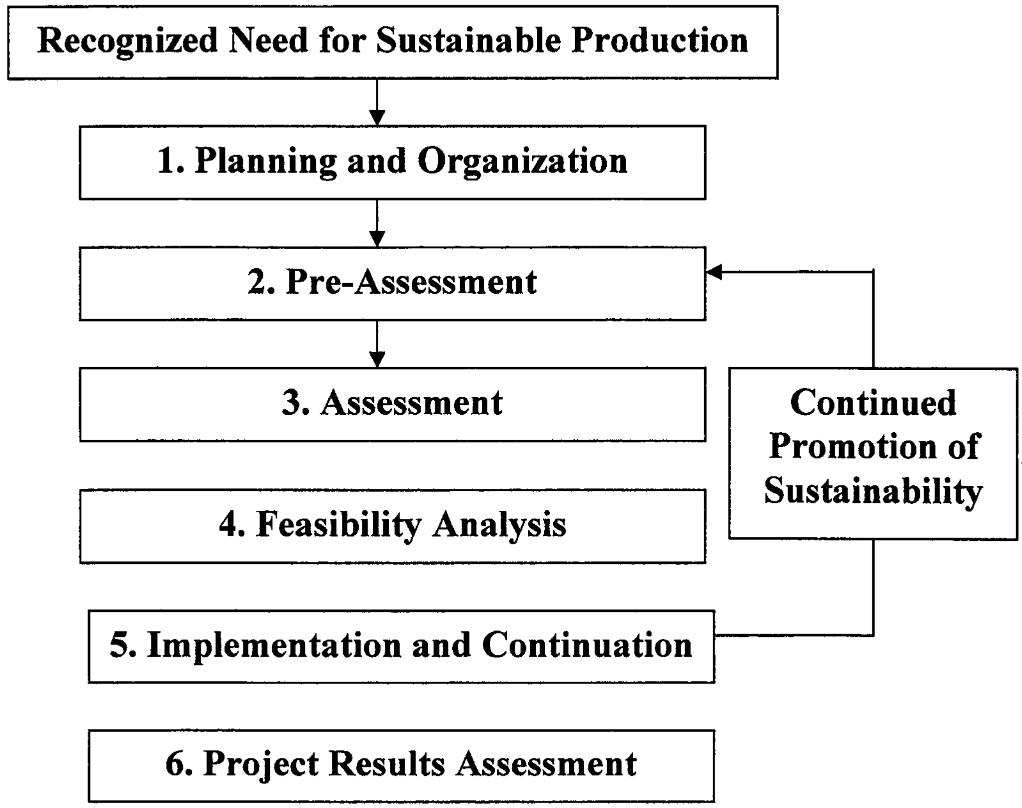


Figure 5.3. Sustainable production evaluation methodology (adapted from UNEP, 2002).

in Costa Rica and Central America was completed. Information gathered during this period was instrumental in the identification of potential environmental strategies and by-product uses.

5.2.1.2 Pre-Assessment (Qualitative Analysis). Prior to commencing each phase of fieldwork, various researchers, government officials and stakeholders within the Costa Rica coffee industry were contacted. Information was collected with regard to experiences related to the implementation of environmental programs and cleaner production strategies, production issues and complaints, and Costa Rica's pollution prevention strategy for the coffee industry. A list of additional individual and groups to be contacted was created based on the initial communications and was augmented as additional information became available (See List of Contacts - Appendix A).

Upon arrival, general information was collected on the farming and beneficio processes, particularly regarding the inventory of inputs and outputs. Site visits to beneficios and coffee farms throughout Costa Rica were conducted, and discussions with managers, farmers and production engineers were carried out.

5.2.1.3 Assessment (Quantitative Analysis). Quantitative data was collected through site visits and more extensive interviews with farming operations and beneficios, and the_sharing of data with stakeholders and researchers in both industry and government. Due to the reluctance of stakeholders to respond to formalized survey documents, a list of questions was followed during these meetings with beneficio operators and farmers to ensure the consistency and comprehensiveness of each interview (Appendix B). Typically, interviews were conducted under the basis of anonymity. Book keeping and house keeping records, and consultant reports were made available from beneficio operations. Information about beneficio operations, both general and statistical, was also provided by the Instituto del Café de Costa Rica (ICAFE) and the Centro de Investigaciones en Café (CICAFE), the scientific division of ICAFE. Data on the material and energy inputs of the production phase was collected from larger farming operations that maintained such information, as well as the farming branch of ICAFE. Large amount of anecdotal information concerning production and processing operations was also obtained through in-depth discussions with smaller farmers, production managers and plant engineers over the course of the two-season field evaluation.

5.2.1.4 Feasibility Analysis (Technical). Alternative methodologies for sustainable coffee cultivation and alternative uses for industry by-products were investigated through discussions with international development organization, non-governmental environmental groups, industry researchers and leaders and government officials. An evaluation of possible farming and processing alternatives based on production and by-product usage patterns within other agro-industries such as sugarcane, cocoa and palm oil was completed. Options were identified for making more efficient use of the resources used within the coffee industry.

5.2.1.5 Implementation and Continuation. The development of a sustainability evaluation support model to aid in the selection of the most applicable solutions will be completed and evaluated before the implementation of any option described is undertaken. The framework to be developed will include an analysis of the economic, social, cultural and institutional conditions necessary for the proper implementation of sustainability solutions.

5.2.1.6 Project Results Assessment. After a complete analysis, recommendations will be submitted to the government of Costa Rica for implementation. The success of such implementation and any unforeseen obstacles will have to be evaluated in the future. It is hoped that this case study will be a model for other developing countries in the region as well as other industries.

5.2.2 Analysis of Non-technical Factors Influencing Sustainability

An analysis was undertaken for the purpose of gaining a better understanding of the social, cultural and institutional conditions that would need to be considered if any sustainability strategy is to be successfully implemented. It consisted of face to face, informally structured surveys (Appendix C) and personal interviews and communications with various stakeholders in the Central American coffee industry and government officials of Costa Rica. The focus was on the obstacles to the economic advancement and environmental improvement of the coffee industry within a sustainability framework. Interviews were also conducted with stakeholders within other Central American agro-industrial chains with the aim of gaining a broader understanding of the perceptions held with regards to the general barriers faced for future development.

4.3 Data Collection and Observations

4.3.1 Coffee Industry in Central America

Coffee has come to be a source of substantial income and the base for the economic and social development in Central America (Figure 5.4). It is of vital importance to many countries as a source of both employment and foreign exchange earnings. Coffee, after oil is the largest valued commodity (legal) in international trade. In Central America, coffee production presently provides direct employment for over 5 million people in the seven countries, generates over 2 billion dollars in 2000 harvest (FAO, 2003) and represents a large portion of some Central American countries total annual exports (Table 5.1). Unfortunately, both the total revenue generated and annual production has been dropping over the last few years as coffee prices continue to drop and more farmers are not harvesting their crops (Table 5.2). This is particularly difficult for the small farms that make up the bulk of the industry (Table 5.3), and do not have the depth of financial security or access to assistance that is available to the larger plantations. The coffee prices make it difficult to cover production costs (APOT, 2003; and Danse, 2003).

4.3.2 Coffee Industry in Costa Rica

4.3.2.1 Background. The democratic republic of Costa Rica is located in Central America, just north of Panama (Figure 5.5). It was founded in the 1824, three years after Mexico lead a Central American declaration of independence from Spain in 1821. Instead of joining with other Central American territories to form a Central American republic, Costa Rica opted for sovereign independence. Since the late 19th century there have only been two brief periods of conflict. Today, although still a largely agricultural country, it

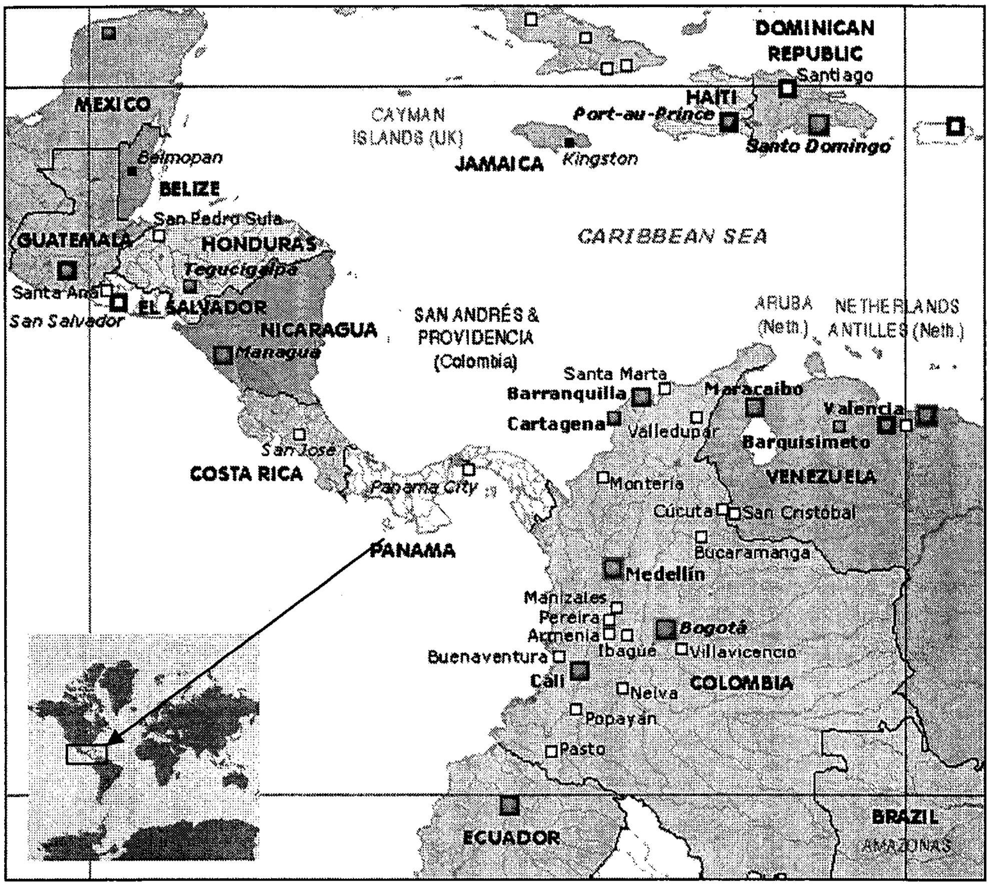


Figure 5.4. Map of Central America (adapted from World Sites Altas, 2003).

Table 5.1. Dependence of major producing countries in Central America on coffee exports (ICO,2002).

Country	Coffee as % of Country's Exports	Market Share as % of Total Exports
El Salvador	59.6	3.6
Guatemala	32.4	3.6
Nicaragua	30.4	0.8
Honduras	21.2	2.1
Costa Rica	20.7	2.9
Mexico	2.4	5.8

Table 5.2. Total exports and revenues from coffee production in 2000 – 2002.

Coffee Exports	Country							
	Central America	Costa Rica	El Salvador	Guatemala	Honduras	Mexico	Nicaragua	Panama
2002[a] Qty (Mt).	677,040	116,160	86,520	244,200	149,820	240,000	71,940	8,400
Value (1000$)	1,198,313	157,216	116,110	300,854	201,058	323,136	88,630	11,309
2001[b] Qty (Mt)	861,174	131,122	92,130	247,590	141,303	252,000	78,490	7,022
Value (1000$)	1,241,777	168,543	131,462	306,877	277,404	345,047	98,564	11,194
2000[b] Qty (Mt)	1,018,749	137,236	150,441	291,814	66,511	282,951	82,352	7,443
Value (1000$)	2,183,863	288,278	340,342	575,357	130,581	662,613	170,604	16,086

a – ICO, 2004
b – FAO, 2003

Table 5.3. Influence of small farmers in the Central American coffee industry (ICO, 2002).

Country	Number of farms	Number of small farms	Small farms as percentage
Guatemala	43,352	34,000	78
El Salvador	43,779	34,569	79
Honduras	38,800	37,881	98
Nicaragua	17,483	14,924	85
Costa Rica	65,000	55,250	85
Panama	30,742	29,000	94
Mexico	280,333	274,835	98
Total	519,489	480,459	92.5 (mean)

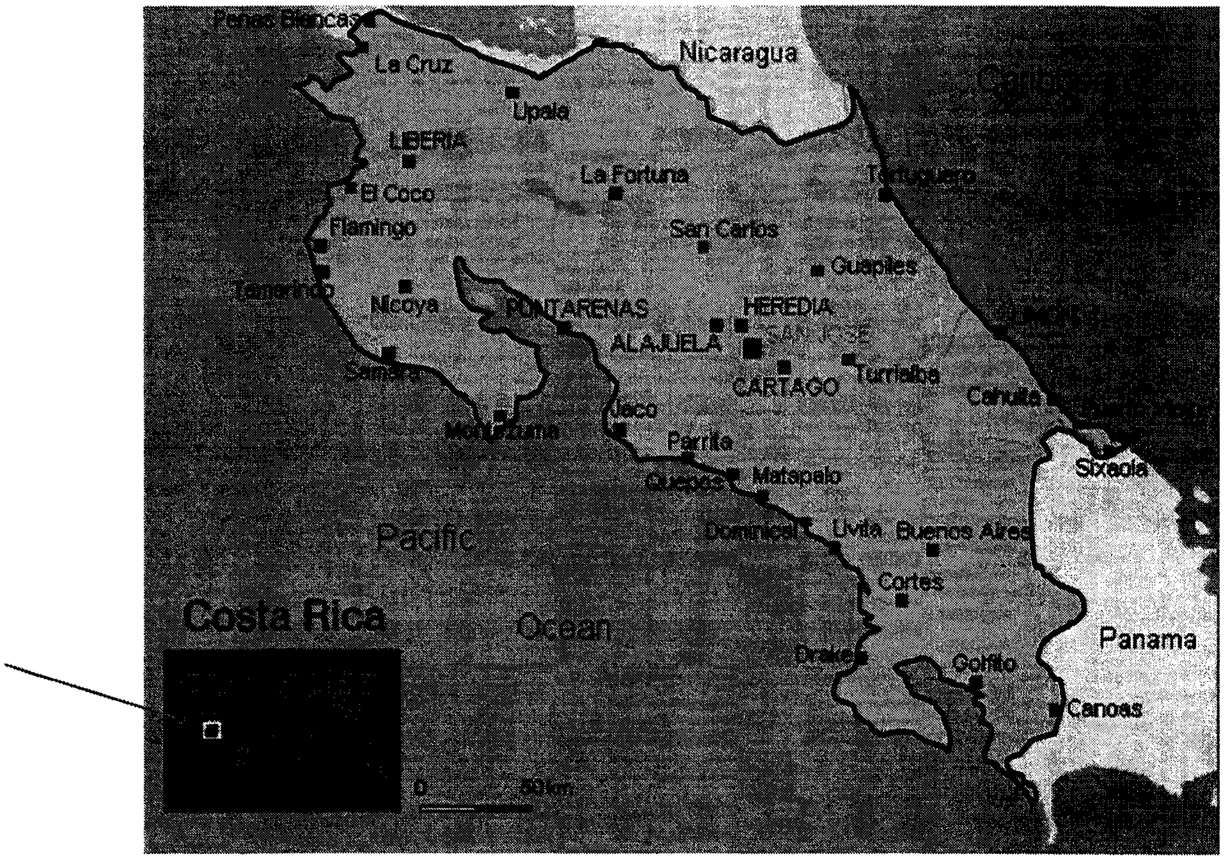


Figure 5.5. Map of Costa Rica (adapted from Yeess, 2003).

has expanded its economy to include strong technology and tourism sectors with a significantly higher standard of living as compared to its neighbours.

Poverty has been substantially reduced over the past 15 years, and a strong social system has been put into place. The country's political stability and high education levels attract foreign investors, and tourism continues to bring in foreign exchange. However, traditional export sectors have not kept pace. Low coffee prices and an overabundance of bananas have hurt the agricultural sector. The government continues to struggle with its large deficit and massive internal debt and with the need to modernize the state-owned electricity and telecommunications sector.

Costa Rica has a significant number of revolving political parties that rise and fall with the mood of the population. The three main parties that make up this democratic republic are the National Liberation Party (PLN), the Social Christian Unity Party (PUSC) and Citizen Action Party (PAC). In May 2002, the Social Christian Unity Party (PUSC) was elected. Other general national statistics are listed in Table 5.4.

Coffee production started in Costa Rica at the end of the colonial period and was first exported in 1820. The leaders of Costa Rica wanted to find a cash crop to export since Costa Rican economy had been a subsistence economy up to this point. They promoted coffee by offering free land and seeds to all peasants willing to grow it. This policy of homesteading transformed Costa Rican society into a nation of small farmers and landowners and lead to the rise of the middle class presence that differentiates Costa Rica from its neighbours. Until recently, coffee was Costa Rica's number one agricultural product (FAO, 2003), but the low coffee prices of the past few years have dropped it into second place after bananas in terms of total revenue.

The series of volcanic mountain chains runs from the Nicaraguan border in the north-west to the Panamanian border in the south-east essentially splits the country in half. In the center of these ranges is a high-altitude plain that consists of dark, volcanic soil and a climate ideal for the growth of high quality Arabica[†] coffee. Today, some of the world's most sought after coffees are grown in the mountain ranges surrounding this plain. Presently, coffee grows in seven regions of Costa Rica: Tarrazu, Tres Rios, Orosi, Brunca, Turrialba, Central Valley, West Valley (Figure 5.6). Costa Rica has an annual production of around 3 million kg of green coffee of which 85 - 90% is exported.

5.3.2.2 <u>Organizational Structure</u>. There are approximately 72600 farmers harvesting coffee from over 100,000 hectares in Costa Rica (Table 5.5). These farmers sell their crop to one of 97 processing mills (or *beneficios*) throughout the country with capacities ranging from 14,000 kg to 7.7 million kg/year. However, 50% of Costa Rica's production

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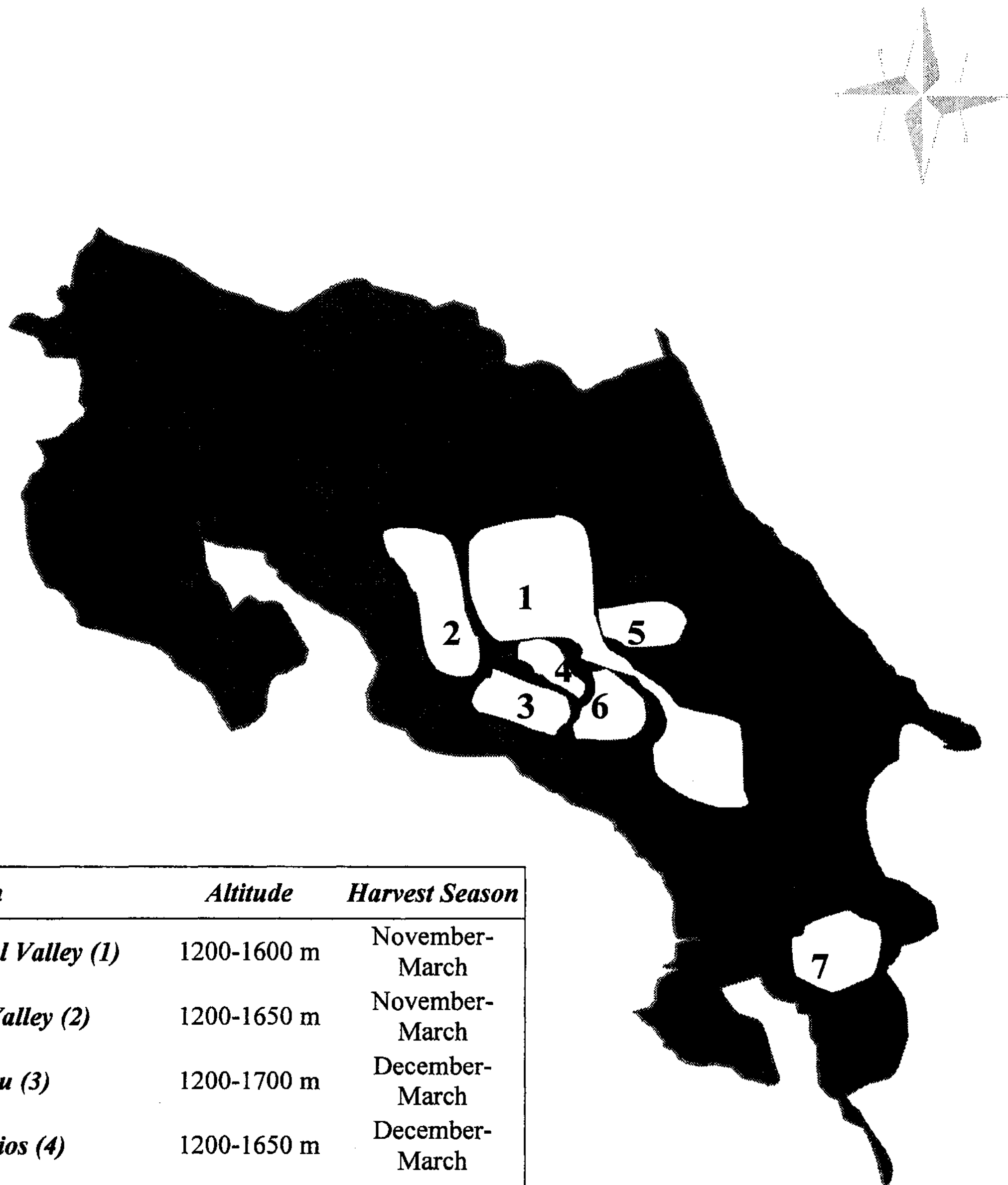
[†] Arabica coffee is the only coffee that can be grown legally in Costa Rica due to legislation making it illegal to grow any other species of coffee for any purpose other than research.

Table 5.4. Costa Rica statistics.

Parameter	Value
Economic	
Currency	Colones (1 US$ = 390 Colones – May 2003)
GDP per capita	4,500 US$
GDP by sector	agriculture 11%
	industry 37%
	services: 52%
Unemployment	5.2%
Labour by sector	agriculture 20%
	industry 22%
	services 58%
Principle Agricultural Exports (based on revenue)	Bananas 9.8%
	Coffee 4.0%
Geographic	
Land Area	51,100 sq km
Location	Latitude: 10° 00' N
	Longitude: 84° 00' W
	(Borders both Atlantic and Pacific Ocean, between Nicaragua and Panama)
Land Use	arable land: 4.41% permanent crops: 5.48% other: 90.11% (CIA, 2003)
Climate	Tropical and subtropical; dry season (December to April); rainy season (May to November); cooler in highlands
Social	
Population	3,834,934 (July 2002 est.)
Life Expectancy	76.22 years
Literacy	95.5%



Region	*Altitude*	*Harvest Season*
Central Valley (1)	1200-1600 m	November-March
West Valley (2)	1200-1650 m	November-March
Tarrazu (3)	1200-1700 m	December-March
Tres Rios (4)	1200-1650 m	December-March
Turrialba (5)	600-900 m	July – December
Orosi (6)	900-1200 m	September - February
Brunca (7)	800-1200 m	August - January

Figure 5.6. Coffee producing regions (adapted from Vocafe, 2002).

Table 5.5. Coffee industry statistics.

Parameter	Value
Area Planted	106,000 hectares
Average Yield/Hectare	1,380 kg or 30 fanegas*
Coffee Farmers	72,600
Beneficios	97
Exporters	15

***1 Quintal** = 46 kgs (100 pounds) of green coffee

***1 Fanega** = volume equivalent of coffee cherries to produce 1 quintal of coffee beans

Table 5. 6. Beneficio capacities in Costa Rica.

Capacity	Mills		Total Produced	
(quintals)	(number)	(%)	(kg)	(%)
0 to 920	53	54.6%	366,426	11.6%
921 to 1840	13	13.4%	334,645	10.6%
1841 to 2760	13	13.4%	614,484	19.5%
2761 to 3680	5	5.2%	338,870	10.8%
3681 to 4600	6	6.2%	563,018	17.9%
4601+	7	7.2%	931,195	29.6%
Total	97	100.0%	3,148,638	100.0%*

Table 5.7. Percentage production of beneficio types.

Beneficios type	Production Breakdown (%)
Co-ops – Cooperatives owned by member farmers	39
POCRCs – Privately Owned Costa Rican Companies	31
TNCs – Trans National Companies (Foreign Ownership)	30

is processed in 15 of these mills. All but one are located in the upper Central Valley within close proximity of the San Jose urban area.

Tables 5.6 and 5.7 show the relative capacities for the various groups. Beneficios are operated as one of three types: (a) privately owned Costa Rican companies, (b) transnational companies and (c) as co-operatives, where the farmers growing the coffee also own and operate the beneficio that processes their crops.

The government controls all coffee activity through the Instituto del Café (ICAFE). ICAFE represents the coffee sector at all International Coffee Organization (ICO) events and activities and all coffee transactions need to be registered. ICAFE is the authority governing all laws regarding coffee production and can sanction violations of these laws through suspending licenses, charging fines, and limiting individual quotas.

Figure 5.7 shows the stakeholders within the production chain of Costa Rica. Farmers deliver their berries to the receivers of their choice on a daily basis and the receivers then deliver the cherries to the beneficios. Coffee cherries must be processed within 24 hours of being picked to avoid fermentation, which may result in a significant reduction in quality. Some receivers are associated directly with beneficios while others are private operators. Beneficios process cherries into green coffee. This coffee is effectively being worked as a consignment from the farmers. In 2003, the beneficio charged a processing fee of $10US per 46kg bag (or quintal) of coffee and received a 9% commission of the total coffee sales. Both the fee and % commission are fixed each year by ICAFE. Green coffee is sold to the exporter at a price fixed by the market (commodity). Some beneficios will advance money against coffee deliveries if farmers request it. Farmers are expected to repay the beneficios within that harvest year. If there is a difference (positive) between the sale price established at the end of harvest (market fluctuations) and what was paid to the farmers, the beneficios are required to repay this difference to the farmers (less the processing fee and the commission). If the difference is negative, the loss is absorbed

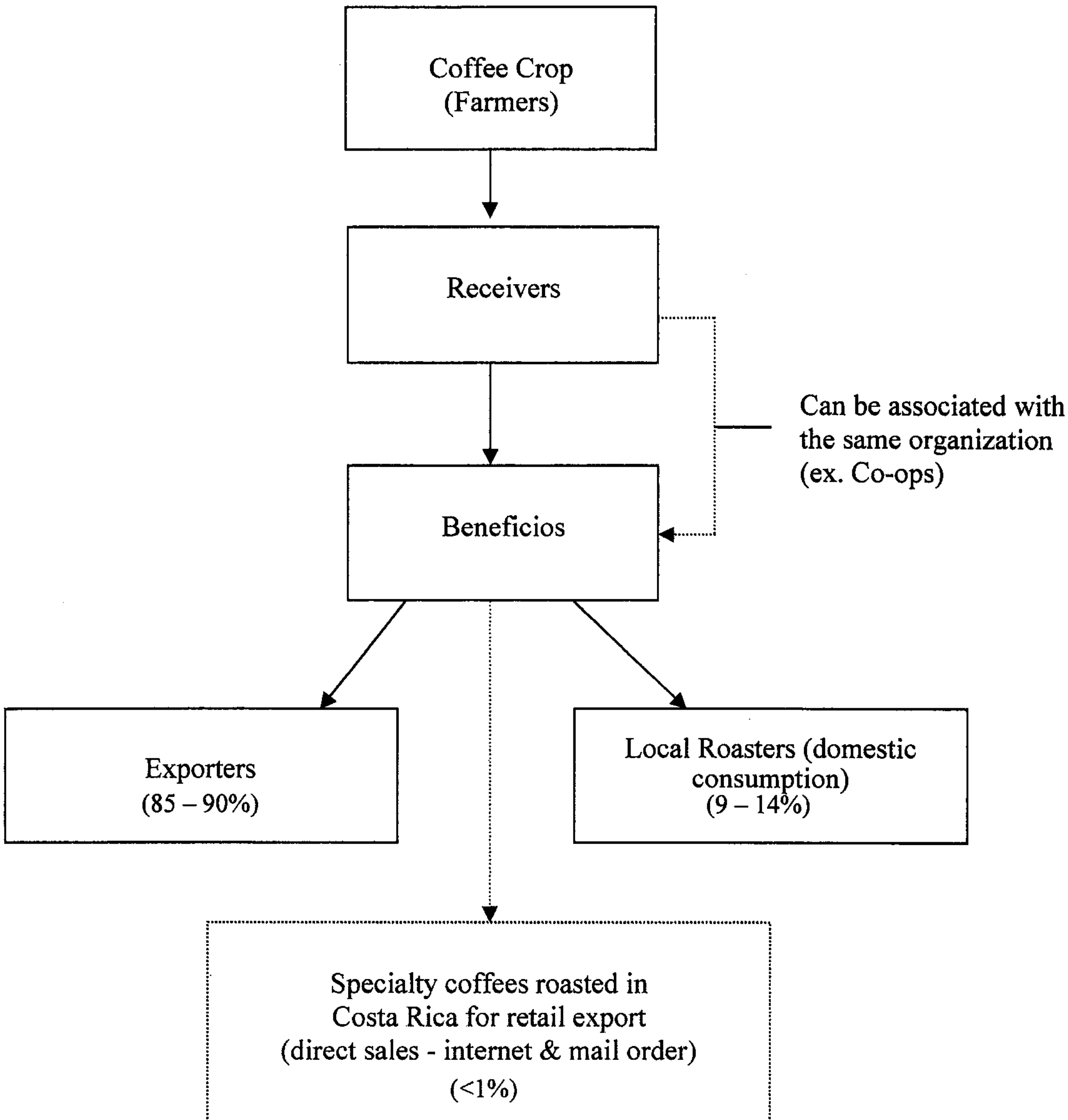


Figure 5.7. Coffee production chain in Costa Rica.

by the beneficio. The 39% of beneficios that operate as cooperatives divide the profits from the season amongst its membership of coffee farmers. Table 5.8 demonstrates the price structure within the coffee chain.

Exporters buy green coffee from the beneficios at the rieles price and sell it at the Free

Table 5.8. Price calculations for coffee at different stages (per fanega or 46kg of coffee).

FOB price (Price received by exporters)	
	Minus (-) transport costs to harbour
	Minas (-) crop insurance
	Minas (-) ICAFE contribution (1.5% of FOB)
	Minas 1.65$ exporter profit (fixed by ICAFE)
Equals (=) Rieles price (Price received by beneficios)	
	Minas(-) profit of 9% of Farm Gate price (fixed by ICAFE)
	Minas (-) 10$ processing cost (assessed and fixed by ICAFE)
	Minas (-) contribution back to cooperative (if applicable)
Equals (=) Farm Gate Price (Price received by farmers)	

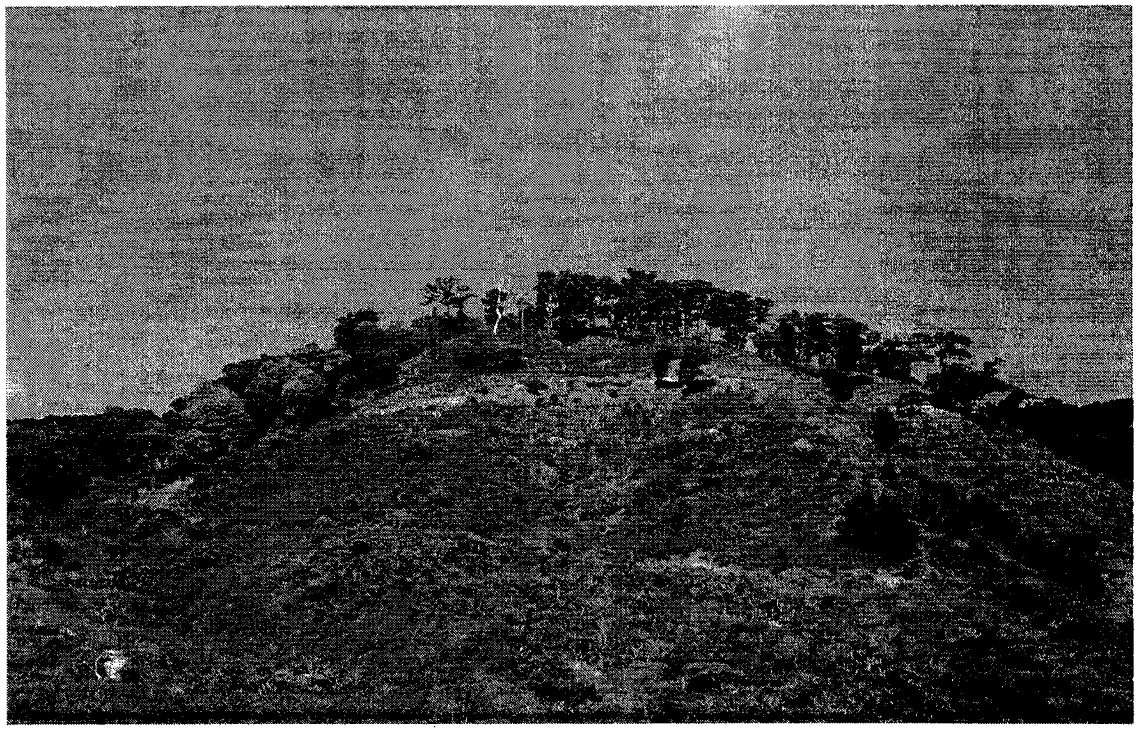


Figure 5.8. Monoculture sun-coffee plantation in St. Maria del Dota, Tarrazu Region.

On Board (FOB)[†] origin price. The difference between the FOB and the rieles price is 1.5% fee that goes to the Instituto del Café de Costa Rica (ICAFE), a fixed $1.65US/quintal that is the exporter's profit, and crop insurance, if applicable. Transportation costs from the origin to the shipper will either be added to the FOB origin price received by the exporters or paid directly by the receiver of the coffee. Many beneficiadores are also involved in the process as exporters, but this is not always the case.

5.3.2.3 <u>Coffee Cultivation</u> In the past ten years, the majority of new coffee cultivation has been conducted on previously cultivated land. Coffee has been replacing other crops as opposed to new plantation being developed on previously uncleared land. In Costa Rica at least, coffee plantation are no longer contributing to the deforestation of virgin forests.

The change in how coffee is produced is having a negative effect on environmental sustainability of the land. The Costa Rican coffee industry's production methodology has been transformed to one of an almost exclusive use of technified-shade and sun production. Within the last decade 96% of all new coffee plantations have been technified-shade or sun coffee. Presently, ICAFE does not have a census of the total coffee areas that are shade, technified-shade or sun. The last census was completed in 1985. However, some believe that presently more than 90% of land planted with coffee is cultivated as a mono-crop using technified shade and sun techniques (ABCR, 2003; and APOT, 2003).

With this transformation has come an increased use of agricultural chemicals, deforestation of previous shade plantations, loss of biodiversity, increased dependence on foreign markets and increased soil erosion. However, a traditional coffee farm can be a virtually self-sustaining ecosystem, with little or no pesticides, fungicides, or fertilizers

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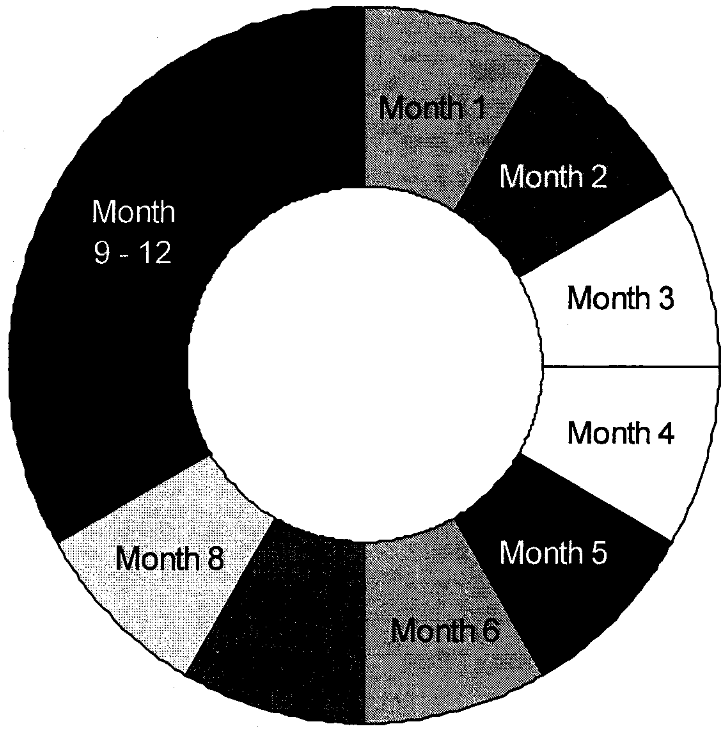
[†] Free On Board (FOB), is a transportation term that indicates that the price for goods includes delivery at the seller's expense to a specified point and no further. 'FOB Origin' means that the price does not include any shipping expenses.

necessary. Predation by birds, spiders, ants, and wasps helps keep insect pests in check and coffee's alkaloid leaves make them unpalatable to most insects. Weeds and erosion generally do not cause problems on traditional coffee farms. Leaf litter forms a thick carpet of mulch, reducing evaporation, protecting the soil from erosion, and keeping weeds at bay. Also, the protective canopy buffers the soil from desiccating winds and the erosive forces of rain. The same cannot be said for modernized coffee farms (Figure 5.8).

5.3.2.3.1 *Annual Production* Cycle. The management of a coffee plantation basically consists of six tasks that are repeated every year: pruning coffee bushes, shade management (if not sun coffee), fertilization, weed control, pest and disease management and harvesting . The timing of each task is dependant on the region as the life cycle of the coffee plant varies from one location to another. Figure 5.9 shows the various tasks carried out throughout the season.

On coffee plantations with any shade, the annual production cycle usually starts with collection of remaining coffee berries (both from the trees and the ground) and the first pruning of the shade trees, which is done shortly after the harvest. The pruning of the coffee bushes and the first fertilization then follow. In sun coffee productions, the pruning of the coffee bushes and fertilization are the first tasks. In the traditional 'selective' pruning technique, the exhausted branches are cut back from every plant. New coffee plants replace older trees every 20 to 30 years. More recently (particularly in sun plantations), 'total pruning' has been promoted, where the entire plant is cut back to about 40 cm above the soil (ICAFE, 2002). This type of pruning is done by selectively cutting individual exhausted plants or by trimming entire rows every 3 to 5 years.

Fertilization is the most important external input in coffee production, with application being made one to four times a year. Most plantations carry out the first application after pruning, while subsequent applications will depend on rainfall, soil quality, slope (i.e. level of erosion), degree of shade (and thereby level of available organic materials) and coffee prices (i.e. can they afford to purchase fertilizer).



Month	Activity
1*	Pruning of shade trees, collection of berries, first herbicide application
2	Pruning of coffee bushes, planting of seedlings, collection of berries, first fertilization application
3	Weeding, planting of seedlings, application of soil amendments, second fertilization and herbicide application
4	Weeding, application of soil amendments, second fertilization and herbicide application, pesticide application (if needed)
5	Fungicide application
6	Weeding, third fertilization application, pesticide application (if needed)
7	Second pruning of shade trees (only necessary for technified shade coffee)
8	Final herbicide and fertilization application
9-12	Harvest season - typically a four month period (can be six in the Brunca and Turrialba regions)

* Month 1 equals: January for Turrialba region
February for Brunca region
March for the Orosi Valley region
April for the Central and West Valleys, Tarrazu and Tres Rios regions

Figure 5.9. Annual tasks during coffee cultivation.

Weeds can be managed mechanically or chemically, with the focus being more on the chemical control within the larger or more technified plantations. Two to four chemical applications a year are usually practiced depending on the region and the plantation management style. The humid regions such as Turrialba and the Orosi Valley require more weed control than semi-arid regions, such as the Tarrazu, and the Central and West Valley regions. As well, plantations that have established an intercropping system (i.e other crops being grown around the coffee) require less weeding than mono-crop plantations that have no other vegetative cover between the coffee bush hedgerows; sunshine strongly favors weed growth. The first herbicide application is usually made just before pruning and the last application is made just before harvest begins. Paraquat, glyphosate and 2,4, D are the most popular active ingredients in Costa Rica.

Fungicides are also commonly used as the primary diseases within coffee plantations are fungal diseases. The most important fungi in Costa Rica are brown eye spot (*Cercospora coffeicola*) and coffee rust (*Hemileia vastatrix*). Farmers who use fungicides usually apply them two to four times a year, whenever there are extended periods of elevated moisture levels. In most cases, preventative, copper-based fungicides are applied. If fungal diseases are prevalent, curative products may be used, but are much more expensive than protective fungicides.

Pests have only recently become a problem in Costa Rica with the arrival of the coffee berry borer *(Hypothenemus hampei*) in the 2000/2001-harvest year from Nicaragua. Its impact is still scattered and the primary method of control is through use of endosulphan in affected plantations. ICAFE is taking serious precautions to prevent its further spread. All vehicles are sprayed with endosulphan when entering coffee production areas that have yet to be affected. Another control measure is the controlled releases of parasitic wasps that are a natural enemy of the pest. In sun coffee plantations, the complete removal of all berries from the trees and ground have been helpful in reducing populations as the adults have nowhere to lay their eggs and, therefore, cannot procreate. Pesticide application begins two to three months after the harvest and can continue throughout the year until the middle of the following harvest. Frequency of application has yet to be determined due to the pest's recent arrival. However, in other countries which are more familiar with the berry borer, farmers have been known to apply pesticides once a month during this period (Mörner et al., 2003). Table 5.9 lists the various agrochemicals that can be found in use in Central American coffee plantations.

5.3.2.3.2 *Preparation of Coffee Seedlings*. Large and small plantations depend on good quality seedlings for the success of the coffee plantation. Exhausted plants should be replaced each year. The cultivation of new seedling can be done on the farm or in government run nurseries from which the seedlings are purchased. Ideally, seedlings will be of the same variety as those already grown on the property to ensure the highest possible productivity. Cross-pollination between different Arabica varieties can reduce the productivity of individual plants.

Typically, the farmer collect beans from bushes that have demonstrated the highest quality and yield and are without disease or defect. The pulp is removed by hand and is washed slightly, but not fermented. It is then dried in the sun for a maximum of one day. The beans are then stored in shaded, well-ventilated drying racks until needed.

The seed plot is prepared with loose earth or sand in an area with constant warmth in order to provide conditions ideal for germination. In higher elevation areas, seed plots will often be in covered patios to lessen the heat loss after the sun goes down. The coffee beans are evenly spaced and covered with a thin layer earth. A layer of leaves, such as banana or palm is then placed over the seeds to help maintain a suitable level of humidity. The germination period takes from 30 and 45 days. It is important to monitor the seed plots to ensure that the leaf layer is removed the moment the bean begins to germinate. Once the seedlings are upright and the stem has acquired a green coloration the seedling is ready for transplant.

The land is prepared for transplant ahead of time. Row and seedling spacing and time of transplant depend on issues such as the slope, level of rainfall and soil type. Other factors include seed variety factors such as optimal amounts of shade and nutrient requirements.

Table 5.9. Most common pesticides in Central American coffee farms.

Pesticide	Uses	Health and Environmental Effects
DDT	General Use organochlorine insecticide (banned in most developed countries, still found in Nicaragua and Honduras)	Acute – effects on the nervous system, liver and kidneys Chronic – linked to increase cancer rates Environmental – persistent, toxic to aquatic invertebrates and fish, and linked to reduced reproduction rates in birds.
Endosulphan	Widely used against the 'Broca coffee borer' that is presently spreading through Central America	Highly toxic - repeated incidents of farm worker poisonings throughout Central American coffee plantations.
Paraquat	Intense herbicide used against weeds.	Acute – vomiting, abdominal pain, kidney failure, lung sores and liver injury. Chronic – mutagenic to humans and possible carcinogenic Environmental – not selective, it kills any green tissue on contact.
Glyphosate (Roundup)	Herbicide used against weeds	Acute – vomiting, abdominal pain, eye and skin irritations Environmental – not selective.
2,4-D	Herbicide used against weeds	Acute – serious eye and skin irritations Chronic – associated with non-Hodgkin's lymphoma
Furadan-Carbofuran	Insecticide	Acute – Respiratory system failure Environmental – Highly toxic to birds both through direct exposure and through consumption of small birds or mammals that have been poisoned. Also very toxic to most freshwater fish species.
Terbufos	Insecticide and nematicde	Acute – Vomiting and excessive sweating, exposure possible through ingestion and skin contact, affects nervous system.
Diazinon	Insecticide (heavily used in Guatemala)	Acute – blurred vision, respiratory effects and intoxication related confusion. Environmental – Bird kills linked with application of Diazinon.
Malathion	Used to control mites in coffee plants	Chronic – mutagenic Environmental – Highly toxic to aquatic invertebrates and certain freshwater fish
Oxamyl	General Insecticide	Environmental – Highly toxic to bees

The aim is to have a minimal competition with other species that may be present such as shade trees or secondary crops. Holes are dug to a depth of 30 cm with a 30 cm diameter and ideally organic compost is used to fill in about half of the hole. All remnants of the previous coffee plant is removed to minimize the possibility of nematode infection. Two seedlings are placed in each hole and the earth is replaced. The plants selected for the transplant must be straight, with well-formed roots, and have not opened its leaves. Once planted, foliar nutrients and other soil amendments are typically added.

5.3.2.4 Coffee Harvesting. Coffee plantations are normally located in very mountainous regions and the farms often have very rugged terrain with steep slopes (Figure 5.10). This makes the operation of tractors or other mechanical devices extremely difficult.

Farm size ranges from the family run farm of approximately 1-2 hectares to large corporate plantation operations that can be over 100 hectares. Large corporate plantations are somewhat more rare in Costa Rica than in surrounding countries, although foreign sponsored development is gradually changing this situation (Aguilar and Klocker, 2000). In some monoculture plantation in Brazil, mechanical harvesters are used, but high quality *Arabica* coffee needs to be hand picked and processed when it is ripe (Figure 5.11). Berries that have already dropped from the tree cannot be used because the fermentation of the fruit will affect the flavour of the coffee bean. Green cherries are not desirable as the bean is not fully developed and will reduce the quality of the overall batch. Beneficios will typically not accept crop that contain more than 3% green cherries (Ramero, 2003). Ripe coffee cherries are picked daily; the same worker will pick from a designated area until all the area is completely harvested. The harvesting period for any one particular area is normally three to five months. The average picker can pick ~3800kg (or 15 fanegas) of cherries per month (Ramero, 2003).

In Costa Rica, pickers are normally transient workers from neighbouring countries, particularly Nicaragua. With a shortage of inexpensive labour in Costa Rica, larger plantation owners will offer housing, food and (sometimes) provide schooling for pickers

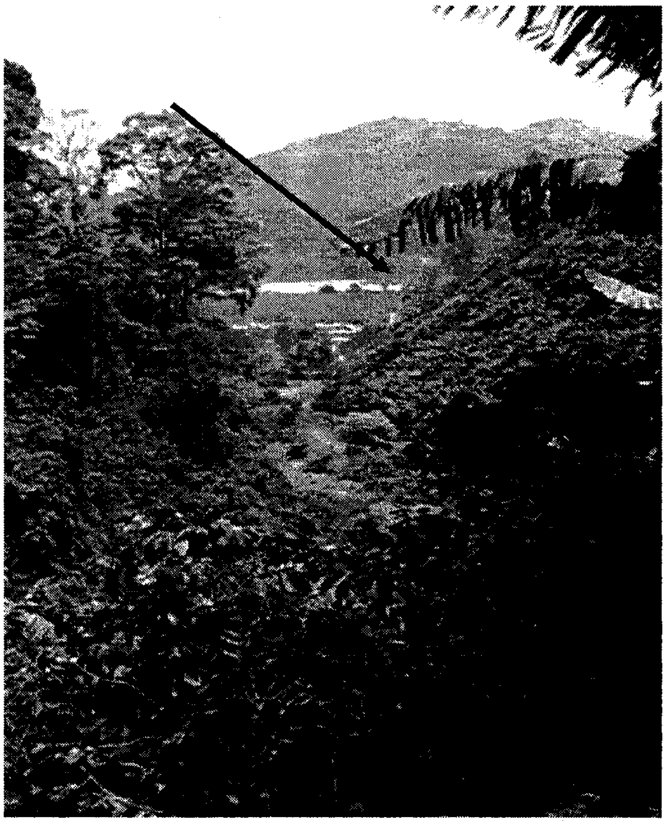


Figure 5.10. Typical Costa Rican coffee farm.

Figure 5.11. Ripe coffee cherries.

and their families in order to entice them to their particular holding. Even small family farmers will normally hire 1-3 pickers to lighten the load placed on his family. Workers work from 6 am to 3 pm, 6 days a week. At 3 pm, the harvest is taken to a receiving station.

Unless farmers have received some kind of advanced payment for their product they may chose which beneficios they bring their crops to. The beneficios operate receiving stations all over the country where the farmers bring their cherries. The cherries are measured (by volume) and their quality assessed, and the farmer receives a receipt for the amount. They are paid at the end of the season, when they 'refund' their receipts for payment (minus any advances and interest). There are also independent receivers who will then take the coffee cherries to the beneficio of their choice. These independents will typically accept lower quality cherries than the beneficio receiving stations and will pay a lower price for them. The trucks that arrive at the beneficios will either be privately owned (more often) or owned by the beneficio.

There has been a steady reduction in coffee production in Costa Rica since 1999 (Figure 5.12). Reduction in harvests has in part been orchestrated by the industry due to over supply, and in part as a result of small farmers walking away from their farms because market prices no longer cover the cost of production (Charveriat, 2001; ICO, 2004;

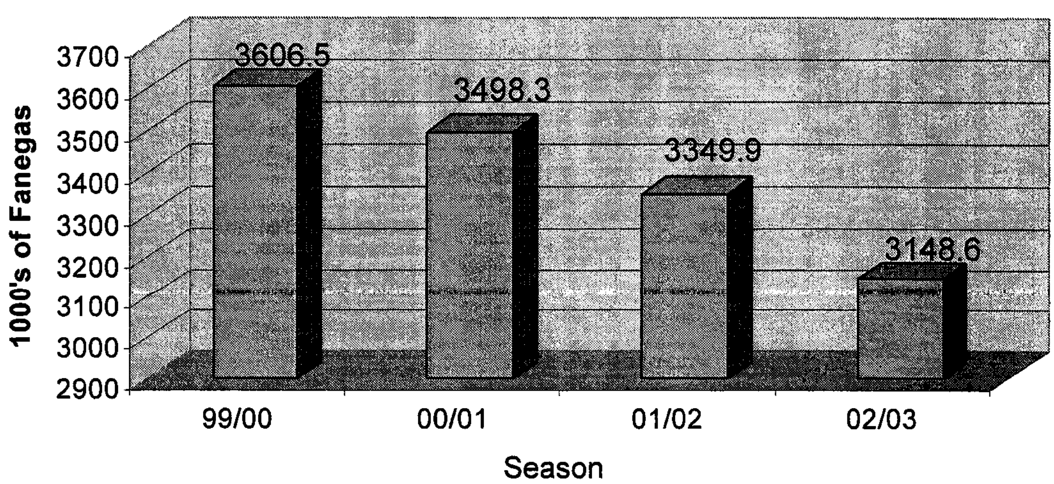


Figure 5.12. Coffee production statistics in Costa Rica (Volcafe, 2003).

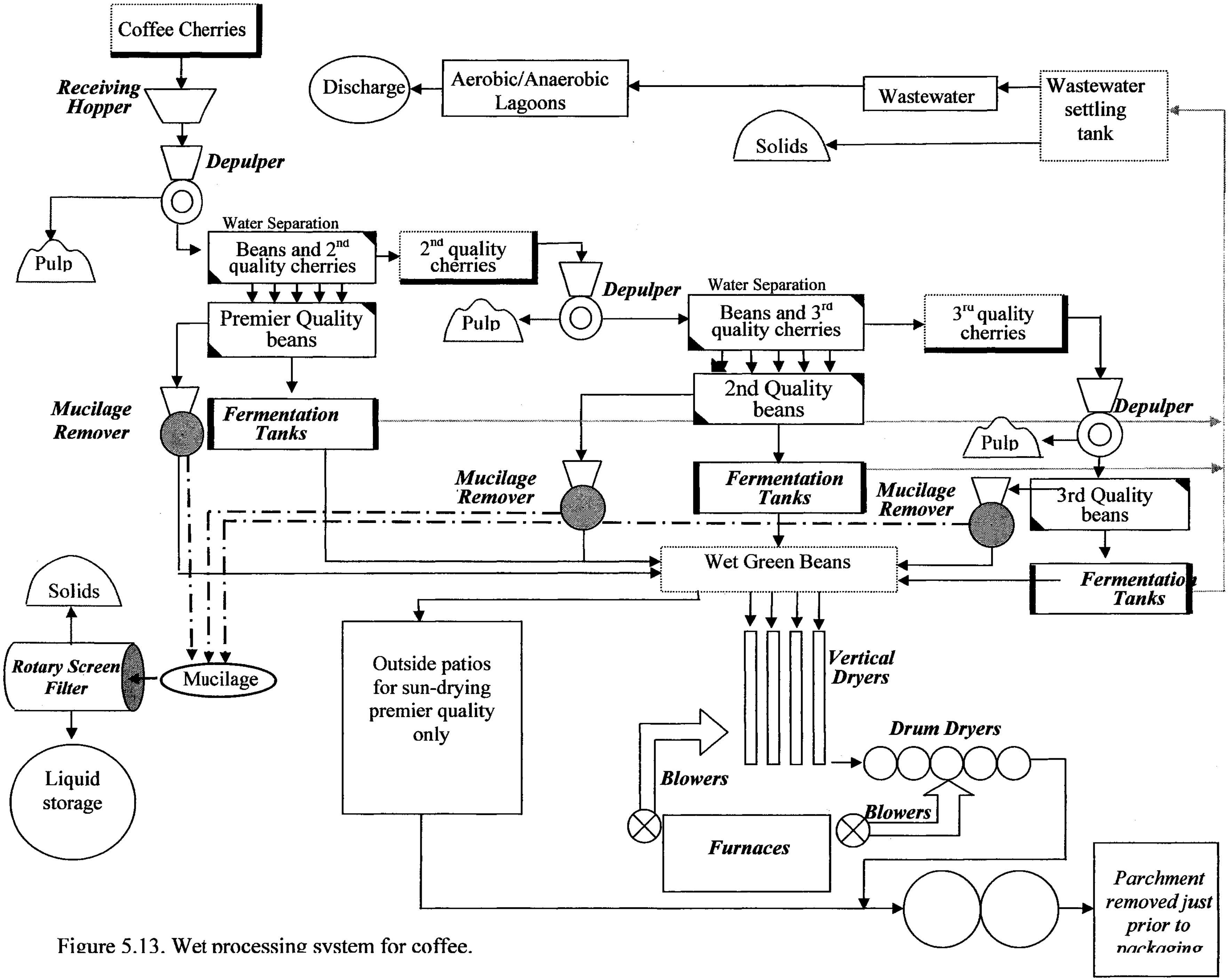


Figure 5.13. Wet processing system for coffee.

Lindle, 2003; and Alfaro, 2003). There has also been a concerted effort by some in the industry to reduce the coffee supply by eliminating poorer quality coffee (i.e. destroying it) from the market. This trend may have had an effect as well, but it is not an official strategy within Central America.

4.3.2.5 Coffee Processing. In Costa Rica, the processing of coffee includes a number of stages that are consistent amongst all beneficios. The wet processing of coffee is the predominant method in all Central American mills. Within the beneficio itself, the operational set up can vary significantly from one to the next. A schematic of the material flow within a beneficio (Figure 5.13) provides a general idea of the system. The positioning of the production lines (i.e. parallel or series), the number of grades produced, the type of mucilage removal system, and the type of waste treatment vary from mill to mill.

4.3.2.5.1 *Depulping.* Once the coffee berries are transported to the coffee mill they are fed into a hopper. The first stage of the process is the depulping of the coffee cherry. The cherries are transported to the depulpers by water, which serves to: (a) remove green or spoiled berries and foreign material that rises to the surface, and (b) act as a transport mechanism (Bressani, 1979a; and Gautho, 1995).

Depulpers (Figure 5.14) are machines that operate like large circular cheese graters where the skin and flesh of the coffee is removed, leaving beans surrounded by a mucilaginous layer between 0.5 and 2.0 mm thick. The pulp is discarded as waste and the beans are transported to fermentation tanks or mechanical mucilage removal systems. Depending on the size and quality being sought, the tolerance of the depulpers can be changed to only removal of the outer flesh of certain cherries (i.e. the largest, most ripe). The unpulped cherries are separated from the coffee beans using gravity separation (Figure 5.15). The coffee beans travel to the mucilage removal phase and unpulped cherries are transported to another set of depulpers with lower tolerances. These second round cherries are considered No. 2 quality and will be kept separate from the No. 1 quality for the remainder of the process. This cyclic system continues to No. 3 quality beans. After

Figure 5.14. Depulping machines.

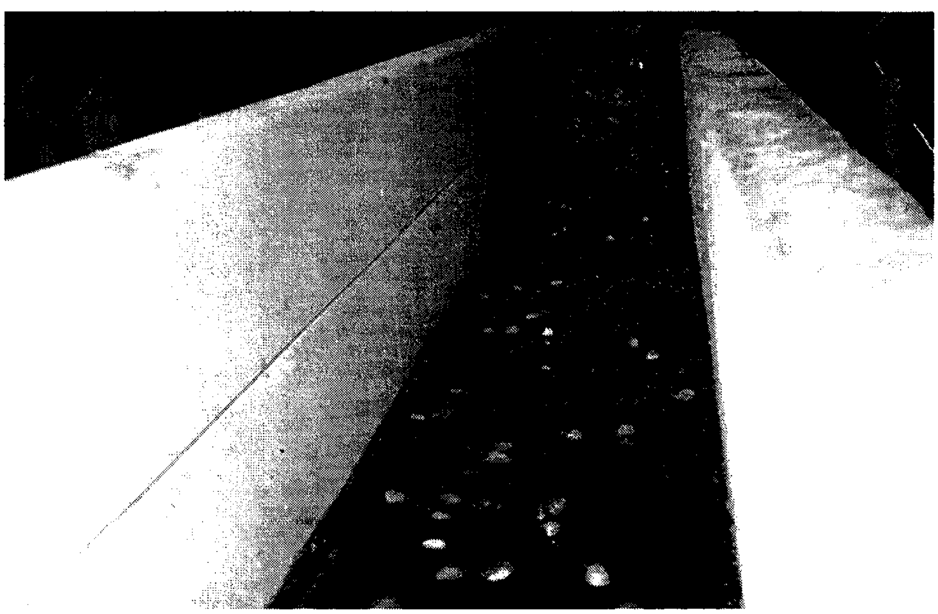


Figure 5.15. Gravity separation.

the third set of depulpers, the remaining unpulped cherries are normally discarded along with the coffee pulp.

5.3.2.5.2 *Fermentation/ Mucilage Removal.* Mucilage is a gelatinous substance with a high sugar and pectin content and is removed from the coffee bean by one of two methods, fermentation or mechanical separation. With the fermentation process, the beans are stored in tanks of clean water, where the mucilage is allowed to ferment from 12 to 48 hours (depending on the condition of the cherry) and is digested through a combination of microbial activity and the work of endogenous enzymes contained within the mucilage (Adams and Dougan, 1981; and Gautho, 1995). The clean, parchment covered beans are sent to the dryers and the water and mucilage are discharged as wastewater.

The mechanical process uses a machine similar to a depulper that removes the mucilage from the exterior of the bean and washes it simultaneously. The industry term for this piece of equipment is an *aquapulper.* The most significant difference between these two processes is the by-product streams; using fermentation the by-product is a concentrated wastewater that contains high levels of BOD and COD, whereas when using the mechanical aquapulper, the by-product stream is 95% mucilage. Older mills typically opt for the fermentation process as it is seen to be less expensive from an operational standpoint. Aquapulpers use about 1 kwh of electricity to process one fanega or 253 kgs of cherries, whereas the fermentation process uses only water, which is viewed as free. However, there is a considerably larger volume of water used and effluent produced when using fermentation process.

5.3.2.5.3 *Drying.* Coffee is dried using two methods, sun drying and artificial drying. Sun drying consists of spreading the wet coffee out on large patios to be baked in the sun. The coffee is manually turned over once a day on order to promote even drying and avoid any development of molds. Some mills have overhead covers to protect the drying coffee from evening moisture and the occasional rain. Particularly in the Western Valley, which has a very dry climate, drying patios are unprotected. Sun drying is normally reserved for the highest quality coffee beans and takes approximately 3-6 days to reach the desired moisture content of 11%.

Artificial drying is typically used by larger mills or those in more humid climates. The coffee is placed in large columns that are screened in and connected to hot air blowers that drive off the bulk of the moisture. The coffee is then transported to large drums dryers (Figure 5.16) that remove the remainder of the moisture. The green coffee is considered dry when it has reached a moisture content of 11%. An experienced operator who can qualitatively discern when this point has been reached normally determines this.

Approximately 1kg of water is driven off in steam for every 1 kg of green coffee produced, resulting in a significant heat requirement. The heat is generated normally by the combustion of firewood and dry coffee parchment. In some mills, the excess methane from anaerobic digesters (wastewater treatment) is used to produce heat for the dryers as well.

5.3.2.5.4 *Parchment Removal.* The last stage within the beneficio is the removal of the outer husk or parchment of the coffee bean. The parchment is left on the beans as a protective layer when they are stored in the beneficio and is only removed when the coffee is to be bagged for transport. The beans are placed on a vibrating screen conveyor that essentially shakes the parchment loose. The parchment falls through the screen, the bean remain on the conveyor and are taken to be package in burlap sacks weighing 46 kg (one quintal). The parchment is gathered by a collection system and taken to the furnaces. This thin layer is predominately made up of structural cellulose and as such has similar combustion characteristics of wood. Most beneficios use this parchment to supplement the firewood needed for furnace operation.

5.3.2.6 <u>Waste Disposal and Utilization.</u> Wastestreams are made up of solid and liquid by-products of coffee processing (pulp, parchment and mucilage) and wastewater. Some are utilized and the rest is disposed of.

5.3.2.6.1 *Coffee Pulp.* All coffee pulp is discarded in large piles that will be collected for transportation to one of four major composting facilities. Any unpulped cherries remaining after the third set of depulpers are also sent to the pulp piles. Presently, Costa Rica has legislation requiring that all pulp from beneficios be composted, either on site or in one of the centralized facilities located in the Central Valley. The composting facilities are run as private operations and the compost is sold for profit. During the period of high banana prices of the late 90's, there was a market for a significant portion of the coffee compost as banana producers began switching to organic operations. With the drop in banana prices in the past few years, this demand has dried up and has not been replaced. Compost facilities have become little more than organic dumps funded

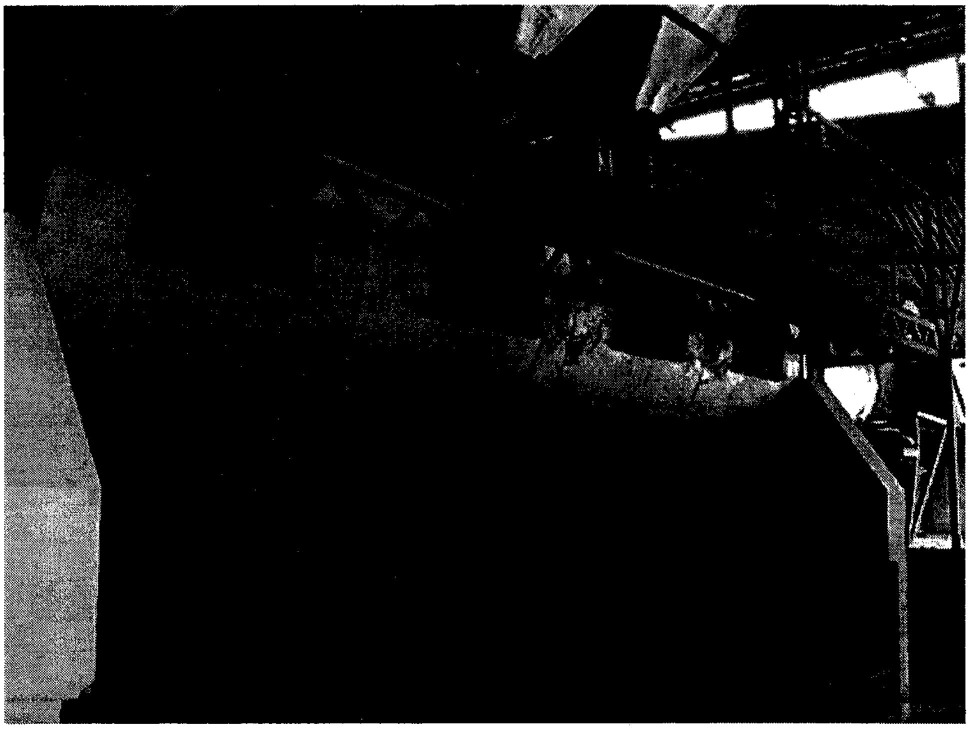


Figure 5.16. Drum dryers.

by the beneficios to maintain operations. The beneficios pay a fee of 0.28$/100L of pulp and the compost is stored. High transport costs are blamed for the inability of the industry to find a new market for this product (ABCR, 2003).

5.3.2.6.2 *Parchment.* The dried parchment is used as fuel for the dryer furnaces, in addition to the significant amount of firewood used to heat the air uses for drying the wet green coffee.

5.3.2.6.3 *Mucilage.* If mucilage is mechanically removed from the coffee bean, it is sent to a filtering system that uses a rotary screen to separate the liquid mucilage from any solids. The liquid is stored in large tanks to await future treatment and the solids are mixed with the pulp piles. Some mills mix the mucilage with the pulp just before it is removed to the compost facilities while others gradually mix it with the wastewater so as to not over burden the organic loading of the system. Beyond that, mucilage is not presently utilized for any economic purpose.

5.3.2.6.4 Wastewater. In 1990, most wastewaters from the beneficios were discharged untreated into the surrounding waterways. The quantity of waste was believed to have an organic loading of the equivalent of approximately 8 million people (Echeverri, 2003; Danse, 2003; and Alfaro, 2003). Much of this was discharged to the badly polluted Rio Tarcoles (river) that ran through San Jose, the capital city of Costa Rica where a majority of the country's population lives. At present, Costa Rica has discharge legislation for the levels of biological oxygen demand (BOD) and chemical oxygen demand (COD) permitted in the effluent from beneficios. They are 1250 mg/L and 1500 mg/L for BOD and COD, respectively.

Most beneficios utilize a settling pond and then aerobic lagoon system to treat the wastewater. However, some mills have recognized the potential of utilizing anaerobic digesters to treat the wastewater and then utilize the resulting biogas as an energy source. Most often the biogas is used to heat the influent to the digester and the excess is used in the furnaces to offset the need for firewood.

5.4 Results

Costa Rica has been reported to use eight times the agrochemical input found in the developed world and double the average use in other Central Amercian countries. Elevated agrochemical concentrations in both water and soil have been reported throughout the coffee producing regions. Lack of ground cover between coffee bush hedgerows and little to no shade, lead to low organic content in the soil and little protection from wind and heavy rains.

Wastes from coffee processing pose an environmental threat if not managed carefully. Aquatic degradation results from the high organic loading of effluents from the processing facilities or beneficios (Segura and Reynolds, 1993; Gautho, 1995; and Rice and Ward, 2002). Coffee beneficios exist in a wide range of sizes. In Guatemala, for instance, where a total of some 4000 processing facilities are estimated to dot the landscape, the National Association of Coffee Growers divides them based on their processing capacity into small facilities (227 to 2,268 kg per day), medium facilities (2,268 to 22,680 kg per day), and large (greater than 22, 680 kg per day). The 100 beneficios belonging to this last category (3% of all Guatemala's beneficios) process 60% of the coffee produced annually (Rice and Ward, 1997). To place this in perspective, each one of these large beneficios discharges to the regions waterways the equivalent of the daily raw sewage produced by a town of 35,000 people.

Elevated biological and chemical oxygen demand levels results from the discharge of organic pollutants from the beneficios to surrounding waterways. This robs aquatic plants and wildlife of essential oxygen. Costa Rican health officials had also expressed concerns over harms to marine life along parts of the Pacific Coast where rivers contaminated by coffee processing wastes flow into the ocean (Segura and Reynolds, 1993). According to Costa Rican Government estimates from the early 1980s, coffee processing residues account for two-thirds of the total biochemical oxygen demand in the country's rivers (Segura and Renyolds, 1993). In 1992, Costa Rica instituted a plan to upgrade the nation's coffee processing systems with the objective of cutting organic pollutant discharges to surface waters by 80 percent within five years. As of 2002, every processing mill in Costa Rica has implemented a waste treatment plan in accordance with this initiative, but there are a number of issues to note: (a) Costa Rica is the exception, not the rule (White, 2002), (b) many of the treatment facilities operate out of compliance for a good part of the harvest season (Kopper, 2003, Marcos, 2003; and Schram, 2003); and (c) the focus of the initiative is regulatory compliance with arbitrary standards, not an overall improvement in operational efficiency or innovation. Some question the protective measures of these arbitrary standards, noting that is some areas as many as six beneficios discharge their effluent into the same river at the height of the dry season (Echeverri, 2003). Moreover, these standards permit the discharge of wastewaters to aquatic water bodies with up to ten times the BOD level permitted for similar agro-industrial processes in countries such as Canada as laid out in the Canadian Fisheries Act and CCME Industrial Effluent Guidelines (DFO, 2003; and CCME, 1997).

Options for reducing the wastes generated from coffee production are explored in this study. This is first achieved by exploring options for production practices, improving the operating conditions of coffee farms by investigating options to reduce agrochemical use and improve soil conditions. Options for improving resource efficiency (input analysis) within the processing framework are investigated. The composition and alternative uses of wastes, namely coffee pulp, mucilage, wastewater and coffee parchment, are discussed. Specific recommendations to optimize the efficiency (such as opportunities to make use of waste heat) and minimize the environmental impacts are made. The operational conditions present within the Costa Rican coffee industry are investigated, in order to determine the parameters need to be considered when considering changes or innovations within the system. An analysis of the resources and material flow patterns in the processing of coffee is presented from the standpoint of improving the resource efficiency of coffee production and, therefore, improving the economic and environmental sustainability of the industry.

5.4.1 Analyses of Coffee Production Operations

Interviews with farmers in 2003 outlined the generalities of the various aspects of coffee production. This lead to a more detailed investigation in 2004 where verbal surveys were conducted with 55 farmers in the Turrialba region to obtain collaborative information with regards to the data obtained from ICAFE in regards to production costs and labour requirement for coffee production. Table 5.10 is an overview of the farmers included in the survey.

5.4.1.1 Labour. Table 5.11 shows the number of man-hours dedicated to specific production tasks according to the ICAFE production model (ICAFE, 2003a). The ideal input is based on ICAFE's recommended production scheme, which does not however take into account issues like regional differences such as climate and terrain, or production style, i.e. shade or sun or farm size. The number of man-hours dedicated to various tasks for organic, traditional shade and monoculture vary from to this model (in approximate percentages) based on the responses from coffee farmers specifically in the Turrialba region. The results demonstrate that there can be significant variations between cultivation styles. Due to the fact that only two farmers with farms over 20 hectares were surveyed, analysis according to farm size was not attempted. Tables 5.12 and 5.13 shows the regression values for two different hypotheses, H_0: (a) that the ICAFE values are statistically the same as those presented by the farmers and (b) labour values for traditional shade are statistically the same as those of monoculture plantations. As can be seen by the t and p values, these hypotheses are not supported for a variety of tasks.

In the case of the first hypothesis, the sun coffee plantations percentages were normalized without the time spent pruning shade trees in order to offer a better comparison. The labour requirements for post-harvest collection, weeding and agrochemical applications in sun plantations were considered statistical similar to those values provided by ICAFE. This may be due to the fact that much of Costa Rica's coffee is sun coffee, on which ICAFE based their projections. Sun coffee productivity is very dependant on the removal of post-harvest berries and agrochemical applications more so than other factors and as such farmers may follow ICAFE recommendations more closely in these areas.

Table 5.10. Turrialba farmers involved in study.

Type of Farm	Size of Farm (ha)	Number of Farmers
Organic	<5	5
Traditional Shade	<5	10
	5-20	2
Monoculture (Techno-shade or Sun)	<5	31
	5-20	5
	20+	2

Table 5.11. Labour inputs for coffee production.

Task	Man-hours (% of total)					
	Sun (ideal)	Sun	*Techno-shade (ideal)*	Techno-shade	Traditional Shade	Organic
Harvest	*63.1*	55.7 (4.7)	*60.2*	53.5 (4.4)	52.6 (6.1)	52.0 (5.7)
Post Harvest Berry Collection	*5.3*	5.5 (1.1)	*5.1*	5.2 (1.0)	2.5 (2.4)	1.6 (1.5)
Pruning of Shade Trees	*n/a*	n/a	*4.5*	5.6 (0.9)	5.5 (1.4)	2.0 (1.2)
Pruning of Coffee Plants	*6.4*	10.0 (1.5)	*6.1*	6.3 (1.0)	5.4 (0.7)	5.2 (0.4)
Fertilizer Application	*5.3*	6.8 (1.6)	*5.1*	6.6 (1.5)	6.0 (1.8)	11.6 (2.1)
Weeding (Manual)	*1.7*	1.6 (2.4)	*1.6*	2.0 (1.5)	6.7 (3.6)	9.6 (0.9)
Agrochemical Application (if appl)	*8.7*	9.2 (1.4)	*8.3*	9.9 (1.4)	7.0 (3.3)	n/a
Seedling Cultivation and Planting	*5.7*	5.0 (1.4)	*5.5*	5.3 (1.8)	3.0 (1.7)	0.8 (1.1)
Soil Maintenance	*3.8*	6.2 (1.5)	*3.6*	5.6 (2.1)	3.8 (2.3)	4.4 (2.9)
Other (Crops, Timber, etc…)	*na*	na	*na*	na	7.5 (5.0)	12.8 (2.2)
Total	*100*	100	*100*	100	100	100

( ) – standard deviation

Table 12. Statistical analysis of labour values.

Task	t- Value		P - Valure	
	Shade	Sun	Shade	Sun
Harvest	-7.69	-7.52	0.000 (n)	0.000 (n)
Post Harvest Berry Collection	-3.79	0.98	0.001 (n)	0.336 (a)
Pruning of Shade Trees	1.57	n/a	0.126 (a)	n/a
Pruning of Coffee Plants	-1.56	11.71	0.130 (a)	0.000 (n)
Fertilizer Application	4.57	4.70	0.000 (n)	0.000 (n)
Weeding (Manual)	4.80	-0.27	0.000 (n)	0.793 (a)
Agrochemical Application	-1.50	1.58	0.131 (a)	0.128 (a)
Seedling Cultivation and Planting	-4.30	-2.49	0.000 (n)	0.021 (a)
Soil Maintenance	2.83	7.70	0.008 (n)	0.000 (n)

H_o = ICAFE values are statistically the same as those presented by the farmers
a - H_0 hypothesis accepted
n - H_0 hypothesis rejected

Table 13. Statistical analysis of labour values.

Task	t- Value	P – Valure
Harvest	1.17	0.259 (a)
Post Harvest Berry Collection	4.01	0.002 (n)
Pruning of Shade Trees	-5.30	0.000 (n)
Pruning of Coffee Plants	7.66	0.000 (n)
Fertilizer Application	-1.27	0.221 (a)
Weeding (Manual)	-4.51	0.001 (n)
Agrochemical Application	2.51	0.027 (a)
Seedling Cultivation and Planting	3.74	0.002 (n)
Soil Maintenance	2.98	0.009 (n)

H_o = Labour values for traditional shade are statistically the same as those of monoculture plantations
a - H_0 hypothesis accepted
n - H_0 hypothesis rejected

In the area of weeding, ICAFE does not promote the use of manual weeding and instead promotes the application of herbicides to control weeds, a practice routinely used by sun coffee farmers.

When comparing the labour distribution between monoculture and traditional plantations the trends were noticeably different, as demonstrated by the t and p values. Some reasons for this could be: (a) the time spent attending other crops, (b) the time spent on manual weeding, which is very time consuming, in place of chemical control. Similarities were found in the time requirements for harvest and the time spent fertilizing.

4.4.1.2 Costs. Very few empirical studies could be found the provided specific information on inputs in Costa Rica's coffee production. Most studies that were of that level of detail were specific to selected farms in particular regions. Based on ICAFE data from the various regions, Table 5.14 displays the average production costs in Costa Rican Colones of the various aspects associated with coffee production. Similar to the labour data, farmers noted deviations from these presented costs. However, most could not provide numerical data on the amounts of expenditures and as such a numerical analysis was not performed. However, qualitatively, all 55 farmers indicated that their costs were not the same as those forecasted by ICAFE, and 42 farmers indicated that they believed that their costs and cost breakdowns varied substantially from those forecasted by ICAFE (ICAFE, 2003a).

4.4.1.3 Yield. Within each of the three main individual types of cultivation, there can still be a very broad range for crop yields that can be produced. This deviation can be caused by present soil conditions, climate as well as the farmers' individual capabilities and have as much effect on yield as the specific cultivation methodology in use.

4.4.1.3.1 Organic. The elimination of agrochemicals has not been a serious limitation for organic coffee production. According to ICAFE (2003c) and the Rainforest Alliance

Table 5.14. Production costs per hectare of coffee in Costa Rican Colones (CRC).

Description	Direct Costs		Indirect Costs	Row Total
	Labor	Material		
Harvest	187200	0		
Post Harvest Berry Collection	15680	0		
Pruning Coffee Trees	18816	0		
Pruning Shade	14112	0		
Fertilization	15680	85922		
Agrochemical Application	29792	34779		
Weeding	4704	0		
Cultivation/Planting of Seedlings	17248	9306		
Soil Management	11760	0		
Social Security (26.7%) - incl family labour	34120	7620		
Subtotal (A)	**349112**	**137627**		**486739**
Transportation			46315	
Other Costs[a]			181004	
Subtotal (B)			**227319**	**227319**
Total				**714058**

a-includes maintenance and depreciation of equipment, taxes, license fees and loan interest

(Rusillo, 2004) intensive organic farms can produce up to 1220 kg of dry green beans per hectare (or 26.5 fanegas/hectare). The national average is 1380 kg/ha (or 30 ff/ha). Proper shade management allows for control of fungal diseases, which are the most important threat to coffee in Costa Rica. The arrival of the coffee berry borer has proven a bit more troublesome, but the higher biodiversity level found in organic plantations has aided through the presence of predatory birds and insects. The more significant problem with organic growth is fertilization. However, there are some high quality organic fertilizers available on the market prepared from seaweed extracts, and some farmers have demonstrated the ability to make their own fertilizers using coffee and farm detritus mixed with chicken dropping that rival commercial grade fertilizers in quality (Campos, 2003). In the Turrialba region yields ranged from 635 to 1136 kg (or 13.8 to 24.7ff/ha), with an average of 925 kg/ha $\pm$ 193 (or 20.1 ff/ha $\pm$ 4.2).

5.4.1.3.2 Traditional Shade. 1600 kg/ha (34.8 ff/ha) is the projected yield for traditional shade or "bird-friendly" plantations, normally utilizing an Integrated Pest Management (IPM) approach. Agrochemicals can still be in use, but typically at much lower quantities as shade management and high biodiversity aid in the prevention of disease and pest infestations, similar to organic plantations. The major difference is the permissible addition of chemical fertilizers, which accounts for the higher yields. In the Turrialba region, the survey outcome demonstrated yields ranging from 395 to 1638 kg/ha (or 8.6 to 35.6 ff/ha), with an average of 1165 kg/ha $\pm$ 414 (or 25.3 ff/ha $\pm$ 9.0).

5.4.1.3.3 *Monoculture*. ICAFE (2003c) indicates that it is possible to produce up to 2355 kg/ha (or 51.2 ff/ha) on conventional monoculture plantations. However, even the most productive regions, such as the Tarrazu region, some farms are presently producing less than 2070 kg/ha (or 45 ff/ha). Mata (2004) indicated that while productivity is still good in the region, yields in the area have been dropping over the last ten years. Unlike many other regions, the Tarrazu region is generally paid a premium for the quality that is inherent of the area and as such has not been as affected by external pricing as other regions. For this reason, it could be suggested that a reduction in fertilizer applications is not likely to be the reason for this reduction, as is the case in other areas suffering more greatly by economic hardships. Widespread soil erosion and soil baking was apparent during a tour of the area. Within the Turrialba region, an area with slightly sub-optimal growing conditions, it was found that the average monoculture plantation yield was 1352 kg/ha $\pm$ 409 (or 29.4 ff/ha $\pm$ 8.9)

5.4.1.4 Other Products. Products available from coffee plantations range from firewood (in the form of biomass from pruned shade trees and coffee bushes) to commercially sough-after timber and food crops. Typically, shaded monoculture plantations try to supply some of the wood needed for furnaces in beneficios. This is the case, however, in farms within close proximity to a centralized facility. In other more remote areas, the excess biomass is sold to restaurants as fuel for the wood-fired, chicken-rotisserie ovens that are extremely common throughout Costa Rica.

5.4.1.5 Revenue. It is possible for organic and 'bird-friendly' coffee to command higher prices when the appropriate marketing scheme is in place, in the form of a strong cooperative or international support through fair-trade organizations or socially responsible corporations. However, even without these opportunities, in times of low coffee prices, organic and traditional farmers are generating revenue from the sale of alternative crops and materials. Intercropping of crops such as legumes, blackberries and medicinal plants (such as chamomile) along with the presence of banana, macademia, citrus and timber trees as part of the shade cover. This additional revenue is supporting them both financially and from a subsistence point of view during times of low prices. Of the 17 organic and traditional shade coffee plantations, all indicated that they obtained a significant portion of their income (they consider food income as well) from alternative products. This is not the case in monoculture plantations. Even in the shaded monoculture plantations, the shade trees are typically not useful for timber or other products and are solely planted for their nitrogen-fixing capabilities (Muschler, 2003).

5.4.1.6 Socio-Economic Issues. There are a host of socio-economic aspects that are intimately related to the well being of the coffee industry and the stakeholders who depend on it. Understanding these issues is key to helping develop a more sustainable system.

5.4.1.6.1 *Economic Development.* In September, 1995, average variable costs in Costa Rica were estimated at or approximately 2087US$ (388,068 Costa Rican colones (CRC)). In 2003 these costs were estimated at 1855US$ or CRC 714, 059. The effect on the average farmer is not inherently clear due to fluctuations in coffee prices and devaluation of the colone. If one looks at the cost in US dollars it appears that the cost of production has gone down. However, coffee farmers are paid in colones and purchase in colones and as such, the reduction in cost is not necessarily a reality. For example, the price of coffee averaged at ~ CRC 268/lb in 1995 and 2003.

Deflation of the CRC against the US dollar has been approximately 10% annually, since 1995. However, the cost of living in Costa Rica according to the price index of consumer goods has risen 15.6% annually since 1995. By becoming dependent on foreign income through the sale of coffee to the overseas market, coffee farmers have seen the buying power of their earnings drop approximately 33% regardless of variations in the actual price of coffee. For those who earn their living supplying the local market the price index will not affect them as greatly. They operate within the system of CRCs and the devaluation of the CRC as compared to the US dollar will not affect them as readily as those who receive their income based on a rate of exchange between the CRC and the US dollar. As shown in Table 5.15 what someone could buy with the equivalent of one US dollar in 1995 will now cost them the 1995 equivalent of 1.50 US dollars (not to be mistaken for inflation due to economic growth).

Secondly, because the purchase prices of materials needed for conventional coffee farming (agrochemically intensive) are sold in CRC at rates set by US companies, the farmers have to pay more in local currency to produce the same amount of saleable product. Finally, because many farmers switched to coffee farming when prices were

Table 5.15. Rate of exchange and consumer goods inflation.

Year	Value of CRC against US$	Value of Consumer Goods
1995	185	185
1996	204	214
1997	225	247
1998	246	285
1999	270	330
2000	298	382
2001	328	440
2002	360	510
Mid-2003	385 (at time of harvest- 400 by Dec 2003)	590

high, they were able to purchase the food and materials that were once produced on-site. However, with the reduction of their purchasing power and the plummeting coffee prices, farmers cannot afford to purchase these foods and materials. Therefore, while theoretically the farmer may appear to have a greater income due to the transition to Green Revolution type farming, they cannot afford to maintain their operations nor purchase the goods that they once produced themselves for sustenance.

5.4.1.6.2 *Working Conditions*. As a result of the poor economic conditions facing many coffee farmers, some families are abandoning their fields and moving to the cities in search of work. In other cases the male heads of the household are seeking alternative paid work and leaving the operation of the farm to the women and children family members, thus adding additional burdens on that demographic. The other scenario on larger farms is the owners are more and more turning to illegal workers that are paid a minimal fee (typically <50% of legislated minimum wage of US$8.00/day) and are not provided with the social security coverage necessary for legal workers. While interviewed farmers were not formally asked about the use of illegal workers, some ICAFE officials believe illegal workers are now making up to 30-50% of the worker population (particularly during harvest) depending on the region (Ramirez, 2004).

Of the 55 farms surveyed, 3 were owned by women (2 organic and 1 sun) and 7 were run by women (all techno-shade or sun). The two organic farms owned by women had obtained the farms through divorce. The sun coffee farm owned by a women had been abandoned by her husband. The seven farms run by women have spouses who either have or are seeking additional paid employment in other regions.

Of the 38 farms being operated as techno-shade or sun farms, 18 were either home-schooling their children or sending them to evening school so that they would be available to help with the farm tasks (particularly harvest, post-harvest berry removal and manual weeding). The children of the 5 organic farmers were attending regular school.

Children of 7 of the 12 traditional farmers were attending regular school, 1 family sent their children to evening classes and 4 farmers had no children still at home.

5.4.1.6.3 *Evaluation Criteria for Sustainability.* Five key elements to be addressed when analyzing the farm level adoption of new practices aimed at sustainability as identified by farmers:

(a) role of a new crop or timber species in the overall farm/household strategy ($, effects),
(b) management requirements for the system,
(c) rate of return relative to the status quo (or other alternatives),
(d) sensitivity of related economic return to externalities beyond the farmers' control, and
(e) environmental and off-site impacts (where they have become important at the community level - largely noted by co-op member farmers).

A key element for farmers in any evaluation seems to be the level of risk associated with the any innovation. Attitudes towards adoption of new technologies/methodologies did not appear to be strongly associated with profitability as defined by financial institutions, but more associated with the farmers' quality of life, economically, but also socially. Those farmers associated with a cooperative demonstrated higher acceptance of sustainable options in light of support from their surrounding community. The "Sustainable Coffee" (Suscof) project undertaken by the Center for Technology and Industrial Information Management (CEGESTI) has tried to integrated ISO14000 protocols (and other environmental management initiatives) into a group of seven coffee beneficios. It has demonstrated the positive influence that the formation of cooperatives and the cooperation between cooperatives can have on sustainable farming practices. By making decisions as a group some cooperatives within the Suscof project are obtaining higher prices for their coffee due to the market recognition for their environmentally and socially responsible practices (Danse, 2000; and de Groot, 2002).

5.4.2 Analyses of Coffee Processing Outputs

Table 5.16 shows the average input and output inventory of the processing aspect of the industry within Costa Rica. Materials used in the production of green coffee include: coffee cherries, water, and energy (electricity and firewood).

During the field study, comprehensive quantitative analyses of water and energy usages were very difficult as very few mills keep data on per unit usage. The available data varied substantially from one beneficio to another due to different operational practices. Therefore, the following analyses were performed on the average usages and ranges available to illustrate certain points.

5.4.2.1 Coffee Cherries. There is little opportunity to improve the input efficiency of the coffee cherries harvested and brought to the beneficios for processing. Farmers are very conscious about the quality of the coffee cherries that they harvest as it directly affects the price that they receive. Since coffee is handpicked daily, over or under ripe beans are avoided because there is a minimum standard that the receivers will accept. Any harvest with more than 3 – 5 % green or overripe cherries will not be accepted by the receivers and is, therefore, useless to the farmer. New pickers are thoroughly trained with regards to what cherries are to be picked and the importance of not leaving ripe cherries on the tree. There is no pre-processing that will affect the usefulness of the coffee cherry and as such there is a minimal effect possible with regards to resource-use efficiency at this stage.

However, pesticide use at the farm level can affect the usefulness of the coffee pulp as an output material. Elevated levels of pesticides can limit its usefulness as compost or a growth medium due to the fact that organic farms are the largest user of compost in Costa Rica and elevated levels of pesticides will render the compost unacceptable to these operations.

Table 5.16. Quantities of inputs and outputs to and from the coffee processing industry of Costa Rica. (Based on 2002/03 estimates).

Parameter	Value
Inputs	
Coffee Cherries	797,500 tonnes (~3,150,000 fanegas)
Water	3,190,000 cubic metres
Electricity	~63,000,000 Kwh
Fire Wood	315,000 cubic metres
CaCO3	3,150,000 kg
Outputs	
Green Coffee	145,000 tonnes (~3,150,000 quintals)
Mucilage	130,500 tonnes of mucilage
Wastewater	3,190,000 cubic meters
Waste heat (from firewood)	2,874,000,000 MJ[1] (~97% of total available heat)
Evaporation to atmosphere	159,500 tonnes (cubic metres)
Ash	Not measured
Coffee Pulp	326,250 tonnes
Coffee Parchment	32,250 tonnes

1 This was calculated by determining the total heat contained within the firewood at 4440 kcal/kg Cheves, 1995) and then determining the amount of heat need to raise the total amount of water to be evaporated from the coffee beans (159,000 tonnes) from an ambient temperature of 20C to 100C.

5.4.2.2 Water. Water usage is a concern in many of the coffee producing countries of Central America. The surrounding population often competes for water for their own use and irrigation from the same source supplying the beneficios. Also, the coffee harvest normally occurs at the height of the dry season, so the water levels in some rivers and reservoirs are already low, which is then exacerbated by the tremendous withdrawals of water made by the beneficios. In 1994, the government of Costa Rica finally entered into negotiations with the coffee industry to reduce the environmental impact.

The quantity of water needed within the beneficio system depends on three main factors: (a) whether the mucilage removal system is mechanical or by fermentation, (b) type of transport system used to move cherries and beans throughout the beneficio, and (c) amount of recycling takeing place within the system.

The fermentation process can increase the overall water use of the mill by up to 500% (Marcos, 2003) as compared to a similar mill that uses a mechanical removal system. The reason for the reluctance to change is the elevated operational cost of the mechanical removal system as compared to fermentation and the belief, by some producers, that fermentation produces superior flavored coffee. It would be beyond the scope of this study to develop a valid argument to counter the second issue, but the first issue could possibly be addressed if a case could be made for the economic benefits of producing a separate mucilage waste stream. This could only be accomplished through the use of a mechanical removal system.

It is possible to reduce the water consumption by switching from a strictly water transportation system to one that uses screw conveyors. Water transportation uses diaphragm pumps and a significant volume of water to move the cherries and (later) the beans from the hoppers to the depulpers to the mucilage removal (or fermentation systems) and so on. The screw conveyor system use only minimal water, in order to create thick slurry out of the coffee fruit, which facilitates their movement by the conveyor.

The government initiative in the mid 1990s, included a recommendation to the beneficios for a 40% recycling of the wash water/transport water. The reason that these streams are specified is that they typically have lower organic loading than the wastewater emanating from the fermentation system (wash water is used to rinse the beans after the fermentation process and transport water is used to move the cherries from one process sub-system to the next) and as such can be reused without fouling the coffee cherries. The fermentation water cannot be reused because the high organic contents quickly begin to decompose and will adversely affect the flavor of the coffee beans.

5.4.2.3 Energy. Energy inputs to beneficios come from traditional sources: electricity and firewood. Electricity is normally drawn from the grid and heat energy is created through the combustion of firewood and coffee parchment. Electricity in Costa Rica is expensive and is one of the significant costs in the operations of the beneficio. The cost is 0.093$ Cdn/kwh or 28.4 colones/kwh, as compared to the Canadian industrial rates of 0.045 – 0.049$ Cdn/kwh. Costa Rican law does not allow for the independent generation and sale of electricity, but it does grant license for a facility to generate up to 20000 KW for internal use. Much of Costa Rica's electricity (86%) comes from hydroelectric, but the environmental impact is significant as the bulk of these facilities are large-scale hydroelectric damns that cause significant flooding and drastically alter the ecosystems downstream. Run-of-river electric generation facilities that do not disrupt the flow of the river could be used to meet the rising need for electricity in the industrial sector, including the coffee industry.

Sustainable energy generation such as solar power or run-of-river hydroelectricity is given little consideration. Mills that utilize solar energy for the drying of coffee beans typically only do so for a small percentage of the coffee produced (there are a few exceptions). Land requirements for the construction of patios are significant and can be very expensive for beneficios located in urban area. The time line for a complete return on investment for the more technically advanced solar dryers can be up to five years.

Beyond investing in greener energy, there is very little that can be done to improve the energy input from a traditional viewpoint. The one exception would be ensuring that the moisture content of the firewood used in the furnaces is kept to a minimum (less than 15%). Beyond this point the moisture content can dramatically affect the specific heat of the wood and further reduce the efficiency of the drying systems. Many of the facilities are located on rivers of significant flow and the economic feasibility of installing run-of-river hydroelectric facilities should be investigated.

One large beneficio producing ~7.45 tonnes of green coffee/year (162,000 quintals/year) in the Naranjo area of Costa Rica is operating the anaerobic digester at an efficiency (82%) that permits the economical generation of electricity using biogas as the fuel for the generator. The biogas used for production of electricity is the excess that remains after wastewater has been preheated and the drum dryers are working at capacity. This situation is a single case out of 97 beneficios and has been dependant on the innovative outlook of the beneficio manager and the support of the cooperative that own the beneficio. However, this case demonstrates the possibilities for other beneficios of similar scale to use biogas as a source of energy.

5.4.3 Analyses of Coffee Processing Output

There are essentially seven outputs of the coffee processing operation. These include: green coffee, coffee pulp, mucilage, parchment, wastewater, waste heat, and ash/air emissions. There is a lack of quantitative data regarding waste heat and ash/air emissions. These by-products will, therefore, be discussed from a qualitative point of view. Coffee pulp, mucilage and coffee parchment represent 82% of the natural resource of the coffee cherry. Despite ongoing research into possible uses of these products there is still very little progress beyond the pilot-study, demonstration phase. Any treatment of by-products is still almost wholly focused on environmental controls initiated as a result of government legislations. Sanchez et al (1999) indicated that there is an urgent need for efficient technologies to transform coffee by-products into useful products for both economic and environmental reasons. Table 5.17 lists the general parameters of the various by-products.

5.4.3.1 Green Coffee. The dry, green coffee that is the desired output of this process, represents 18.1% of the total input weight. It is stored with a moisture level of approximately 11% until it is shipped to a roasting operation, which is normally located outside of the region in either North America or Europe.

5.4.3.2 Coffee Pulp. According to Elias (1979), coffee pulp is made up of a number of constituents including organic components (carbohydrate fractions, tannins, pectin, caffeine, chlorogenic and caffeic acid, and amino acids), and mineral matter. There have been numerous studies completed since this data was published, but his values aregenerally accepted as the standard and are most often quoted, even in more recent literature (Ananda Alwar et al., 1990; and Mburu and Mwaura, 1996). Table 5.18 lists the minerals of interest found in coffee pulp. Table 5.19 shows some of the organic

Table 5.17. Composition of coffee pulp, parchment and mucilage from 1kg of cherries (Gautho, 1995; Elias, 1980; Adams and Dougan, 1981; and Ananda Alwar et al., 1990).

Parameter (%)	Pulp (400-432 g)†		Parchment (35 – 61 g)†	Mucilage (33 - 51 g)†
	Fresh (%)	Dry Basis (%)	(%)	(%) @ Dry Basis
Moisture	76.7	0	7.6	-
Dry matter	23.3	100	92.4	-
Ether extract (fat content)	0.5	2.1	0.6 - 1.5	-
Crude fibre	3.0 - 3.4	12.9 – 14.6	70.0	17.8 – 18.0
Crude protein (% N x 6.25)	2.1	9.0	1.0 - 2.4	-
Ash	1.5 - 1.9	6.4 – 8.3	0.5-1.0	0.4 – 0.6
Nitrogen-Free Extract	15.8	67.8	18.9	45.8
Total Pectin Substances	1.5	6.5	-	35.8
Total Sugars	3.4	14.4	-	45.8
Reducing sugars	2.9	12.4	-	27.8
Non-reducing sugars	0.5	2.0	-	18.0
Tannins	0.4 – 2.0	1.8 – 8.6	-	-
Other Carbohydrates	8.9 – 10.5	38.3 – 45.1	-	-

† per Kg of coffee cherries

(-) data not available or not applicable

Table 5.18. Mineral content of coffee pulp ash (Elias, 1979).

Parameter	Dry Weight
Calcium (ppm)	5540
Phosphorus (ppm)	1160
Iron (ppm)	150
Sodium (ppm)	1000
Potassium (ppm)	17650
Magnesium	Traces
Zinc (ppm)	4
Copper (ppm)	5
Manganese (ppm)	6.25
Boron (ppm)	26

Table 5.19. Organic components present in coffee pulp (Elias, 1979; and Gautho, 1995).

Parameter	% (Dry Weight)
Tannins	1.8 – 8.6
Total Pectic Substances	6.5
Reducing Sugars	12.4
Non – Reducing Sugars	2.0
Caffeine	1.3
Chlorogenic acid	2.6
Total Caffeic acid	1.6

components present in coffee. Table 5.20 lists the amino acids found in the protein portion of the pulp as compared to the levels found in soy. Table 5.21 presents the carbohydrate fraction.

Coffee pulp contains similar levels of essential and non-essential amino acids to products such as soybean and cottonseed meal, and has higher concentrations than corn. It has a relatively high level of lysine, but is deficient in sulfur containing amino acids. It appears that there has been little other research into the amino acid potential of coffee pulp. There

Table 5.20. Amino-acid content in g/16g N (dry weight % of protein fraction) of coffee-pulp protein (Elias, 1979).

Parameter	Dry Weight of Protein	Compared to Soybean Meal
Lysine	6.8	1.7
Histidine	3.9	2.8
Arginine	4.9	3.1
Threonine	4.6	3.3
Cystine	1.0	1.0
Methionine	1.3	1.6
Valine	7.4	5.0
Isoleucine	4.2	4.3
Leucine	7.7	16.7
Tyrosine	3.6	5.0
Phenylalanine	4.9	5.7
Hydroxyproline	0.5	-
Aspartic acid	8.7	-
Serine	6.3	-
Glutamine acid	10.8	-
Proline	6.1	-
Glycine	6.7	-
Alanine	5.4	-

Table 5.21. Carbohydrate fraction (Elias, 1979).

Parameter	% DW
Crude Fibre	36.8
Acid Detergent fibre	34.5
Hemicellulose	2.3
Cellulose	17.7
Lignin	17.5

is the belief that these amino acids may not be biologically available due to the high tannin content which is know to react with protein (Elias, 1979). Research has been undertaken over the past 24 years to try and develop a treatment that would render coffee pulp appropriate as livestock feed (Bressani, 1979a; and Elias, 1979). Chemical and microbial treatments have been tested and tried with minimal success. Bressani (1979a), Adams and Dougan (1980) and Mburu and Mwaura (1996) indicated that it is likely that the level of tannin and caffeine (1.3% dry wt) hinder the applicability of coffee pulp as livestock feed as did the high potassium content.

Presently, Costa Rica has legislation requiring that all pulp from beneficios be composted, either on site or in one of the centralized facilities located in the Central Valley. The composting facilities are run as private operations and the compost is sold for profit. During the period of high banana prices in the late 90's, there was a market for a significant portion of the coffee compost as banana producers began switching to organic operations. With the drop in banana prices in the past few years, this demand has dried up and has not been replaced. Compost facilities have become little more than organic dumps funded by the beneficios to maintain operations. As previously noted, the beneficios pay a fee of 0.28$/100L of pulp and the compost is stored. Many beneficios blame high transport costs are blamed for the inability to find a market for this product (ABCR, 2003).

5.4.3.3 Mucilage. As noted in Table 5.16, mucilage has both high sugar (45.8%) and pectin contents (35.8%). This by-product is normally removed via fermentation and is discharged to the wastewater stream, largely due to the low operational costs associated with this method (water usage is cheap). However, there are mechanical means to remove mucilage from the coffee beans. As such, it can be separated from the wastewater stream if needed.

5.4.3.4 Parchment. Presently, coffee parchment is used almost exclusively as direct fuel. Table 5.22 outlines its chemical composition.

5.4.3.5 Wastewater. The effluent emanating from processing units is high in both suspended and dissolved solids and contains pectins, proteins and sugars. Table 5.23 outlines the typical pollution load that the International Coffee Organization has cited as the average found in the total combined effluent (ICO, 2001). It also presents the data broken down by wastewater stream. In 1990, most wastewater from the beneficios was discharged untreated into the surrounding waterways. The quantity of waste was believed to have an organic loading of the equivalent of approximately 8 million people (ICAFE, 1997). Much of this was discharged to the badly polluted Rio Tarcoles that runs through San Jose, the capital city of Costa Rica where a majority of the population lives.

The 1994 legislation discussed earlier was largely aimed at the control of this pollution. Wastewater discharge guidelines in Costa Rica are 1250 mg/L and 1500 mg/L of COD and BOD, respectively. However, monitoring of effluents is internally policed and it is believed that many mills routinely exceed these figures (ABCR, 2003; Schram, 2003). Discharge guidelines remain the same regardless of the size of the receiving watercourse or the number of mills discharging into it. Some rivers in San Jose region receive effluents from up to 6 mills. In these situations the regulations fail to protect the quality of these waterways as the shear volume of organic matter being discharged is believed to be beyond their carrying capacity. The most accepted wastewater treatment that has had any economic return has been the production of biogas using anaerobic digesters. In March 2003, there were twelve mills in Costa Rica that had operational digesters. The rest of the mills still use lagoon systems (both aerobic and anaerobic) that have minimal operational costs, but no economic return. Many operators acknowledged (unofficially) that there is some doubt that these lagoons have the ability to bring the wastewater within the necessary guidelines during peak operations.

What must be considered when seeking alternative uses for wastewater is the fact that coffee mills operate on a batch (not a continuous) mode, and therefore, the quantity and composition will vary substantially during the daily and seasonal operations of the beneficio. Any system implemented to make use of wastewater must be designed to accommodate changes in concentrations, volumes and flow rates.

Table 5.22. Chemical composition of coffee parchment (Elias, 1979; and Adams and Dougan, 1980).

Parameter	%	% (Dry Weight)
Moisture	7.6	0
Dry matter	92.4	100
Extractable Ether (Fat content)	0.6	0.7
Protein	2.4	2.6
Ash	0.5	0.5
Crude Fibre	70.0	75.8
Nitrogen-free Extract (NFE)	18.9	20.4
NFE + Crude Fibre Fraction	88.9	96.2
Soluble Carbohydrate (Total)	0.4	0.5
Glucose	0.4	0.5
Structural Carbohydrate (Total)	61.0	66.2
Hemicellulose	18.8	20.3
Cellulose	42.2	45.9
Lignin	22.5	24.4
Other	5.0	5.1

Table 5.23. Pollution loading for coffee effluent.

Parameter	Pulping Waters	Fermentation and Washing	Total Mean
Total Suspended Solids	13.2 g/L[b] 6.2-11.0 g/L[c] 3.6-5.0 g/L[d]	2.9 g/L[b] 1.95-4.8 g/L[c] 2.2-4.6 g/L[d]	7.0 - 10.9 g/L[a]
Biological Oxygen Demand (BOD)	1.8-2.9 g/L[b] 1.8-9.0 g/L[c] 0.9-2.4 g/L[d]	1.3-2.2 g/L[b] 1.2-3.0 g/L[c] 1.4-3.9 g/L[d]	10.0 - 13.0 g/L[a]
Chemical Oxygen Demand (COD)	13.9-28.0 g/L[b] 2.95-14.6 g/L[c] 1.4-3.9 g/L[d]	3.0-10.0 g/L[b] 1.65-2.8 g/L[c] 0.85-1.75 g/L[d]	18.0 - 23.0 g/L[a]
BOD: COD ratio			0.5 – 0.6[a]
N: COD ratio			0.08[a]
P: COD ratio			0.02[a]

a - ICO (2001)
b – Adams and Dougan (1980)
c – Gauthoet al. (1991) - with recirculation
d – Gautho et al. (1991) - without recirculation

4.5 Discussion

4.5.1 Current Socio-Economic Conditions

The average cost of production in 2003 on a normal farm producing the equivalent of 30 – 46 kg bags (or 30 quintals[1]) of coffee beans per hectare (national average) is 23800 colones /quintal (1.34$US/kg). The market price paid to farmers in 2003 was 21000 colones[2]/ fanega which converts to 1.18 $US/kg. As can be seen, the gate price does not cover production costs of the farmer. Production prices per unit drop with increased yield per hectare. For example, ICAFE (2003c) has noted that the approximate unit cost for coffee produced on 40 ff/ha[3] farms is 1.17 US$/kg and on a 45 ff/ha farm the cost is 1.09 $US/kg. This has lead to the situation that only large-scale mechanized farmers are surviving. These farms are the only operations capable of such high yields.

The beneficio revenue is approximately 20% of coffee selling price. The low prices have adversely affected them due to two issues: (a) the reduction in actual quantity of coffee processed, and (b) the reduction in gross income.

4.5.2 Maximizing Sustainability in Production

Both ICAFE (2003b) and Rainforest Alliance (2004b) have established sustainable agriculture standards for coffee farms. These models provide broad descriptive statements about sustainability within the various aspects of coffee production. Unfortunately these standards are very qualitative and largely open to the interpretation of both the farmer and the extension officer who may be trying to assist. With the exception of large, commercial-type operations very few farmers appeared to keep close track of material usage, levels of soil erosion, agrochemical input, man-hours or total production costs. Therefore, it is difficult to assess any move towards or away from sustainability. One thing that will be important in order to begin maximizing the

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[1] One quintal of dry coffee equals 46 kg. The volume of coffee cherries required to produce one quintal of green coffee is called a fanega. Coffee farmers are paid by the fanega.

[2] In 2003, 1 US$ = 385 colones

[3] ff/ha = fanega per hectare. One ff/ha = 46 kg/ha of green dry coffee

sustainability of coffee is for farmers to begin keeping track of these things so that they can monitor improvements or deterioration over time. Rainforest Alliance (2004) has performed qualitative sustainability analysis on a number of farms throughout Central America. Similar to environmental management systems such as ISO 14000, both Rainforest Alliance (2004b) and ICAFE (2003b) promote that the monitoring inputs, outputs and farm conditions is one of the first major steps towards sustainability within their certification framework.

There have been two major aspects that have been left out of these sustainability models: (a) the integration of farm processes with beneficio process into a mutually supportive system, and (b) the integration of alternative crop and products into the coffee plantation. ICAFE is solely focused on the sustainability of the coffee crop, not the full sustainability of the coffee farmer in terms of their quality of life or ability to avoid risk. The Rainforest Alliance has been slightly more forward thinking on this front and suggest to farmers that they find alternative crops in areas of their farms that have sub-obtimal conditions for coffee growth (Rusillo, 2004). However, to date they provide little assistance beyond qualitative suggestions as to how to make this transition. There are, however, plans to improve the information provided to farmers by partnering with researchers and NGOs that have experience in transforming monoculture farms (of any sort) to integrated agriculture that provides a more stable socio-economic environment as well as one more environmentally sustainable.

5.5.3 Maximizing Operational Efficiency in the Mill

Very few mills monitor their material and energy usages beyond a seasonal calculation of production outputs versus total seasonal inputs. This applies to water usage, as well as heat and electrical energy. Similarly, the mills do not monitor the quantity of their wastewater or, in mills with anaerobic digesters, the quantity of biogas produced, or the efficiency of its production and use. This is a very key issue as it is impossible to implement technical innovations and changes that focus on the improvement of resource use efficiency if there is little data on the use patterns of the various resources.

Table 5.24 provides an overview of the various steps that can be implemented within the industry to improve operational efficiencies. Some mills have begun to implement a certain number of these steps. However, these strategies have not been implemented to any great extent in most other Central American countries. El Salvador has been concentrating on water reduction , but this has been implemented as a result of water shortages, not for environmental reasons.

5.5.3.1 Water Use. Of the 30 mills contacted, 26 (87%) do not monitor water usage beyond paying the monthly bills to the municipality (urban centres) and recording total water use for the season. For those that draw their water from rivers or wells, which are not metered, the total used within the harvest season is recorded as it must be submitted to the Department of Natural Resources at the end of the harvest season to be in compliance with the water use license. Currently, the 40% water recycling that has been requested by the government is typically implemented simply by having two pipes at the end of the system, one pipe leads to the settling ponds and a second pipe (that is 66% of the size of the original pipe) leading back to the water intake pipe. No monitoring of the flow rates or volumes is actually performed. Similarly, there is no monitoring of water usage at the sub-system level. The amount of water used to transport the cherries from the receiving hoppers to the depulpers and that used in the fermentation process are unknown. Therefore, it is only from qualitative observations that management can determine how to implement water reduction procedures, which does not appear efficient or effective. In order to properly evaluate the cost effectiveness of various water reduction plans this very basic data must be available.

Before randomly implementing water reduction programs management of the mill must have a good understanding of the treatment technology or the desired end-use for the wastewater. If an anaerobic digester is to be implemented, the ideal volume, concentration and flow rate need to be considered when designing the water reduction

Table 5.24. Environmental Initiatives for the Coffee Industry.

Resource	Step/Use	Description	Impact
Water			
	Water Recycling	Wash water is reused with an addition of ~40% new water during each cycle	Reduces strain on local water supply. Increases BOD/COD in wastewater effluent: more efficient operations of anaerobic treatment systems.
	Mechanical Transport of Cherries/Wet Coffee	Use of screw conveyors for transportation instead of water	Reduction in water consumption and, therefore, wastewater requiring treatment
	Use of Mechanical Mucilage Removal	Use mechanical means to remove mucilage instead of water intensive fermentation	Reduction in water consumption and organic loading of wastewater. Also, make mucilage available for possible alternative usage.
Wastewater			
	Separation of Solids	Screening/filtering of wastewater	Reduces organic solids in effluent. More effective wastewater treatment
	Sedimentation of Residual Wastewater	Sedimentation lagoon/tanks constructed for wastewater	Sedimentation of suspended solids as a first step in treatment of wastewater
	Use of Biogas	Gas produced by reactors is used as fuel in the mill	Biogas used to generate electricity or heat for the drying of green coffee.
Pulp			
	Compost	Applied to non-coffee plantations (broca bettle can survive compost process and be introduced to non-infected areas)	Eliminates disposal to watercourses, leachate from pulp piles, foul smells and vector breeding associated with rotting pulp. Produces organic fertilizer
	Growth Substrate	Industry itself uses pulp for cultivation of other value added products (i.e. mushroom cultivation). Once spent can be used as soil conditioner	Similar benefits with greater economic return for produce
	Fuel	Can be dried using waste heat and used as fuel	
Parchment			
	Fuel	Burning parchment generates heat for artificial drying of green coffee	Reduction in use of firewood (traditional fuel for drying coffee)
Energy			
	Parallel Systems	Use of parallel systems to permit the shut down of equipment during periods where mill is operating at less than optimal capacity	Reduction in energy requirements for equipment operations
	Use of Waste Heat	Use of heat exchanger to capture waste furnace/dryer heat and use it to heat influent to digester	Elevated influent temperature will aid in improved digester efficiency and permits use of biogas in other mill systems.
	Energy Efficiency	Investment in high efficiency pumps, fans and motors. Proper sizing of equipment for the required task	Reduction in electricity costs.

plan. For example, for optimal biogas generation the minimum and maximum organic loading desired in the wastewater should be considered in the water use plan. If the water use is reduced too much it will result in an increased concentration of organic loading of the wastewater. This could potentially be higher than what can be efficiently handled by the digester, then a positive impact that has been made due to the reduction in water use will be offset by the discharge of effluents that are out of compliance. Potential fines or a drop in biogas production will offset any financial savings from reduced water bills. Similarly, if the wastewater is to be used as a feed source for aquaculture or hydroponics operations there will be upper and lower limits on the concentration of the waste stream for optimal usage within the system. These limits need to be determined. While it is not desirable to limit the efficient use of a resource, one needs to be cognisant of the fact that the by-products of a process do need to be treated. For example, a 5% increase in resource efficiency should not necessarily be considered if it means that the resultant waste stream will be significantly more difficult to treat. The two aspects need to be balanced.

4.5.3.2 Energy Use. There are two major energy requirements within the beneficio: (a) electrical energy for the operation of motors and pumps that are integral to the operation of the depulping and coffee transportation systems within the beneficio. The other energy requirement is the heat energy to dry the coffee beans. Approximately one kilogram of water needs to be evaporated to produce one kilogram of dry green coffee. The burning of firewood and coffee parchment normally produces the heat energy that is required. In the very few mills (3 as of March 2003) with operational biodigesters, the biogas is used as a heat source for the drying of coffee as well. A large number of the 30 mills interviewed did not monitor their energy usage beyond paying the electric bills and purchasing the same volume of firewood each year. There is no information on the efficiency of the furnace/dryer combination and no measurement taken of the heat contributed by biogas, wood or parchment.

The specific heat of the firewood used in these furnaces is approximately 18.4 MJ/kg at 15% moisture content. The old style box furnaces used in the typical beneficio operate at a heat loss of 70% of the heat energy contained in the fuel and only 30% of the heat content of the fuel reaches the dryer (Cléves, 1995). The dryer designs have not changed in any fundamental way since the turn of the century. Much of the energy supplied is released as waste heat. The heat required to drive off the 1 kg (~1 L) of water in order to produce 1 kg of dry green coffee is 2.7 MJ. This is calculated from the following equation:

$$Q_c = m_w C_w(T - T_a) + m_c C_c (T - T_a) + L_w m_w \tag{5.1}$$

where:

Q_c = the heat required to produce 1 kg of dry coffee beans

m_w = the weight of water (1000 g)

m_c = the weight of coffee (1000 g)

C_w = specific heat of water (4.2 J/g C°)

C_c = specific heat of coffee (based on wood) (1.6 J/g C°)

L_w = latent heat of water converted to steam (2.26 KJ/g)

T = Temp at which water turns to steam (100 C°)

T_a = ambient temperature (20 C°)

The heat required to dry a 46 kg unit of dry green coffee is 125 MJ (46 x 2.7 MJ). The volume of firewood used in a typical beneficio ranges from 0.09 - 0.14 m^3 per 46 kg bag, with an average density of 500 kg/ m^3. This amounts to 45 - 70 kg of firewood per 46 kg unit with a heat content ranging from 828 MJ to 1289 MJ. Additionally, approximately 11.5 kg of coffee parchment is burned with a heat value of 16.7 MJ/kg for a total heat of 192 MJ. Therefore:

Total Heat	= 1020 - 1481 MJ
Heat to Dryers (30 % of total heat)	= 306 - 444 MJ
Efficiency	= 28.2% - 40.8%

There are furnace/dryer systems available on the market which have higher energy efficiencies that should be considered for any beneficio operating at such low efficiency. One major problem is that the firewood used for drying is inexpensive and the payback period for any capital expenditure would be longer than most mills (or financial institutions) would deem appropriate (+ 3 years) due to the high interest rates (up to 30%) associated with external loans (Schram, 2000).

However, the energy balance demonstrates that it is possible to supply all heat using coffee parchment. Coffee parchment has a similar specific heat value (16.7 MJ/ kg) to that of firewood (Cléves, 1995). It is currently used as a supplement to firewood as opposed to being depended on to supply a steady source of fuel. About 2.9 MJ of heat is theoretically needed to remove 1.1 kg of moisture to produce 1 kg of dry coffee. For every kilogram of dried coffee produced there is 0.25 kg of parchment that contains 4.2 MJ (16.7 MJ/kg x 0.25kg). With the appropriate technology, it should be possible to provide the heat requirements for the beneficio using only parchment. Research has been conducted on efficient (95%) fluidized-bed reactors that use coffee parchment of fuel (Saenger et al., 2001). The Asociación del Beneficiadores del Costa Rica has been actively promoting the incorporation of more energy efficient systems in the drying section of the mills (ABCR, 2003).

The Coopedota beneficio in the Tarrazu region of Sta. Marie de Dota is presently operating two high efficiency (96%) fluidized bed furnaces that use exclusively parchment and dried coffee pulp as fuel. However the fuel requirements cannot be met by parchment alone due to the inefficiencies of the dryers used. As such, Coopedota is using coffee pulp to augment the system. The coffee pulp is sun dried by local farmers and transported back to the beneficio at high transportation costs, making the system more expensive than necessary. According to the General Manger of Coopedota, any technology or system change that would either increase the efficiency of coffee dryers or be able to make use of the dryer waste heat to dry the coffee pulp on-site would be a welcome alternative (Mata, 2004).

5.5.4 Maximizing Resource Efficiency

The sustainability of the coffee processing system can be substantially improved though the use of by-products. Some options may require simple process modifications, while others may require more analysis to determine the economic and institutional feasibility of their integration into the system.

5.5.4.1 Coffee Pulp. Coffee pulp is used almost solely to create compost as a saleable product. This does not fully exploit the nutritional content of the coffee pulp, nor provide an economic return of any real significance because: (a) the market demand for coffee compost cannot keep up with the voluminous supply, (b) due to the centralized nature of these operations, the cost of trucking compost to the end-users is high and makes it difficult to recover profits from the sale and (c) the composting process presently used does not guarentee the destruction of the broca insect that may be infecting some of the coffee pulp.

In Costa Rica, composting operations are centrally located on major transportation routes to ease transport from the beneficios. It may be feasible to convert these large facilities into urban farming operations. However, the economic and social feasibility of this needs further exploration. Table 5.25 provides some options for pulp utilization. There has been significant research (Pandey at al., 2001; Lopez et al., 1995; and Martinez-Carrera et al., 1992) into using the coffee pulp as a growth medium for commercially desirable products. Using the coffee pulp as a growth medium for other products that could be sold for profit by the coffee producers should be investigated more thoroughly. The end product would be of higher economic value and, once spent, the substrate could still be used as a soil conditioner within the farming operation.

5.5.4.1.1 *Mushrooms*. Martinez-Carrera (1987) showed that P.*ostreatus* and P.*floridans* mushrooms could be cultivated using coffee pulp as a substrate. Subsequently a pilot-scale mushroom farm was designed and implemented on-site at a benefiicios in Veracrus, Mexico. The design was kept simple and inexpensive so as to make it feasible

Table 5.25. Some options for pulp utilization.

Strategy	Description	Impact
Growth Substrate	Used for production of other value added products; once spent can be used as soil conditioner	Greater economic return
Compost	Application to non-coffee plantations	Eliminates leachate from pulp piles, foul smells and vector breeding associated with rotting pulp and produces organic fertilizer
Amino Acid Substrate	Used as a commercial source for amino acids	Greater economic return
Fuel	Dried using waste heat for use as fuel	Reduction in firewood use

for local farmers and processors. The farm covered an area of 145m^2 and was divided into four sections: (a) area for coffee pulp fermentation, (b) pasturization area, (c) spawning area, and (d) mushroom production and growing area. The coffee pulp was fermented and then pasteurized before spawning. Seven different strains of mushrooms were used, five strains of P. *ostreatus* (4 Mexican, 1 European), one strain of P. *floridanus* and one strain of P. *sajor-caju*. One Mexican strain of P. *ostreatus* and the American strain P. *floridanus* showed the most promise, demonstrating biological efficiencies of 159.95% and 175.6%, respectively (wet weight of mushrooms per dried weight of coffee pulp). The study concluded that simple mushroom cultivation using waste coffee pulp could be made a part of an integrated bio-system designed to better utilize this organic waste.

Further investigation by Martinez-Carrera et al. (1992) reiterates the usefulness of mushroom cultivation as a means of providing a simple, nutrient-rich, economically viable resource to developing nations. The appropriateness of coffee-pulp as a substrate was demonstrated again when biological yields of 100-150 % were obtained (wet weight of mushrooms per dried weight of coffee pulp), depending on species (Table 5.26). The technology was thought to be simple and could be designed to suit local conditions. Mushrooms improve the bioavailability of the carbohydrates and proteins found in coffee by-products and could be produced rapidly with relative ease. It would also

Table 5.26. Mushroom biological efficiency (Martinez-Carerra, 1987).

Strain	Dry Weight (g)	Average Yield (5 day fermentation period) (g)					Total Yield (g)	Biological Efficiency (%)[d]
		1st batch	2nd batch	3rd batch	4th batch	5th batch		
P. floridanus[c]	999	1179	350	177.5	50	-	1756.5	**175.8**
P. ostreatus (e)[c]	999	500	-	-	-	-		
P. ostreatus (m1)[a]	999	818	441	174	91	74	1598	**159.95**
P. ostreatus (m2)[b]	999	381	205	193	225	125	1129	**113.01**
P. ostreatus (m3)[b]	999	594.5	220	173	193	-	1182.5	**118.36**
P. ostreatus (m4)[b]	999	424	300	229	196	-	1149	**115.01**
P. sajor-caju[c]	999	630	246	240	164	-	1280	**128.12**

a – average yield from 100 replicates
b – average yield from 10 replicates
c – average yield from 50 replicates
d – biological efficiency is the wet weight of mushrooms produced compared to the dry weight of coffee pulp utilized

render the remaining substrate more appropriate as livestock feed or as an organic fertilizer/soil conditioner.

Lopez et al. (1995) reported that much of the coffee pulp and mucilage produced in Mexico during the 1993-94 harvests was discharged directly to the rivers untreated. They concluded that there was significant development opportunity for the commercial production of the edible mushroom, *Pleurotus ostreatus* (oyster mushrooms) using coffee by-products as substrate. Pandey et al. (2000) conducted studies that support these earlier conclusions.

A number of Costa Rican beneficio managers expressed interest in this concept, and some have begun to do their own research. However, there is an obvious lack of available data. Managers have expressed frustration due to this, as well as the lack of support from government and R&D organizations,. Also, interestingly enough, at the present time some researchers and beneficiadores estimate that close to 90% of mushrooms sold in Costa Rica are imported from Columbia (Schram, 2003; and Cutie, 2003), bringing up the possibility of a market for locally produced mushrooms. In discussion with farmers (Campos, 2003; and Cutie, 2003), many indicated that they would include mushrooms into their diet if they were accessible and could be safely produced (there is apprehension about the possibility of not being able to discern between edible mushrooms and the inedible ones that grow naturally on coffee pulp at the moment).

5.5.4.1.2 Compost. Another alternative is to create compost, but instead of bulk sales they would generate income from the production of a more marketable product. For example, some Mexican coffee producers have integrated the cultivation of exotic flowers and bamboo into their operations as a mechanism to generate economic value while using environmentally sound measures to eliminate their wastes (Bejarano, 2003). The waste coffee pulp from the processing operations is composted through vermi-culture and is then moved to on-site greenhouses where it is used as a growth medium for orchids, hyacinths and other commercially desirable species. The spent hothouse substrate is then given to the coffee farm as a soil conditioner.

The President of the ABCR (2003) supported the hypothesis that the centralized compost facilities could become more competitive if the compost was packaged and sold retail as compost for landscaping and flower beds to the middle-class population. While a market study would need to be completed, it was noted that compost was sold retail and by landscapers throughout the San Jose and Guanacaste regions at prices higher than the compost facilities were receiving for their bulk product.

5.5.4.1.3 *Biogas*. Calzada et al. (1984) were interested in the utilization of waste liquids from coffee pulp. They studied the possibility of producing biogas from the a mixture of water and coffee pulp juice, using one- and two-phase digestion systems. Using a two-phase system (with 25% coffee juice in the feed) consisting of acidogenic phase with a 0.5 day HRT and a methanogenic phase with a 8 day HRT resulted in stable conditions, with an optimal gas production of 1.204 L/gram of volatile solids and a CH_4 content of 74%.

5.5.4.1.4 *Alcohol*. Bressani (1979b), Adams and Dougan (1981) and Mburu and Mwara (1996) indicated that it was unlikely that economies of scale would make the commercial production of alcohols or vinegars from coffee by-products economically feasible. However, it was technically possible. As the coffee crisis deepens, the economical feasibility may change.

5.5.4.1.5 Dryer Fuel. In areas that have limited access to sustainable fuel, dried coffee pulp could provide a viable alternative fuel for high efficiency furnaces. While these furnaces are receiving some accolade within the industry, the dryers are still of such a low efficiency that they are not able to make use of the complete heat energy being release through the combustion of coffee parchment. Presently there are no viable new dryer designs aimed at improving drying efficiency. Therefore, if the waste heat from the dryers could be used to dry the coffee pulp on site, it could allow beneficios to become self-sufficient with regards to fuel.

5.5.4.1.6 *Livestock Feed.* The studies into the suitability of coffee pulp as livestock feeds are exhaustive. As early as 1966, scientists have been looking for ways to make coffee by-products more palatable to cattle and other ruminants. Bressani (1979) conducted a long-term study of the impacts of coffee pulp on livestock at various percentages of total feed. It was found that coffee pulp could be substituted at levels up to 20% with no appreciable negative effects for cattle and other ruminants. Levels above 20% were found to cause erratic behaviour, weight loss, reduced water retention, increased urinary activity and heart palpitations. The same study demonstrated that even low levels (<5%) would impair growth and in some cases cause death in chickens and young livestock. This has been attributed to high tannin and caffeine levels and the probable effects of these components on the pulmonary system.

Fermentation, dehydration and silage techniques have been explore to alter the chemical makeup of coffee pulp so that the negative impacts could be mitigated to some extent (Bressani, 1979; Murillo, 1979; Adams and Dougan, 1981; Gautho et al., 1991; Mburu and Mwaura, 1996; and Diaz, 2002). However, there has been minimal success and the introduction of coffee pulp into the regular diets of livestock has not been widely implemented (Mburu and Mwaura, 1996; and Diaz, 2002). The author believes that this area of study has been exhausted and researchers should be abandoned in pursuit of more economically-valuable products.

5.5.4.2 Wastewater. At present, wastewater is generally dealt with in four different ways: (a) direct discharge (i.e. no treatment), (b) treatment using an aerobic lagoon, (c) treatment using an anaerobic lagoon, or (d) treatment using an anaerobic digester. Of these, only the anaerobic digester is designed to obtain a possible economic return from its operation. It has the potential of providing the overall operation with a source of energy that would otherwise be wasted. The other two water treatment options are an economic drain and offer no economic incentives for their operations beyond bringing the beneficio into legislative compliance.

Table 5.27 shows some wastewater treatment/utilization options. Wastewater can be utilized as a feedstock to an external operation that utilizes the nutrients in the wastewater. Through the use of an aquaponic system it may be possible to develop such a system with commercially viable fish and plant production that utilize the organic matter in the wastewater as sustenance and reduce its harmful BOD level to an acceptable level for release to ambient water bodies. Species such as tilapia and duckweed have demonstrated possible application to such a system (Leng, 1999; and Iqbal, 1999). Tilapia has been integrated at a small scale within a beneficio in Turrialba and at least one organic coffee farm that was surveyed integrated a small tilapia/duckweed system into their operations.

Table 5.27. Treatment/Utilization Options for Wastewater.

Strategy Use	Description	Impact
Separation of Solids	Screening/filtering of wastewater	Reduction of organic solids as first step in wastewater treatment
Sedimentation of Residual Solids in Wastewater	Sedimentation using lagoon/tanks constructed for wastewater	Sedimentation of suspended solids as a first step in wastewater treatment
Use of Biogas	Gas produced by reactors is used as fuel in the mill	Biogas used to generate electricity or heat for the drying of green coffee.
Aquaponic Ponds	Creation of aquaponic systems to optimize nutrient utilization	Reduces organic loading and permits production of alternative products

5.5.4.2.1 *Biogas*. Optimal operation of beneficio anaerobic digesters need an input temperature of 35 C. Because the ambient water temperature is in the range of 25 to 27 C, the biogas produced by the digester is burned to produce the heat needed to raise the temperature of the digester influent. There are two issues with this arrangement: (a) it is a waste of a resource as the heat needed to raise the temperature of the influent could easily be provided from the waste heat associated with the drying system, and (b) it demonstrates the attitude that the digester is a separate operation from the rest of the mill. Digestion systems are often poorly integrated into the rest of the beneficio operations and viewed as a nuisance as opposed to an integral part of the overall systems. Minimal operator training and lack of management direction has resulted in many of the beneficios having low operating efficiency (16%). For example, biogas burners used to heat the digester influent can be located 150 m away from the digester, using non-insulated pipes to transfer the heated wastewater from the burner to the digester. The loss of heat energy in the transfer process is up to 50%.

The Biomass Technology Group (BTC) of the Netherlands in a joint effort between the Dutch government and the coffee industry of Costa Rica initiated a project to measure the greenhouse gas emissions from treatment lagoons in Costa Rica. The extension of this project saw the replacement of the poorly operated and ineffective aerobic and anaerobic lagoons at nine coffee mills with anaerobic reactor systems. The methane production was 28 L/kg of coffee processed which was sufficient to be used as a source of heating for the reactor system with the excess being used as fuel in the drying of the green coffee (Hensen, 1998). Presently, these digesters have been taken over by beneficios operaters as the BTG operator contracts have expired. Efficiencies in a number of these beneficios have dropped significantly. The belief is that it was related to minimal operator training and the nature of beneficio laborers to be uneasy about making judgments with regards to the digester operations. Most would wait until they can bring a problem to a manager or supervisor rather than making their own decisions to correct it (Marcos, 2003). This often means that problems will go unresolved for an entire shift before being addressed.

According to the Associación del Beneficiadores del Costa Rica, there are presently (as of March 2003) twelve beneficios in Costa Rica that have installed anaerobic digesters, which are used to generate biogas. However, very few of them are operating efficiently. For example, during an inspection of a digester in San Jose, it was found that the overall efficiency of the system was less than 15% when one considered the volume of biogas generated and the effectiveness of the system in the removal of BOD and COD from the wastewater.

5.5.4.2.2 Aquaponics. Some co-op producers in Turrialba utilize the wastewater from coffee processing operations in aquaculture operations producing tilapia. The effluent from the aquaculture operations has higher ammonical nitrogen content as well as higher levels of methanogenic bacteria making it better feedstock for their small anaerobic digester. The bulk of the methane is used to raise the influent temperature. The excess is used to provide heat to the coffee dryers (Cutie, 2003). However, in the absence of an anaerobic system there is the possibility of integrating this type of operation with a hydroponic system that in combination with the aquaculture operations, will produce clean water and crops. A modification of the solar aquatic ^{TM} systems developed in Canada for sewage treatment could possibly be applied.

5.5.4.3 Mucilage. No mill was found in Costa Rica that utilizes the mucilage for any purpose. Most mills use a fermentation process to remove the mucilaginous layer from the coffee bean, which results in the dissolution of the mucilage into the wastewater. The main reasons given by beneficio owners/operators for using this method are: (a) some believe that_it produces better-flavoured, although Cléves (1995) debates this belief, and (b) they are opposed to the increased cost of mechanical removal of mucilage. The electricity cost of mechanical mucilage removal is approximately 16.2 kwh/tonne of dry coffee produced as a 30 hp motor removes mucilage from coffee at a rate of 30 fanegas per hour (the dry coffee equivalent of 1.38 tonnes). A typical mill operation requires a total of between 209 and 330 kwh/tonne of dry coffee depending on operational efficiencies. As such, mechanical removal would represent an approximate cost increase of 4.9 and 7.8% in terms of electricity use. Therefore, any use of mucilage must either provide an economic return. or a savings in wastewater treatment costs in order to cover the increased operational costs. Table 5.28 shows possible utilization of mucilage.

Table 5.28 Options for Mucilage Utilization.

Strategy	Description	Impact
Pectin Production	Used as raw material for the production of pectin and pectic products.	Substantial reduction in the amount of wastewater requiring treatment while providing an economic return
Livestock Feed	Sold to ruminant farmers as a rich source of carbohydrate	Similar as above with a much more simplified process
Fish feed	Feed stock for onsite aquaponic operations	Treats wastewater and provides economic return from production of saleable products

It is possible to extract pectin from the mucilage of coffee, which contains up to 38% pectic substances (Bressani, 1979a). However, research on the use of this by-product was largely abandoned as it was felt that the systems operation of the beneficios would not allow for the mucilage to be recovered in a useable form. This was due to the fact that the process used to remove the mucilage from the coffee bean included fermentation in a water bath and then rinsing. The fermentation process and the dilution factor rendered the mucilage virtually irretrievable. However, the implementation of new regulations for monitoring the use of water in beneficios in Costa Rica and El Salvador has lead some facilities to replace the fermentation process with mechanical removal of mucilage (Cutie, 2003; and ABCR, 2003). This change not only reduces the water consumption, but changes the by-product outputs. Where there was once one, highly contaminated wastewater effluent stream, there is now a less contaminated wastewater output plus a separate effluent of almost mucilage. With this change, the possibility of commercially viable pectin extraction from coffee mucilage should be subject to renewed investigation. In laboratory studies, it was demonstrated that pectin could be recovered at a ratio of 17 g pectin/100g mucilage. The study did not include an economic feasibility analysis of the process (Bressani, 1979a). However, Cleves (1995) indicated that research done at the Columbian Coffee Institute demonstrated the possibility of extracting 'good quality' pectin from C. Arabica mucilage. The economic viability of coffee pulp pectin being able to compete commercially with pectin presently produced from citrus and apple by-products (which are not overly abundant in Central America) should be investigated.

5.5.4.4 Parchment. Parchment is almost entirely used as fuel in the beneficio furnaces and it is not anticipated that there should be a major shift in this mindset. However, in mills that rely on passive solar energy for drying there are areas that should be subject to further study for the use of this parchment in the production of xylitol or other value-added products.

5.5.4.4.1 *Xylitol.* In Upsizing, Pauli (1998) discusses the economic conversion of hemicellulose to xylan and then to xylitol, a sweetener with all the sweetness of cane sugar, but fewer calories and without the cavity producing side effects of sugar. Xylitol is produced largely in Finland typically using birch hemicellulose. However, it is possible, based on the hemicellulose content of coffee parchment (Bressani, 1979a), that they could provide a commercially viable source of this alternative sweetener.

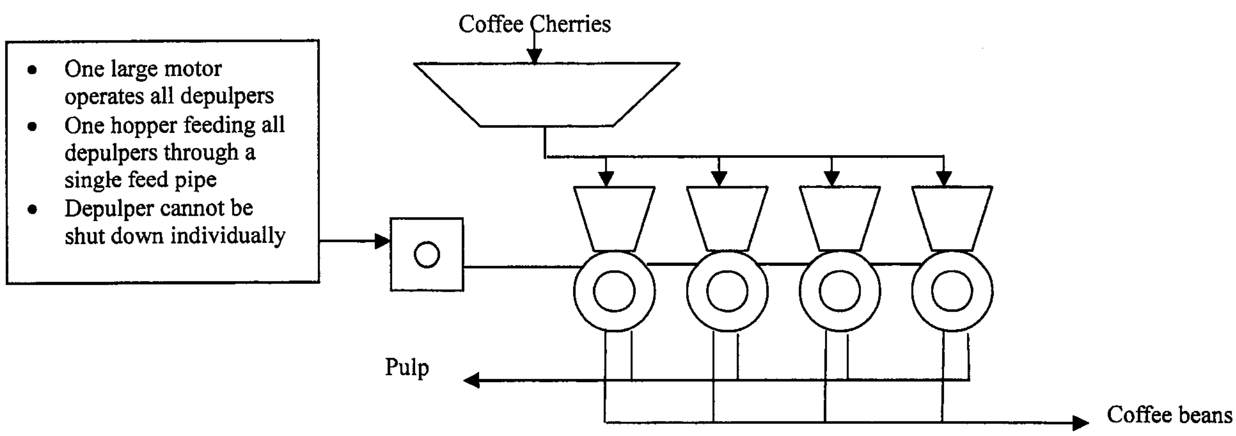
4.5.4.4.2 *Specialty Papers*. It was discussed with some small beneficio operators who have an excess of parchment that the production of a specialty paper out of the coffee parchment for sale to tourists has been feasible. The few involved provide this 'coffee paper' to gift shops and souvenir stores throughout Costa Rica. It is a small, niche market, but is an example of the fact that these producers recognize that a set of paper and envelopes will produce a higher economic return than the burning of it.

4.5.5 Operational Design

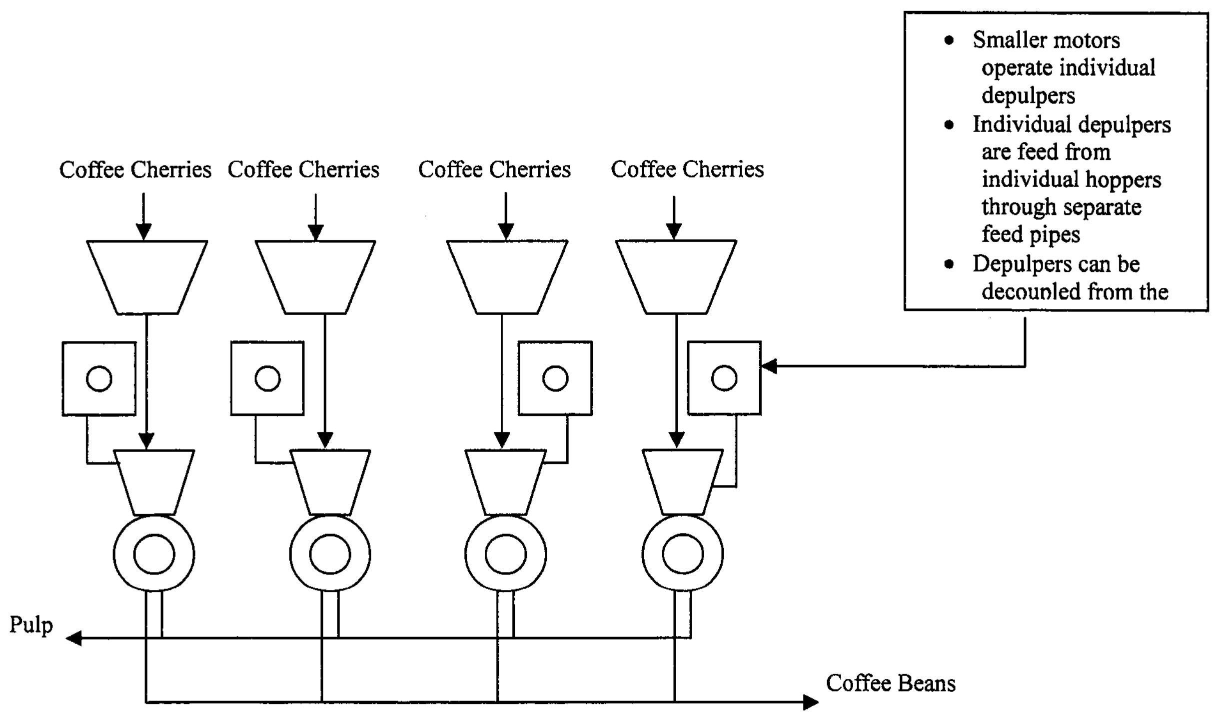
Another cause for inefficiency within the beneficio is the system's operational design. Costa Rican beneficios are designed for maximum capacity. The machinery is connected in series, meaning that all pieces of equipment are engaged when the system is operational. Therefore, at times of low operating capacity, separate lines cannot be shutdown to account for the lower throughput, thus resulting in considerable inefficiency in electricity and water usages. A reconfiguration of the piping and machinery systems that will allow for unnecessary equipment to be taken off line could result in considerable saving. Figure 5.17 demonstrates this idea within the depulping stage.

4.5.6 Improving Management

Any technological innovation must consider the producers' goals and lifestyle choices. Management decisions should reflect not only environmental and broad social considerations, but also individual goals and lifestyle choices. For example, adoption of some technologies or practices that maximize profitability may also require such intensive management that employees' or farmers' lifestyle actually deteriorates.



(a) Particial-Series Operations



(b) Parallel Operations

Figure 5.17. Alternate Operations of Depulpers.

Management decisions must promote sustainability that nourishes the environment, the community and the individual.

Much of the focus has been on financing environmental improvements through improved market placement (better pricing, improved market share). There has been limited success with estate coffees, small organic associations and cooperatives receiving foreign aid financing, but it is not feasible to depend on such capricious strategies to finance environmental improvements in general. Therefore, environmental innovations must, largely, pay for themselves in terms of reduced energy and material uses, reduced treatment costs, or income from additional crops and/or value-added products (biogas, compost, livestock feed, fishfeed, mushroom, etc).

Environmental problems in the coffee industry have been viewed as technical problems. However, technical solutions can only represent part of the solution. Environmental and social issues need to be incorporated as part of the overall system management and as such embraced as the responsibility of management. Management experience with documentation is very limited and, therefore, beneficios are often operated with rudimentary strategies that do not analyze production and financial strategies beyond the bare minimum needed for survival. Energy and resource throughput is not normally measured in an disaggregated form, and as such mill managers do not know what processes are more/less costly, where inefficiencies lay, or the cost effectiveness of the various innovations that have been implemented. A large portion of the mills in Costa Rica reported that they do not keep detailed data on the costs of waste treatments. The only costs reported were the cost of transporting the coffee pulp to the centralized composting facilities ($5.30/tonne of coffee pulp) and the cost of $CaCO_3$ that is sometimes used to aid in the precipitation of suspended solids in settling lagoons (9.7kg of $CaCO_3$/tonne of dry coffee). There was no recording of any professional development programs such as employee training or accreditation, thus eliminating any voluntary employee contribution to sustainability enhancements in the mill. Occupational health and safety programs are virtually non-existent. Therefore, there are three management aspects that must be addressed as part of any sustainability plan to be implemented; (a) training, (b) environmental management systems and (c) industry structure.

5.5.6.1 Training. Major research focus has been directed toward the technical and biophysical nature needed for sustainable agro-industrial development, but less studied is the need for alternative approaches to learning and training. Pretty (1998) reported that participation by stakeholders is a critical condition for success in sustainable agricultural and agro-industrial development and farmers' capacity to innovate is paramount for the implementation of sustainable practices. Training that can effectively transfer research methods and technologies to the end users are as important as the message trying to be taught (Ramanathan, 2002; and Pretty, 1995). Training must be at a level that will: (a) facilitate the spread of sustainable behaviours and, (b) institutionalize these approaches (Pretty, 1998; and Sechrest et al., 1997). Within coffee beneficios two of the most significant non-technical problems with implementing innovations or improving resource and operational efficiencies are: (a) the viewpoint of management towards the operation of the various systems of the mills, and (b) their attitude toward the workers who operate them.

The operation of the anaerobic digesters in Costa Rica can clearly demonstrate these problems. Some beneficio managers view digesters simply as waste treatment systems that have been put in place, to maintain compliance with government regulations. They do not consider if properly operated, an anaerobic digester can produce a product that could be of significant value to the mill. For example, a beneficio in the Naranjo region of Costa Rica is presently producing enough biogas to provide heating to the digester influent and generate electricity for the mill. By capitalizing on a system that is already in place, the mill was able to reduce electricity expenses. The reason for this success is not technical in nature but rather related to the management attitude. This could be replicated in other mills with the proper introduction to the costs/benefits of industrial ecology strategies. The other drawback is that the digester operators themselves have minimal training on the operations of the reactor. European companies, using aid money from the sponsor countries, installed most of the reactors in Costa Rica, but no training with regards to troubleshooting problems or a theoretical understanding of the operating principles of anaerobic digestion was given to the Costa Rican operators. Minimal information regarding the importance of influent concentration, flowrate, or influent temperature was provided. Operators, simply following a set of listed instructions and are not comfortable making decisions outside of this standard list of protocols. This results in minimal reactor efficiency that affects the beneficio in two ways: (a) effluent discharged is not in compliance with regulations and, (b) less available biogas for use in the beneficio.

5.5.6.2 Environmental Management Systems (EMS). Often environmental agencies perpetuate the ineffectiveness of past policy approaches by focusing on only one environmental medium at a time. Failing to consider the systemic nature of environmental problems, statutory requirements cultivate a reactionary response from business to only improve environmental performance in specific mandated areas. There is no integration of environmental management into the overall operation. This form of compliance driven environmentalism supports compliant-oriented behaviour, where improvements are performed to comply with laws, accounted for only as overhead costs.

As previously mentioned, the CEGESTI Suscof Project has taken the approach of applying an ISO 14000 system to a consortium of coffee cooperatives with some positive benefits. However, the integration of such a system is expensive and follows closely a compliance driven platform that will limit the innovation with regards to the development of a zero-emissions system. De Groot (2002) highlighted the sustainability indicators being implemented in the program which are similar to other environmental policies that focus on one medium at a time in a reductionist fashion. The performance indicators that participating mills will monitor include quantity of BOD produced per kg of coffee and a number of compliance violations. These will help improve the condition of existing system operations but will significantly limit the opportunity for resource use optimization. Systems developed from ISO14000 protocols need to be implemented in conjunction with a broader mentality that acknowledges the positive usage alternatives of by-products instead of strictly focusing on the application of arbitrary indicators. Van den

Elzen (2002) reported on the sustainability of the coffee industry through the application of LCA, but little innovation was incorporated into the recommendations and no recommendations for alterations in the methods of cultivation and processing beyond compliance monitoring were offered.

Typical EMS does not necessarily foster innovation nor direct the industries towards the integration of true sustainability in their operations (Adams and Ghaly, 2005). EMS based on ISO14000 allows the industry complete freedom to define the issues and improvement targets, which is more likely to result in minimal incremental changes that reflect a traditional mindset towards pollution prevention using treatment technologies and standard economic efficiencies, rather than the incorporation of innovative approaches to improving the efficiency of the overall system by applying the concepts of cleaner production and eco-efficiency. Nonetheless, some aspects of the ISO14000 are beneficial. ISO systems require data monitoring and as such can help lay the groundwork for future initiatives. These systems also lead to the assignment of responsibility for implementation of environmental management and require the operators and managers to acknowledge the significant environmental impact.

5.5.6.3 Industry Structure. ICAFE has much credibility among stakeholder, and as such its recommendations are seriously considered and often implemented. Therefore, it is important to engage ICAFE in programs aimed at sustainability. This, however, remains a challenge as the Costa Rican coffee industry is so tightly regulated, with little room for innovation. ICAFE controls the entire export process as well as national coffee consumption and determines the final price that processors pay the producers, based on a variety of considerations - yet quality is not a determining factor. Farmers who produce high quality coffee are not necessarily compensated for their efforts and low-quality producers are not penalized. Although the government claims that the fixed price system guarantees the producer a fair price for coffee, it is also very rigid because it does not stimulate the production and commercialization of high quality, environmentally sustainable coffee. Coffee is viewed the same regardless of the social or ecological conditions of its production.

As a result of the tightly regulated system, only twelve exporting companies account for 95% of total exports. For example, Cafinter (Esteve) and Ceca (Rothfos), multinational conglomerates, control 30% of total coffee exports. Café Capris, the exporter for Volcafe controls an additional 12% (Volcafe, 2003). The main goal is to sell quantity, not quality, and as a result Costa Rican coffee is a somewhat generic product. This phenomenon has put the country at a disadvantage, as these large players are not necessarily interested in promoting environmentally sustainable coffee in Costa Rica. Producers do not have the opportunity to promote sustainably grown coffee because it is blended with coffee from other producers and becomes indistinct. Processing plants can do little to position their own brands in distinct markets. Without external assistance, processors have little access to the growing markets for sustainable coffee that prevents them from capitalizing on the market differentiation.

5.5.7 Additional Usage of By-Product

Sharma (1995) noted that effective waste treatment of agrowastes should be related to effective utilization of these wastes. While presently biomass wastes are often used as fuels and wastewater digested anaerobically to produce useable biogas, the chemical and nutritional composition of these wastes should be converted to valued added products. In general agricultural wastes are rich in biopolymers such as cellulose, hemicellulose and lignins and as such can serve as raw materials for value-added produces such as glucose, xylose, furfural, ethanol and aromatic chemicals. (Sharma, 1995) As well, the nutritional content of these wastes is substantial, but they are in a form that makes them unavailable as a food source. Microbial degradation can be used to separate these nutrients into a useable form (Rodriguez et al., 1998; Wang, 1998; Roussos et al, 1995; and Martinez-Carrera et al., 1992).

Foo (2000) promoted the conversion of by-products from renewable resource based industries into value-added products as a method of creating a more sustainable and healthy environment, while providing viable income and employment generating opportunities. To apply the concept of industrial ecology to an agricultural operation such as coffee production and processing, there needs to be more emphasis on the socio-economic parameters relating to the systems than normally found in more traditional industrial ecology approaches seen in developed countries that have a much more technological focus related to system design, and environmental protection and restoration.

Wang (1998) discussed the practice of integrated bio-systems in China, which probably has the most advanced institutional support structure for development of integrated systems at the small, rural farm level. There are currently over 2000 pilot projects in villages, townships and counties throughout the country, which are designed to eliminate agricultural waste, produce value-added products, increase product yields and improve nutrients recycling. The success of these projects can be attributed to the networks, administration, advisory services, technical support, monitoring, training and research.

Chen (1996) noted the success of the "Livestock-biogas-fruit" system, which was initiated on a number of small farms in Southern China. In this case, Pomelo (*Citrus grandis)* farmers were encouraged to introduce local breeds of chickens and pigs onto their farms. Pigs were feed with ground litter from the Pomelo trees and a biogas digester was installed under the pigsty. The digester supplied biogas as a domestic fuel and sludge as a fertilizer. Chickens were raised in the orchard and fed on weed and pests, and deposited excreta as fertilizer. The outcome was improved soil condition resulting in decreased need to chemical fertilizers. This system also helped natural pest enemies function well resulting in a reduced input of chemical pesticides. In some case studies, Pomelo yields increased and the families had new sources of income through pig and chicken production. Finally, the biogas production alleviated the scarcity of rural energy in this part of Southern China. Several other studies outlined similar possibilities for rice farming, sugar cane and other fruit plants (Wang, 1998; Chen, 1996; Foo, 2000; Foo, 2001; and Okafor, 1998). It is logical to extend this to coffee farming.

Sustainability strategies such as industrial ecology can be applied at different points along the industry chain. Within Costa Rica and El Salvador, coffee production is normally completely separate from the processing aspects. The coffee fruit is grown and harvested, and then sent to centralized beneficios for processing. Within the processing operation the development of a system that utilizes the by-products to develop value-added products, or new craft-industries based on processing output, is paramount. Coffee pulp, mucilage, high BOD wastewater, coffee parchment and waste heat must be considered. Alternative uses outside of the farm should be found because the current system does not permit the easy integration of wastes into coffee cultivation. Therefore, either a symbiotic relationship with surrounding industries, or an integrated approach incorporating the development of sub-industries, must be promoted to achieve environmental and economic stability. The by-products of processing need to be looked at as the possible economic outputs, and the reduction in energy and chemical intensity should be considered a path to a sustainable industry. Wastes converted to a value added products are an economic plus and reductions in pesticide use reduces the amounts of harmful chemical affecting non-targeted species, and the expenditure by the farmer. Transition from monoculture production towards sustainable farming practices will improve self-sufficiency and reduced economic risk. The frame of reference for the coffee industry needs to be one that follows the ideals of industrial ecology and focuses on the complete and sustainable exploitation of all system resources, while complimenting the social and cultural stability within the system (e.g. local employment, extension of employment periods, use of locally available goods).

In the other Central American countries, it is more common that the processing of coffee is integrated into farming operations. Therefore, in these situations a sustainable system may develop differently. Rodriguez et al. (1998) suggested that integrated bio- systems provide a great opportunity for sustainable development in many of the world's poorest regions, which ironically have some of the richest biological and cultural resources at their disposal. It is purported that the rational exploitation of local vegetation and livestock using an integrated systems approach will support much more sustainable production in the medium and long terms. The cultivation of indigenous feeds and livestock species, instead of trying to model the advanced modern agriculture systems of developed nations (for example, the production cereal crops for livestock feed), has significant merit. The report shows as an example the increased potential of protein production per hectare for some local indigenous feed sources as compared to soybean. While these sources are not suitable for incorporation in traditionally balance rations found in feed mills, they are suitable for livestock in the immediate area (Rodriguez et al., 1998). The added benefit is that they could be grown on marginal lands or as part of low-tech hydroponic operations used to treat wastewater from coffee processing, instead of using higher quality arable land. The high volume that needs to be consumed due to the fiber content and lower nutrient density is only suitable for locally raised animals that are part of the local bio-system and will also leads to the production of more animal waste. This increase in waste can first be used in anaerobic digestion systems to produce biogas. The liquid effluent from the digester could be directed back to a hydroponic system producing the livestock feed, while the remaining substrate can be used as a soil conditioner.

Considerable research has gone into the investigation of possible alternative uses of individual coffee wastes (Bressani, 1979a; Adams and Douglas, 1980; Mburu and Mwaura, 1996; Panday et al., 2000; and Saenger et al, 2001) but few have approached this problem from the standpoint of whole system. Research has been piecemeal and has rarely made it past the pilot project phase to a stage that is being widely accepted by the industry at large. However, depending on the type of coffee production system one is dealing with (centralized or de-centralized processing) there could be a significant range of applicable ideas, ranging from low-tech to more advanced systems.

5.5.8 Barriers to Innovation.

Adams and Ghaly (2005), Ramanathan (2002), Schram (2000) and Secrest et al. (1997) discussed the barriers to technical innovation adoption within developing countries. The Consultative Group of International Agricultural Research (CGIAR) has expressed concern over the apparent lack of influence that researchers have had in addressing the development of the agro-industries in these countries. One of their conclusions was that researchers had been largely unsuccessful taking technical innovations applicable to developed countries and tailoring them for uses in the different social and cultural settings of developing countries (CGIAR, 1997).

Evaluation of the coffee industry demonstrated that the opportunities of by-product utilization have been discussed on numerous occasions in the region (ABCR, 2003; NCPC, 2003; and Adams and Ghaly, 2005). However, only minimal action has taken place. In order to proceed, it is not only necessary to determine the technical and economic feasibility, but the key obstacles that have prevented the integration of such ideas in the first place. The industrial ecology concept within agricultural systems is not new. Examples were found within the sugar cane industry (ABCR, 2003), the Malaysian palm oil industry (Pauli, 1998), and the Namibian brewery industry. Reports dating back to the 70's (Bressani, 1979) discussed the possibility of value-added products being developed from coffee wastes.

In this study, fieldwork (from 2002-2004) was conducted in Costa Rica with stakeholders from the various aspects of the coffee industry. An evaluation was conducted that focused specifically on the perceived obstacles to environmental innovations within the coffee industry in order to investigate the beliefs and attitudes held concerning the opportunities of industrial ecology and cleaner production. This included 69 stakeholders from the Costa Rican coffee industry as well as from Peru, Honduras, Nicaragua, and the Dominican Republic. Table 5.29 gives the breakdown of those involved.

Table 5.29. Stakeholder Involvement.

Stakeholder	Number of Participants
Researchers	7
Independent Beneficios	15
Cooperative Beneficios	13
Farmers and Farming Groups	18
Exporters	3
International Organizations	5
ICAFE	5
Transnational Companies (TNC)	3
Total	69

Major challenges to the integration of sustainable technologies and strategies (including the application of industrial ecology) to the coffee sector include the traditional obstacles to industrial innovation within developed countries such as industry inertia (business as usual) and lack of political will to promote anything other than the most conservative approach (Schram, 2000). There is also a perception of a push by government/research institutions to find a 'one-size fits all' solution to the environmental issues associated with coffee processing (ABCR, 2003). For example, in Costa Rica beneficios are required by legislations to compost all coffee pulp and use either lagoons or bio-digesters for the treatment of wastewater/effluent. The result is an abundance of compost that at the moment has no market. Bio-digesters demonstrate good technical options for wastewater, but in practice operators are having significant problems integrating the digesters into mill operations due to the inconsistency in operator capabilities, irregularities within the waste streams and lack or absence of human resources training. Effluent characteristics vary significantly during the operations season due to volume differences and changes in the chemical composition of coffee being processed as it change characteristics during the season and operators often do not have sufficient skills to adjust for these changes to maintain optimal operations.

5.5.8.1 Stakeholder Perceptions. Aside from the general problems associated with industry conservatism and lack of government foresight, it appears that the industry faces a whole host of additional issues. While the specific perceptions held by stakeholders varied, a number of general themes emerged from the surveys and interviews that were conducted. Table 5.30 provides a quick reference to the concerns most frequently mentioned whereas Figure 5.18 displays the number of respondents who referred to each. The term 'perception' is being used as a descriptor because perceived obstacles can be as effective in preventing progress as real obstacles, as these perceptions represent opportunities that are left unexplored simply because of the belief that something is not feasible.

5.5.8.1.1 *Payback Period (O1)*. Processors indicated the need to focus on short-term solutions with minimal expenditures. Longer term solutions aimed at efficiency and

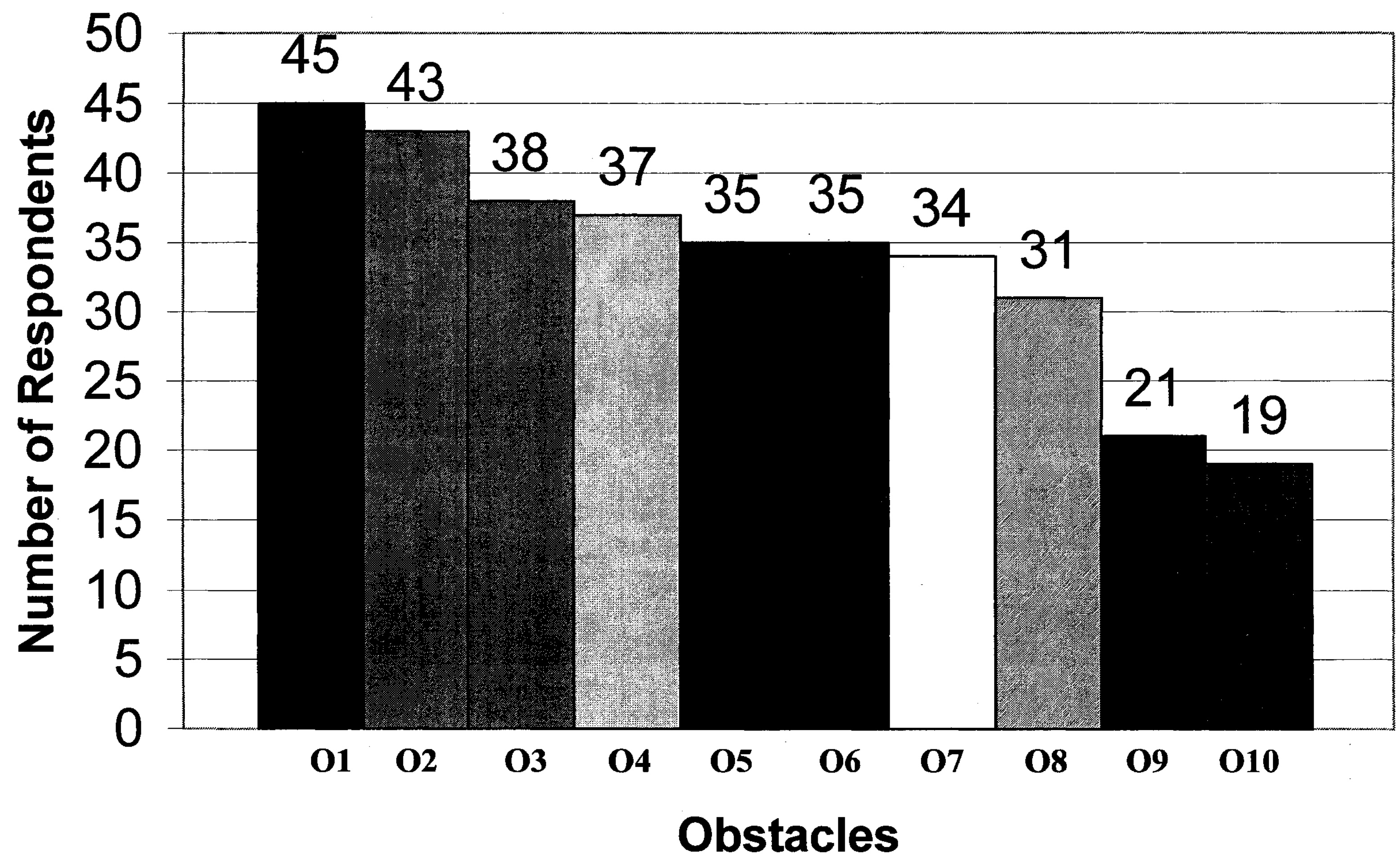


Figure 5.18: Number of Respondents for each obstacle.

Table 5.30. Obstacles to Sustainability.

Label	Response
O1	Payback period
O2	Difficulty attracting market recognition of efforts
O3	Lack of unbiased, adequate information
O4	Loss of Competitive Edge
O5	Limited financing schemes
O6	Reductionist Approach
O7	Lack of Negotiating Power
O8	Economic Repercussions
O9	Under Valuation of By-Products
O10	Mechanism Ambiguity

optimization of resources are not favored, even when it is demonstrated that there will be an economic payback, because the payback period is consider too long.

5.5.8.1.2 *Difficulty in Receiving Market Recognition (O2)*. Beneficio managers highlighted the problems related to receiving proper market recognition for environmental innovations. Market recognition of bird-friendly, certified-organic, and fair-trade operations has not been expanded to recognize environmental improvements in processing. Beneficios can do little to position their own brands in distinct markets. Certain regions receive a premium, simply due to the inherent quality of coffee that is natural produced. However, mills that have demonstrated significant progress in terms of eco-efficiency and social awareness have not been able to capitalize on their efforts. Without external assistance, processors have little access to the growing markets for economically sustainable, environmentally-friendly produced coffee.

5.5.8.1.3 Lack of Unbiased Information (O3). Many beneficio managers face a constant barrage of consultants, sales representatives and engineers all purporting to have the best technology to meet their needs. It is also common for them to face the conflict of interests of government officials who also have personal interests in the industry. The paucity of unbiased, adequate advice when facing decisions regarding changes in industrial processes, and what approaches are necessary (or appropriate) in a particular situation, can lead to inappropriate or ineffective choices. It also makes the industry that much more skeptical when viable alternatives are presented.

5.5.8.1.4 *Losing Competitive Edge (O4)*. There is concern that without concerted government effort, innovators may lose a competitive edge to those operations that chose only to operate with minimum standards. Any major changes in the processing system will be made more viable with establishment of clearly defined government legislation and policies. However, the process needs to be oriented towards complementing and integrating the interests of coffee processors (of all sizes), not just forced compliance.

5.5.8.1.5 *Limited Financing Schemes (O5)*. Present financing schemes only support short-term solutions that maximize pollution reduction with minimal expenditures. Environmental and efficiency optimization solutions have pay-back periods that are traditionally longer than other forms of capital expenditures. Financial institutions need to be educated to this fact, in order to make the financing of such innovations more economically feasible.

5.5.8.1.6 *Reductionist Approach (O6)*. It was suggested that one of the major obstacles facing environmental and economic improvements in the coffee industry has been the push of researchers and officials to apply a singular solution to the industry as a whole, or to approach the issues as piecemeal problems. The tight regulations of ICAFE limit innovation and solutions that could address problems by recognizing the site-specific nature and the requirement for a systems point of view when handling the issues. The inclusion of an integrated approach to sustainability will require a rethinking of how to handle environmental problems on the part of the regulating authorities and extension officers (ICAFE, 2003).

5.5.8.1.7 Lack of Negotiating Power (O7). Within the small and medium size processors, there is a need for mechanisms to assist in the cooperation and communication between coffee producers in order for their membership to be heard and supported. CICAFE, the branch of ICAFE responsible for scientific and technical development offers little in the way of support to beneficios seeking to access technology and funding that would aid in the integration of industrial ecology innovations. Nor does the present Asociación de Beneficiadores de Café de Costa Rica have the mandate to perform such duties and is largely limited to acting as a clearinghouse of information.

5.5.8.1.8 *Economic Repercussions (O8)*. It was suggested that roasters and brokers would use improvements in efficiency to drive coffee prices down further. There was a belief amongst beneficios that any improvement in economic efficiency of the industry would be used as a mechanism to drive coffee prices down further, instead of allowing the beneficios to reap the benefits.

5.5.8.1.9 *Under Valuation of Coffee By-products (O9)*. Despite substantial research efforts, a it was highlighted that a large percentage of stakeholders still have little consideration for the economic valuation of coffee by-products for use as raw materials for alternative products. This could possibly be due to the lack of communication between research bodies and industry as some local researchers complained that research in the region operates largely in a vacuum.

5.5.8.1.10 *Mechanism Ambiguity (O10)*. The sustainability movement within the industry has limited coordination with disjointed and often contradictory efforts that have left stakeholders wary and confused (APOT, 2003; and ABCR, 2003). It was noted that there was ambiguity over who should take the lead for the promotion of environmental technologies and strategies. It is believed that most coffee processors do not belong to industrial associations and instead look at processing as being integrated within agricultural production. However, the processing of coffee is largely ignored within the context of the agricultural sustainability that focuses on the growth and production of coffee fruit. As a result there is little promotion of environmental awareness and training opportunities for stakeholders within the processing sector of the industry.

5.5.8.2 Stakeholder Differences. The breakdown of the group of contributing stakeholders is shown in Table 5.31. Figure 5.19 displays the responses from privately owned versus cooperative beneficios regarding their perception of obstacles. As can be seen there are differing points of view when it comes to the influence of market factors such as economies of scale and sector driven initiatives. This does not come as a significant surprise as the frames of reference of the two types of facilities will be slightly different. Privately owned beneficios are cost driven, therefore more reluctant to take risks that are not in keeping with industry norms and as such risk losing a competitive edge over others that choose to follow only minimum standards. They look to the industry at large to lead the way. However, cooperatives are, by nature, concerned with the overall well-being of the cooperative membership. As such, they are more likely to make decisions based on the collective agreement of the whole cooperative, and therefore, may not be following market norms. This could result in a greater susceptibility to the obstacles raised by a lack of market share, for example, a lack of bargaining power (O7) or opportunities to affect change within the industry's present financing schemes (O6).

Table 5.31. Institutional vs Industrial Respondents.

Industrial Respondents	No.	Institutional Respondents	No
Beneficios	15	Researchers	7
Farmers and Farming Groups	18	International Organizations	5
Cooperatives	13	ICAFE	5
Exporters	3		
TNC	3		
Total	52		17

The attitudes towards other obstacles were similar between the two styles of operation. Both were concerned with the lack of market recognition for any efficiency or environmental efforts made by their operations and had concerns about the lengthy pay-back periods for most innovations (anything over 1 year was considered lengthy). Similarly, both groups expressed significant concerns over the perceived probability that

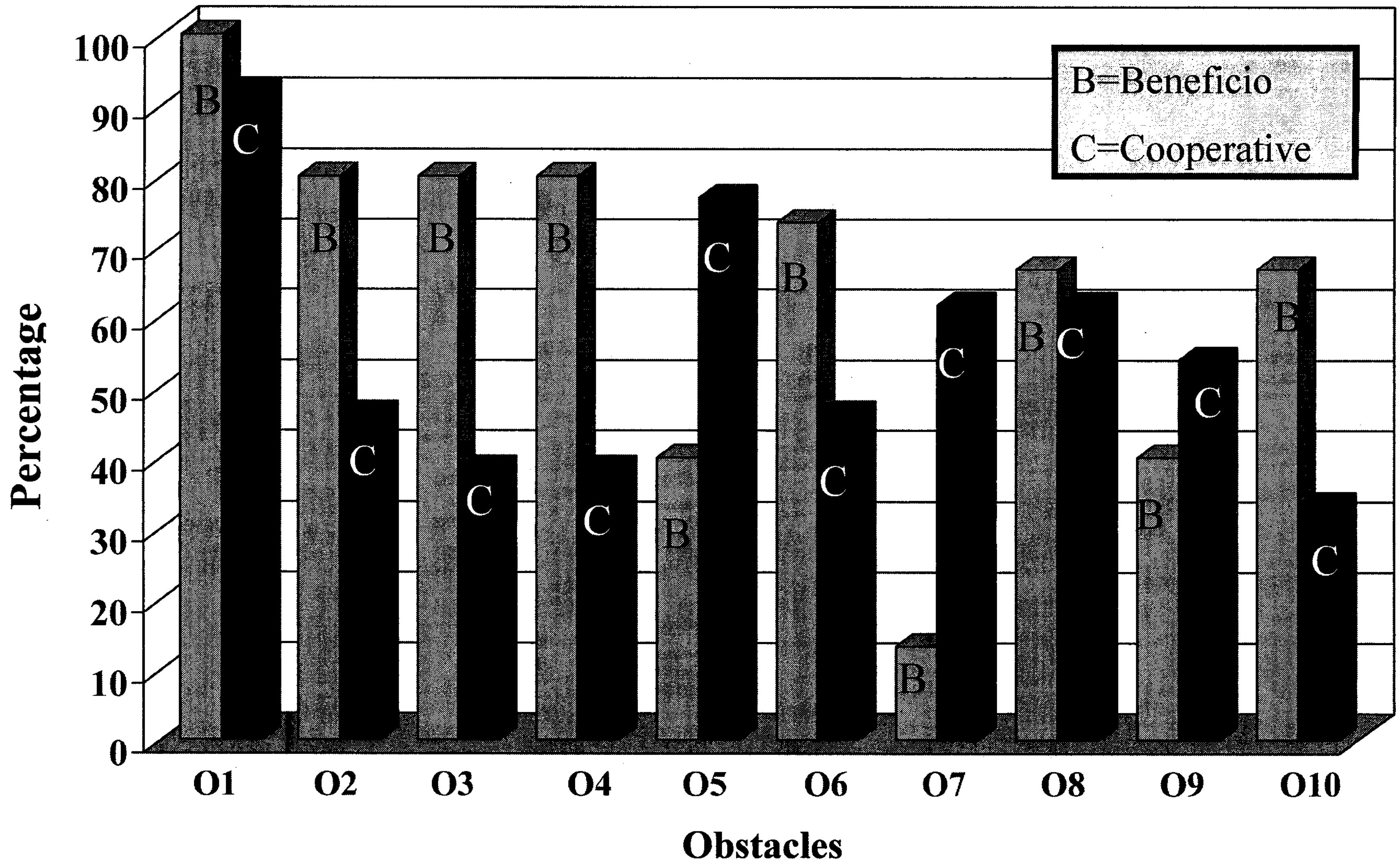


Figure 5.19. Responses of Private and Cooperative Beneficios.

tertiary stakeholders (roaster and exporters) would take advantage of any improved efficiency as an opportunity to drive coffee prices down even lower.

Figure 5.20 shows the comparison between stakeholders that would be considered industrial (or business focused) versus those involved in the industry from a more institutional standpoint, such as researchers, NGOs, and government officials. It demonstrates the significant gaps between the perceptions held by industrial stakeholders versus institutional groups. This can pose significant problems if the reliance to bring about change within the industry lay with NGOs, researchers and other aid/development organizations. For example, a large gap was noted between the research and policy development of institutional groups and the information that the industry sector has access to. Many beneficio and farming groups complain of limited access to good information. However, less than half of the researchers and government officials did not note this obstacle as being an issue. Another difference was the belief by the institutional group that a lack of appreciation for the possible economic value of process by-products, although beneficio managers noted that this was not an issue. The lack of reliable data from which to base appropriate decision, in addition to insufficient economic and institutional support mechanisms for this type of process integration was a concern. This outcome demonstrates a number of areas where the institutional perception of industry needs and actual industry needs have the appearance of being significantly different.

5.6 Conclusions

1. The present Costa Rican coffee industry is, as a whole, inherently unsustainable.
   (a) Soil erosion and excessive quantities of agrochemical inputs are the norm within the conventional coffee cultivation methods.
   (b) Soil erosion has been reduced in some conscientious farmers by integrating better soil management practices, but the level of agrochemical inputs across the industry do not appear to be significantly lower.

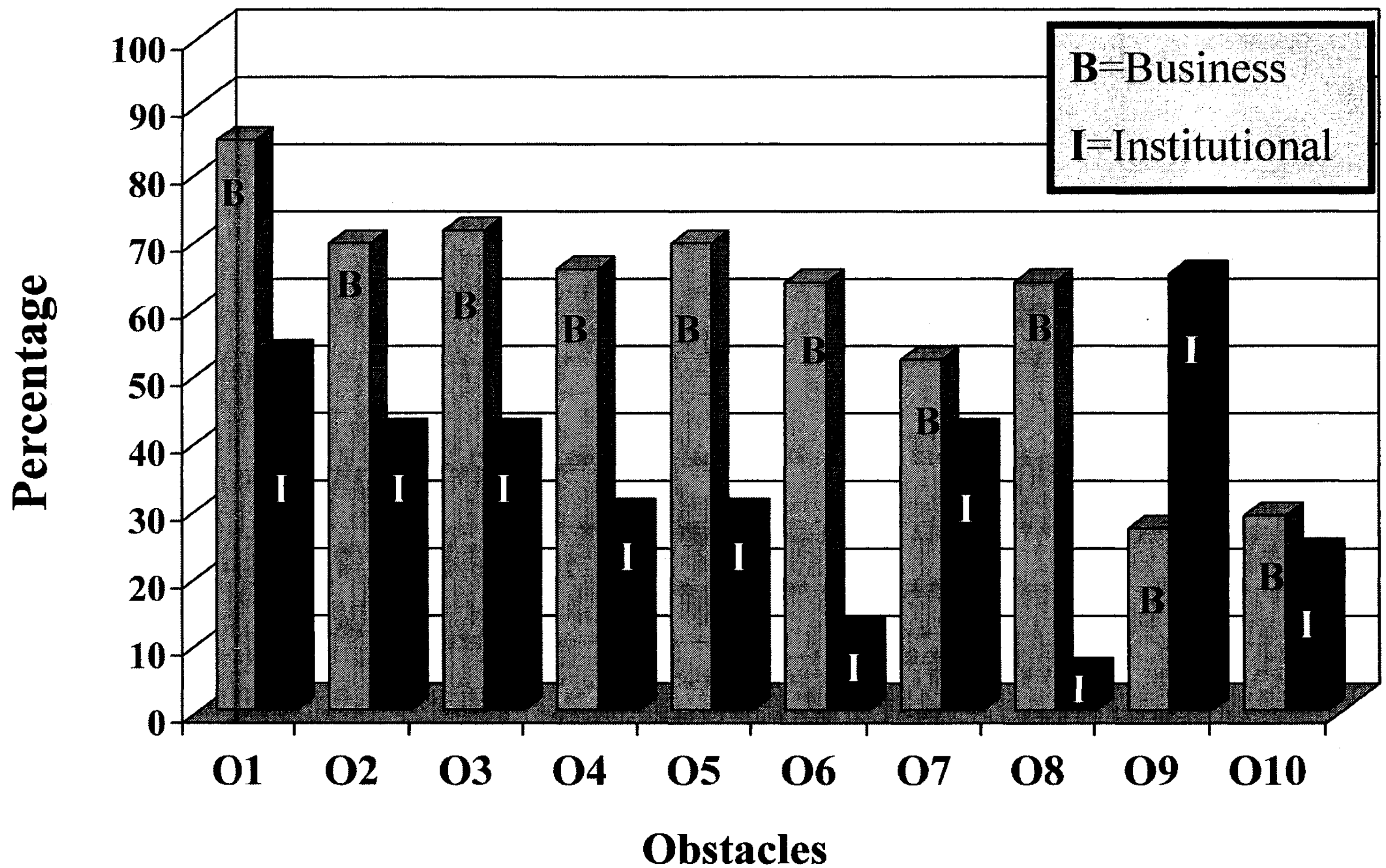


Figure 5.20. Responses of Industrial (Business) and Institutional Respondents.

2. Sustainable coffee programs promoted by ICAFE and Rain Forest Alliance (RFA) are considered insular and do not use a systems approach.

   (a) ICAFE is mainly focused on how to improve the soil fertility within coffee cultivation and ignore pesticide accumulation.

   (b) ICAFE has a singular focus of sustaining maximum yields.

   (c) ICAFE and RFA have minimal impact in assisting farmers become more sustainable from an overall standpoint through the cultivation of alternative products.

   (d) ICAFE and RFA do not attempt to integrate the considerable quantities of organic wastes produced by the beneficios into the system such that it can aid the farmer and increase revenue to the community.

3. Sustainability within the processing facilities is ignored.

4. There is minimal social consideration when developing sustainability strategies for industry and a considerable gap between research and development organization and industry stakeholders with regards to the application of sustainability strategies.

5. Examples of successful integration of cleaner production and/or industrial ecology have not been capitalized on to their maximum benefit in terms of changing the outlook of the industry towards their resources, both raw materials and by-products.

6. There has not been a thorough evaluation of the possibility of using an integrated systems approach to improve the sustainability of the industry.

7. Researchers have looked at specific strategies and technologies in isolation or within the strict confines of coffee production as it presently stands, with a limited view of innovation.

4.7 Recommendations

This study demonstrated the need to approach this issue in a different manner than has been done so in the past.

1. A new methodology to evaluate the sustainability of this system is required and must include:

   (a) all aspects sustainability,

   (b) be able incorporate various system designs and management innovations, and

   (c) be cognisant of the ideals of the participants of the system such that their concerns and wishes can be incorporated into the model.

2. A new framework for evaluating sustainability within this industrial system must be developed.

   (a) The methodology should use a multi-criteria evaluation approach to ensure the incorporation of social, economic, environmental and institutional factors are reflected appropriately,

   (b) The methodology should be designed to offer support to those stakeholders interested in promoting sustainability within their industrial system and the communities it affects.

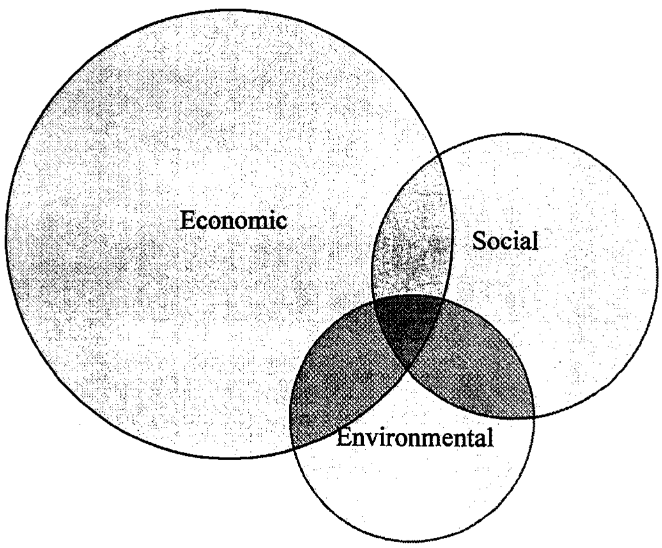
6 DEVELOPMENT OF A MULTI-CRITERIA EVALUATION MODEL

6.1 Background

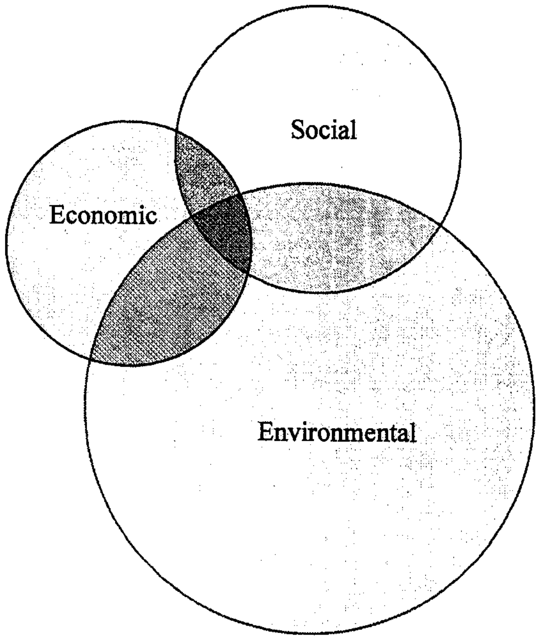
6.1.1 Sustainability Evaluation

Sustainable development has been expanded to include the ideas of fairness and interdependence, not only between generations but also between the countries and peoples of the globe. However, sustainable development is inherently complex, not only because of its holistic perspective, but also because of the conflicting perceptions that resonate among different stakeholder groups. Some complain that the anthropocentric tendency of sustainable development is to focus more on the issues of production and cost-benefit than the quality of life or the need to addressing poverty (McDonach and Yaneske, 2002). Those in the strong sustainability movements often complain that indicators are too anthropocentric with little attention paid to the needs of the ecosystem (Svirezhev and Svirejeva-Hopkins, 1998). Weak sustainability views mankind first and environment second, and the problem is that ecosystem services provided by an environment are not adequately considered. It implies that manufactured capital of equal value can take the place of natural capital, and hence the environment can be 'valued' in such terms, and notions of depreciation and resource substitution can be applied (Getzner, 1999). For example, clean water is valued at the cost it would take to filter non-potable water, but the other more intrinsic values of having an unpolluted water source are not considered. Figure 6.1 provides a simple demonstration of these varying perceptions.

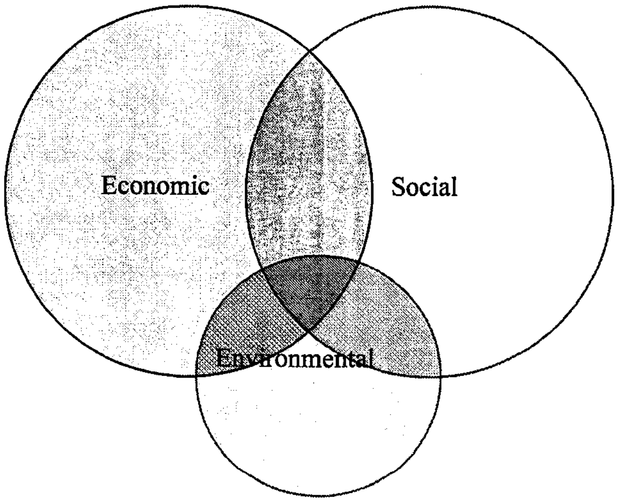
For the purpose of this thesis, sustainable development is defined as a process of evolution that ensures both human and ecosystem well-being is not declining over time and in which well-being is an equal aggregation of the economic, social and environmental dimensions (Figure 6.2). It must be noted that the concept of sustainable development provides society with a general direction, but it is impossible to define it in terms of final attainment levels (Wolter, 2001). Therefore, sustainable development is primarily an incremental process.



(a) Neo-Classical View



(b) Strong Sustainability



(c) Weak Sustainability

Figure 6.1. Various sustainability "points of view".

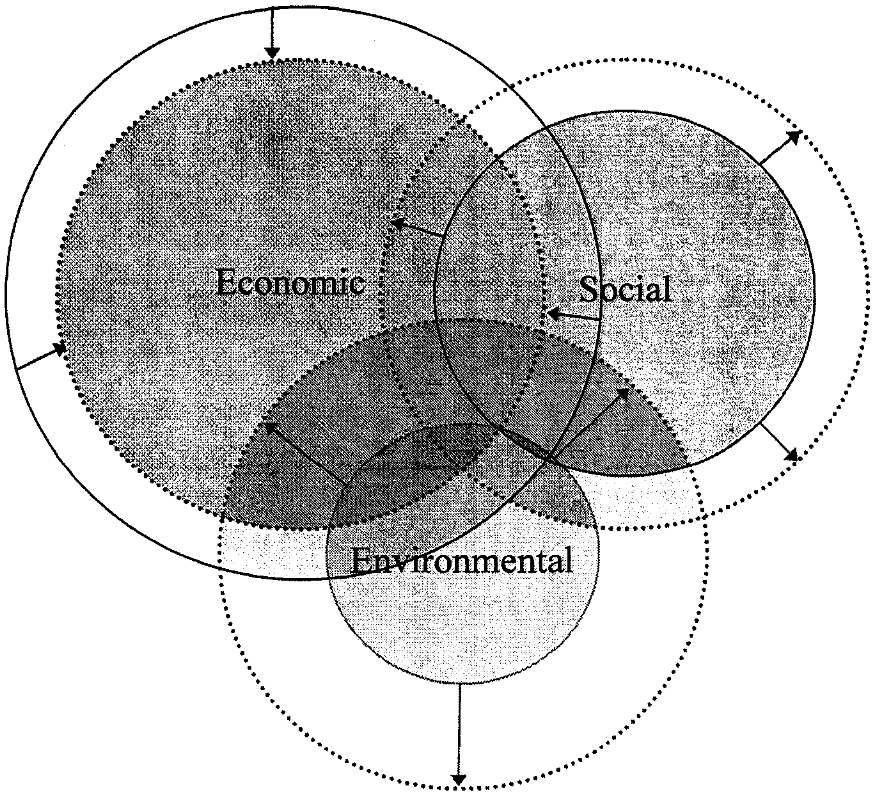


Figure 6.2. Sustainability as defined for this thesis.

Arising from the definition of sustainable development has been the concept of sustainability. Sustainability has become a central issue in various industrial sectors, including the agro-industrial sectors of developing countries. An increasing body of literature has been developed on defining sustainability and methods for the evaluation of sustainability, with special attention given to the environmental aspects (Piorr, 2003; and Brown et al., 2000). However, Falconer and Hodge (2001) reported on the lack of tools to support the design of policy schemes that would ensure the implementation of sustainability in an efficient way. Pacini et al. (2004) suggested two reasons for this: (a) the complexity of the ecological and production processes evoked by the concept of sustainability, and (b) the necessary multi-criteria approach for evaluation and decision-making.

6.1.2 Research Gaps

Despite the importance of sustainable development, much of the research in the area remains abstract and theoretical. There has been a difficulty in operationalizing the concept in terms of practical tools and measures; specifically metrics for the evaluation of sustainability within a specified system. As a result, two problems have arisen: (a) evaluation has largely been approached in a heuristic or trial and error approach (Phillis and Andriantiatsaholiniaina, 2001), and (b) where a more rigorous analysis was completed, the evaluation was typically focused on only one aspect of sustainability (Wackernagel et al., 2004).

One of the more analytically rigorous assessment methods used is cost-benefit analysis. Although, it has formed the foundation for many sustainability assessments, it has shortcomings. It typically focused only on costs and benefits specific to a pre-defined boundary, normally the corporation's economic statement (Elkington, 1997). Full cost accounting was promoted to account for some external costs, particularly those of a social or environmental nature. This method considers environmental expenditures and future liability costs (Elkington, 1997). Although the external costs encompass some social and environmental impacts, not all of these costs can be assessed in monetary terms. In situations with intangible aspects such as ecological functions or the non-economic aspects of quality of life, the method has limited application as all costs and benefits have to be translated into a common monetary unit. As such, incommensurable criteria, from an economic valuation point of view, cannot be included in the evaluation.

Mendoza and Prabhu (2003) tried to provide a much more inclusive measure of sustainability for forest resource management, using the integration of "fuzzy logic", but made no consideration for the social and cultural factors that would influence the sustainability of the system. The concept of forestry is inherently related to and affected by the livelihood and wellbeing of the group engaged in the forestry industry. To not include the factors revolving around the individuals involved leave models incomplete.

Suvedi et al. (2003), Marchettini et al. (2003), Yang et al. (2003) and Brown et al. (2000) suggested the use of "emergy" as a metric for evaluating system sustainability. Emergy is defined as is the equivalent solar energy that would be used directly and indirectly to create a product or make a service available. Its unit is the solar emjoule (Suvedi et al., 2003). However, the drawback of the emergy model is the lack of influence that quality of life plays in the model. Human labour input when aggregated with other inputs is lost due to issues of order of magnitude (energy from human input vs energy from fossil fuel input). As well, health issues, lost workdays and food stability cannot be disaggregated from the data. Emergy treats all agricultural products the same, whether the products are intended (or feasible) for local human consumption. For example, the emergy output from a coffee plantation could be comparable to emergy output from a banana or yucca crop when assessing sustainability. However coffee will not provide food security to a local population without appropriate pricing schemes, the evaluation of which is outside the analytic boundary of emergy analysis (Brown et al, 2000).

Wackernagel et al. (2004) outlined the applications of the "ecological footprint". While this revolutionary approach can help guide the sustainable use of resources by comparing activities in terms of the amount of land that is required to produce the resource consumed in the activity, it does not permit for the inclusion of societal and cultural factors that affect sustainability. As well, it is not particularly well-suited to act as a decision support tool for sustainable development within an operational setting. This is important because, while sustainable development is relevant to all aspects of society, it should be recognized that industry will play a critical role in bringing this ideal to fruition. Without sustainable industrial development, poverty, environmental degradation, inequitable distribution of resource and gender discrimination will continue largely unchecked in the developing nations of the world. Sustainable development implies a long-term view that considers the interests of future generations and, therefore, demonstrates that 'business as usual' is not sustainable and highlights a need for strategies within industry to facilitate these necessary transformations.

6.1.3 Indicator Frameworks.

Indicator frameworks are typically numerical measures that provide key information about a physical, economic or social system. These frameworks typically have three key objectives: (a) to raise awareness and understanding, (b) to inform decision making, and (c) to measure progress towards sustainability (Velva et al., 2001). They can be designed to evaluate sustainable development at the national, regional, local and facility level. However, the various definitions of sustainable development have resulted in the creation of a number of methodologies to measure it and a vast selection of indicators to provide the metrics for these evaluations.

6.1.3.1 Global Reporting Initiative (GRI). Labuschagne et al (2005) report that the GRI is largely a reporting based initiative that provides over 100 sustainability indicators to be used to evaluate social, economic and environmental sustainability (Figure 6.3). A thorough evaluation of this framework revealed that many of the indicators are difficult to evaluate and little guidance is given to industry on how to chose between indicators. According to Velva and Ellenbecker (2001), the drawback from an industrial perspective is the focus on existing systems boundaries, specifically those that define the legal corporate responsibility. In order to develop sustainability at a local or regional level, one most be able to easily integrate external stakeholders and inter-organizational cooperation (Kuhndt and von Geibler, 2002; and Velva and Ellenbecker, 2001). Similar to an environmental management system (EMS), this framework strives for incremental improvements within an established system and as a result does not provide a mechanism for innovation.

6.1.3.2 United Nations Commission on Sustainable Development (UNCSD) Framework. There is an improvement with the UNCSD framework over the GRI in that it builds upon the three pillars of sustainability through the addition of a forth sustainability criteria: institutional sustainability (Figure 6.4). This framework was developed primariliy for the purpose of evaluating the sustainability of governmental progress (UN, 2001). As such it is of limited use when trying to determine the sustainability of industrial system due to its macro-level focus. UN indicators have been developed based on a Pressure-

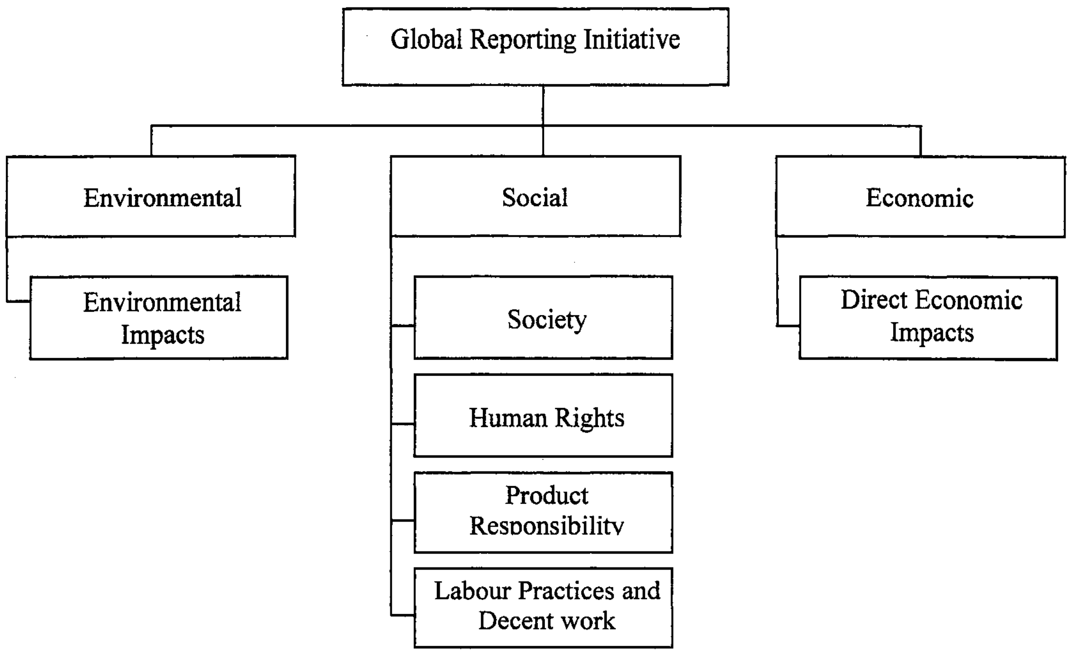


Figure 6.3. The Global Reporting Initiative (GRI, 2002).

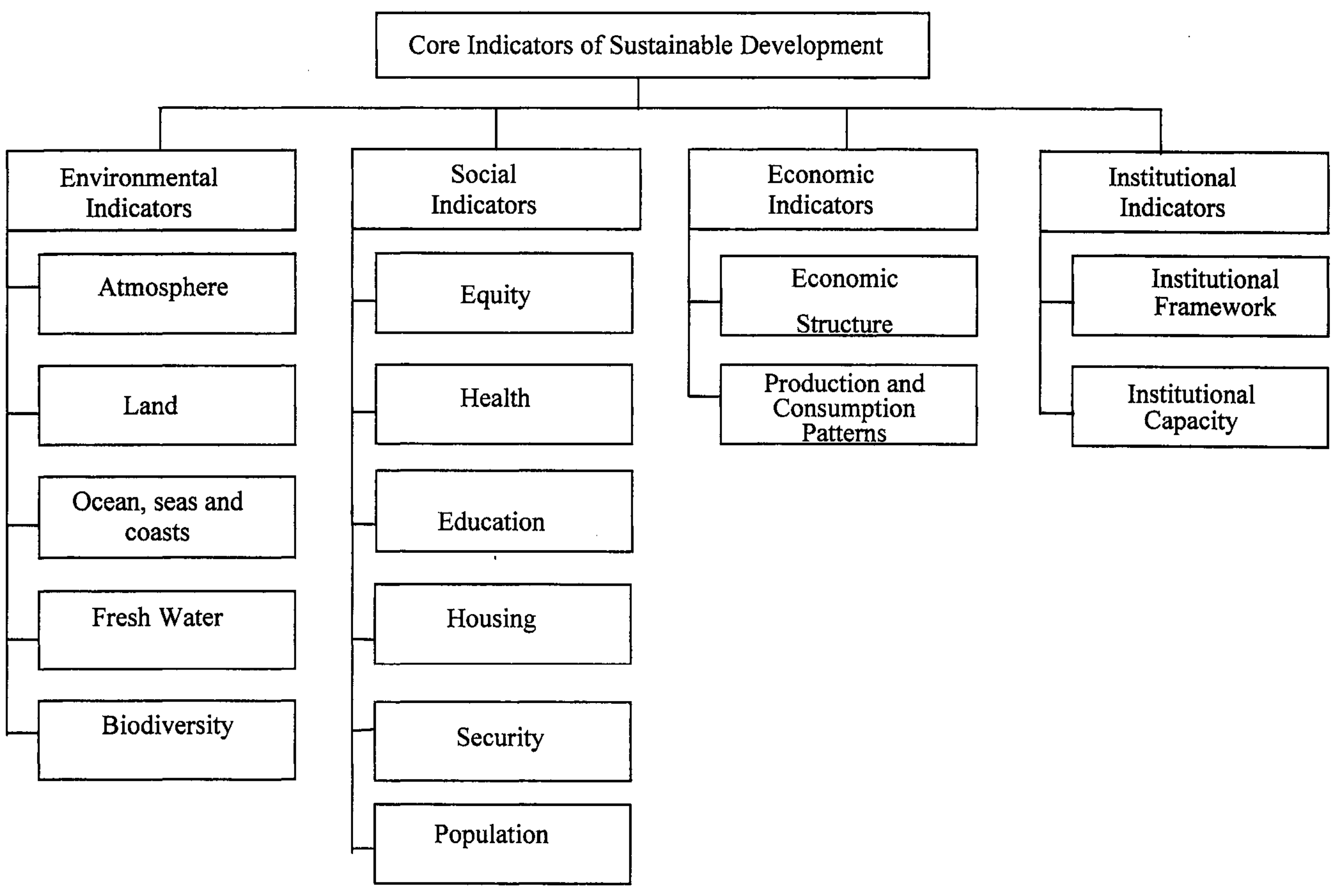


Figure 6.4. UN Commission on Sustainable Development framework (UN, 2001).

State-Response (PSR) methodology that does not consider the interdependences between the causal relationships found in a system and instead assumes a linear relationship between a single pressure and a single response (Sprangenberg et al., 2002).

6.1.3.3 Sustainability Metrics of IChemE. Unlike the previous two frameworks, the IChemE framework (Figure 6.5) was developed to measure the sustainability of process operations (IChemE, 2002). It is of particular usage to the integration of concepts such as industrial ecology and cleaner production into the sustainability framework. However, in its present form it favours measurement of sustainability within a particular system and depends on traditional technological viewpoints. It would have to be developed further to incorporate innovative by-product usage and cleaner production strategies. In addition, this framework is heavily focused on the environmental aspects and as such, the social and economic conditions of the developing world could get overlooked. Even where it considers the other elements, it does so in a one- dimensional manner similar to that of the UNCSD framework and does not consider system interdependencies (Sikdar, 2003). The framework does not permit for the inclusion of any institutional considerations that would be necessary for the implementation and success of any sustainability strategy (Labuschagne et al., 2005).

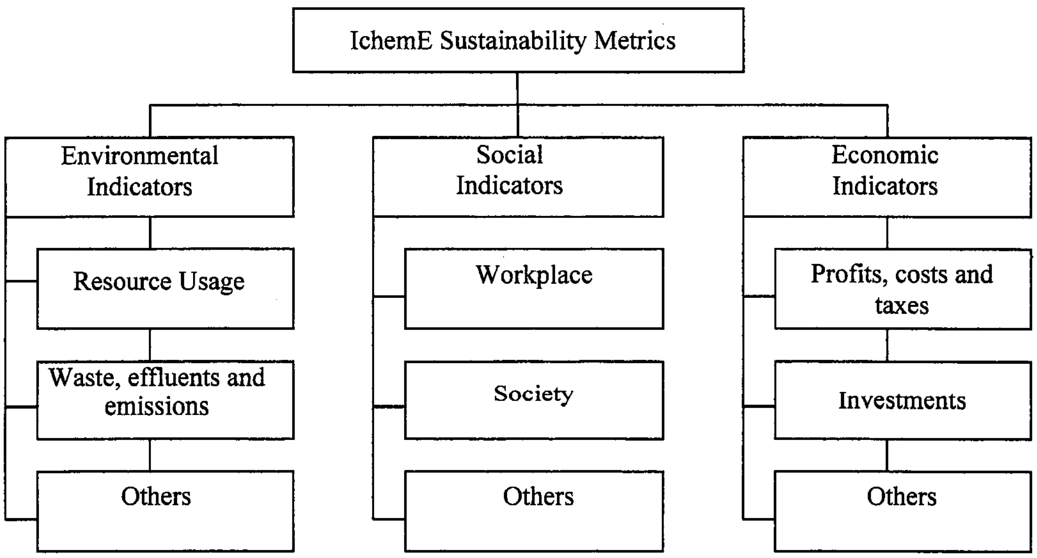


Figure 6.5. Institution of Chemical Engineers Sustainability metrics (IChemE, 2002).

6.1.3.4 Wuppertal Sustainability Indicators. The most significant improvement found within the Wuppertal framework (Figure 6.6) is the acknowledged linkages between the various indicators (Sprangenberg and Bonniot, 1998). According to Labuschagne et al. (2005), this framework should be applicable at the micro or business/industry level, but its economic and social indicators would need modification to reflect this focus. Kuhndt and von Geibler (2002) indicated that this framework permits the integration of technical innovation by focusing on the relationships between improved resource and energy-use efficiencies and improved economic and social conditions. It places the institutional sustainability indicators central to the framework, which is important in a developing world setting where intuitional conditions may hinder the technical and/or economic innovations that would otherwise be easily implemented (UN, 2001).

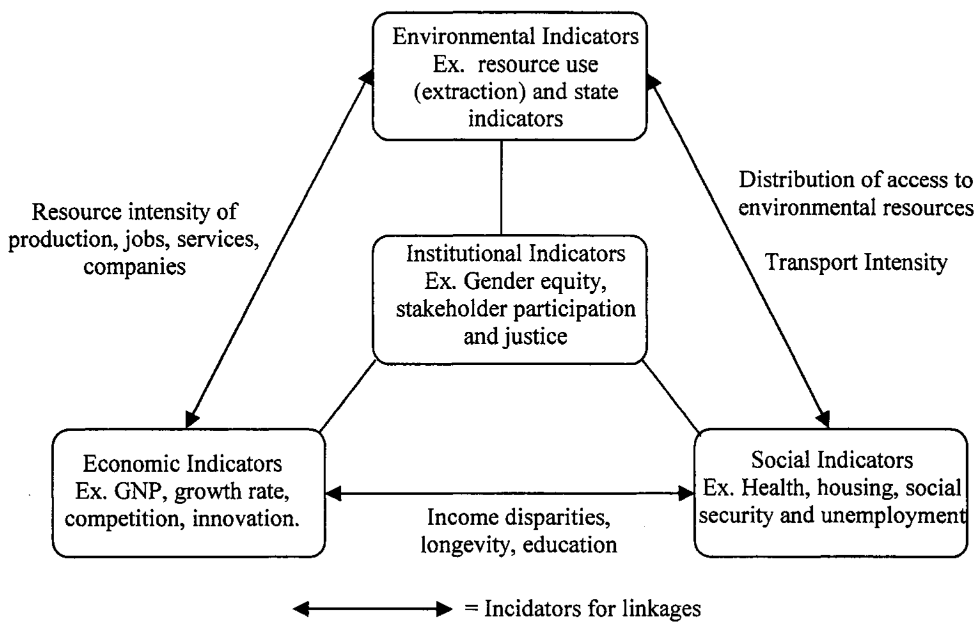


Figure 6.6. Wuppertal sustainability indicators (Spangenberg and Bonniot, 1998).

6.1.3.5 Labuschagne et al. Sustainable Industrial Performance. In developing this framework, Labuschagne et al. (2005) tried to take various elements of a number of the frameworks previously outlined and to develop a more applicable framework for evaluating the sustainability of industry (Figure 6.7). The resulting framework is not significantly different from the other frameworks reviewed. The economic, social and environmental indicators developed for this framework are a synopsis of the applicable indicators seen as having a business focus. However, these indicators are a good start for companies wishing to address sustainability. A major problem with this framework is the way in which the authors integrated the concept of institutional sustainability. They recognized the need to integrate institutional aspect with the other more traditional elements, but used it as a pre-requisite for sustainability not as another pillar of equal (or greater) importance. To make institutional sustainability a platform from which sustainable operations are launched is to doom the possibility of sustainable industrial development in developing countries before it is even attempted. Some institutional stability is required as a starting point, and then institutional sustainability can then be developed along with the other elements as stakeholders move forward determining their best course of action and developing the institutional infrastructure as the need is identified (Spangenberg et al., 2002). Institutional sustainability should go hand in hand with the other three elements. Also, the framework does not consider the advancement beyond traditional end-of-pipe treatments and generic discussions about energy and resource efficiency. There is little motivation for the user of the framework to go beyond the minimum compliance and incremental improvements.

6.1.3.6 Lowell Center for Sustainable Production (LCSP) Framework. Since 1999, the Center has focused its work on developing a framework for evaluating sustainability in production systems. However, to date it has only focused on environmental sustainability, with reported research being conducted into social and economic sustainability measures (Veleva et al., 2001). This framework suggests that the first level of sustainability evaluation begin with facility compliance and conformance (Figure 6.8). According to Spangenberg et al. (2002) and Ehrenfeld (2001), this kind of approach of promoting compliance as the first rule of sustainability can result in a focus on end-of-pipe solutions and lack of innovation.

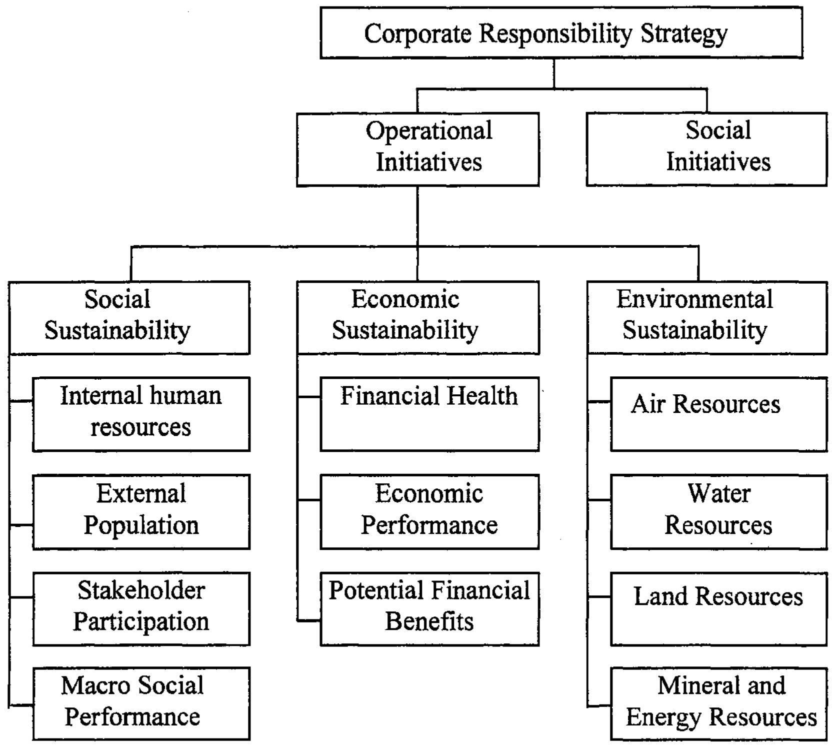


Figure 6.7. Labuschagne et al. (2005) framework.

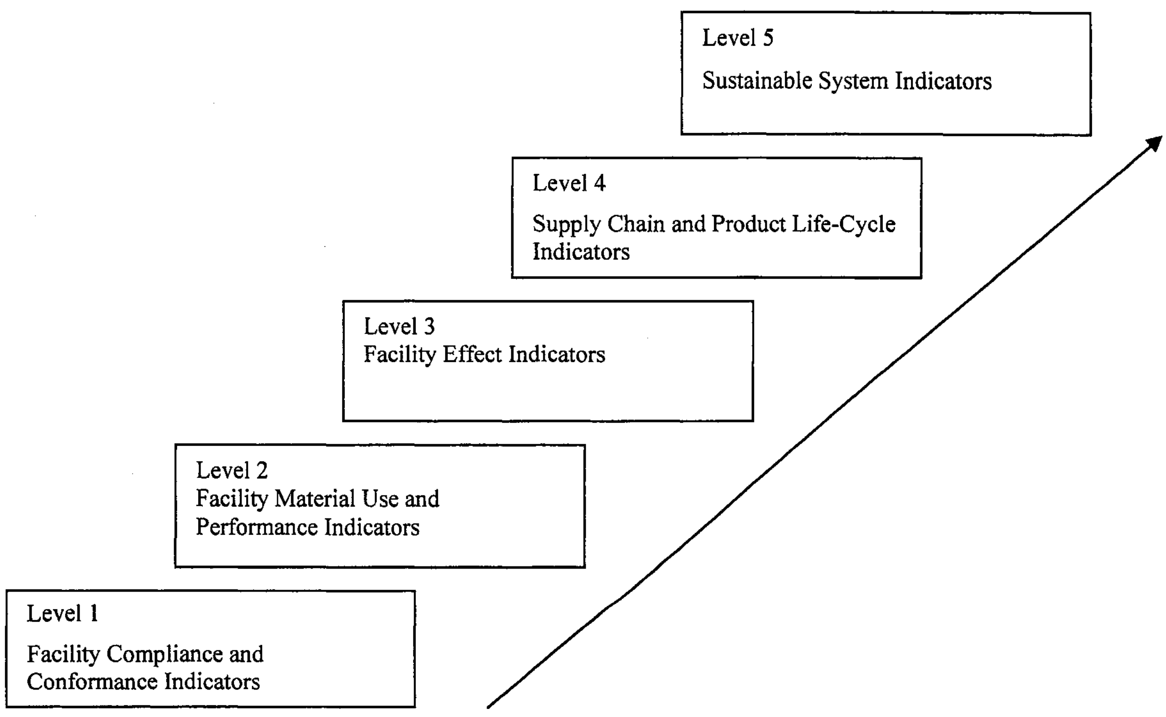


Figure 6.8. Lowell Center for Sustainable Production Framework (Velva et al., 2001).

6.1.4 Evaluation Recommendations.

Despite the overwhelming number of frameworks and indexes there is still a paucity of practically applicable systems, particularly at the industrial level (Adams and Ghaly, 2005). According to Klang et al. (2003), the formulation of the core set of sustainability indicators for industrial systems is a much-needed step in implementing a sustainability strategy for those systems. The OCED (1999) criticized regionally or situationally specific evaluation criteria as they prevent cross-sectoral (or regional) comparisons. However, as previously defined, sustainable development is about the maintenance of well-being over time and as such, should not be the focus of providing an opportunity for comparison exercises. Therefore, the use of a composite indicator that comprehensively integrates the multi-dimensionality of sustainable development is needed. The indicators need to include consideration of the needs of the various stakeholders affected. They also have to be aggregated and presented in a way that is meaningful within the context of the evaluation setting as opposed to using pre-fabricated indicators taken from generic indexes that may not be as relevant to the particular systems or regions being evaluated.

6.1.5 Multi-Criteria Evaluation

Multi-criteria analysis (MCA) is an analytical method that has been gaining some momentum as a sound and more complete alternative methodology for the evaluation of sustainability (Ducey and Larson, 1999; Phillis and Andriantiatsaholiniaina, 2001; Janssen, 2001; and Seppala et al., 2002). It covers a wide range of quite distinct approaches. Some kinds of MCA do not at present offer much help for practical decision taking, but others can be of considerable value. Sustainability evaluations based on MCA are referred to as multi-criteria evaluation (MCE). These approaches make the alternatives and their contributions to the different criteria explicit, and all require the exercise of judgment. However, they differ in the way they combine the data, integrate stakeholder views, develop weights, and score the performance of a particular indicator relative to a specific alternative (Janssen, 2001; and Ramanathan, 2002).

The main role of the techniques is to deal with the difficulties that human decision-makers have demonstrated in handling large amounts of complex information in a consistent way (Kijak and Moy, 2004). MCE techniques can be used to identify the single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities (Ramanathan, 2002). All MCE techniques share the following components: (a) a given set of alternatives, (b) a set of criteria for comparing the alternatives, and (c) a method for ranking the alternatives based on how well they satisfy the criteria.

In their report for the United Nations Environmental Programme (UNEP), Funtowicz et al. (2002) noted:

> *"As a tool for conflict management, multi criteria evaluation has demonstrated its usefulness in many environmental management problems. From an operational point of view, the major strength of multi criteria methods is their ability to address problems marked by various conflicting evaluations. Multi criteria evaluation techniques cannot solve all conflicts, but they can help to provide more insight into the nature of conflicts and into ways in which to arrive at compromises in case of divergent preferences, thereby increasing the transparency of the choice process. The main advantage of multi criteria models is that they make it possible to consider a large number of data, relations, and objectives that are generally present in specific real-world decision problems, so that the decision problem at hand can be studied in a multi-dimensional fashion."*

6.1.5.1 <u>Methods of Analysis</u>. There are three major multi-criteria evaluation methodologies: (a) basic methods, normally based on qualitative factors, with minimal mathematical rigor, (b) multi-attribute utility or value theory, and (c) analytical hierarchy programming. A fourth methodology, called Preference Function Modeling (PFM) has been introduced by Barzilai (2003). It has not yet received broad recognition, but this method (Linkov et al., 2004) demonstrates significant promise in the area of evaluating the multiple dimensions of sustainability.

6.1.5.1.1 *Basic methods.* Elementary methods are intended to reduce complex problems to a singular basis for selection of a preferred alternative. Competing decision criteria may be present, but criteria weightings are not required. While elementary approaches are simple and analysis can be completed without the help of computer software, these methods are best suited for problems with few alternatives and criteria – a condition that is rarely characteristic of sustainability challenges (Vreeker and Nijkamp, 2001). Typical methods that belong to this subset are: (a) maximin and maximax methods, (b) pros and con analysis, (c) conjuctive methods, (d) tree analysis, and (e) lexicographic analysis.

6.1.5.1.1.1 Maximin and Maximax Methods: The maximin method is based upon a strategy that seeks to maximize the worst performing criterion. This is achieved by ranking all alternatives by the strength of their weakest criterion. The alternative that has the highest score for its weakest criterion is preferred. The maximin method can be used only when all attributes are comparable so that they can be measured on a common scale. A related strategy called maximax ranks alternatives solely by their best performing criterion. Maximin and maximax are non compensatory, in that individual alternative performance is judged on the basis of a single criterion, but different criteria may be selected for different alternatives (Linkov et al., 2004).

6.1.5.1.1.2 *Pros and Cons Analysis:* A Pros and Cons Analysis is a qualitative comparison method in which experts identify the qualities and defects of each alternative. The lists of pros and cons are compared to one another for each alternative, and the alternative with the strongest pros and weakest cons is selected. Pros and Cons Analysis is suitable for simple decisions with few alternatives (2 to 4) and few discriminating criteria (1 to 5) of approximately equal value. Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis is a similar procedure that highlights the characteristics of the alternatives in regards to each of the SWOT conditions. SWOT analysis records these conditions and allows for a direct comparison between alternatives (Keeney and Raiffa, 1993).

6.1.5.1.1.3 Conjunctive Methods: The conjunctive methods are non-compensatory screening methods. They do not require criteria to be measured in comparable units. These methods require that criteria pass a predetermined threshold rather than seek the best possible performance from each one (Vreeker and Nijkamp, 2001). The underlying principle of the conjunctive method is that an alternative must meet a minimum cutoff level or performance threshold for all criteria. These simple screening rules can be used to select a subset of alternatives for analysis by other, more complex methods, or provide a basis for selection in and of themselves. In this approach, performance criteria are ordered in terms of importance. Alternatives that fail to meet the most important threshold level are discarded. The remaining alternatives are then tested against the second most important criteria, and so on. The alternative that meets all of the criteria or is the last to be discarded is the preferred choice (Linkov et al., 2004).

6.1.5.1.1.4 *Tree Analysis:* Decision trees are useful tools for making decisions where a lot of complex quantitative information needs to be taken into account. The principle behind decision tree analysis is to link specific outcomes to specific decision nodes. Decision trees provide a useful structure where alternative decisions and the consequences of those decisions can be presented and evaluated (Keeney and Raiffa, 1993). They can assist to form an accurate, objective picture of the risks and rewards that can result from a particular alternative, especially when outcomes may be dependent upon independent choices made by more than one decision maker. The limitation of decision tree analysis is that only fairly simple models can be shown at the required level of detail since every additional criterion expands the tree exponentially (Pomeral, 2001).

6.1.5.1.1.5 *Lexicographic Method:* A lexicographic analysis of any problem involves a sequential elimination process that is continued until either a unique solution is found or all the problems are solved. In the lexicographic evaluation, criteria are first ranked in terms of importance. The alternative with the best performance for the most important criterion is chosen. When there is a tie with respect to this criterion, the tied alternatives are then compared against the next most important criterion, and so on, until a unique alternative is found (Linkov, 2004).

6.1.5.1.2 *Multi-Attribute Utility Theory (MAUT)*. Multi-Attribute Utility (MAUT) is a technique that formally draw multiple perspectives into an evaluation process. The goal of this type of analysis is to directly include the decision makers' preferences into a single mathematical expression. Through the use of utility or value functions, diverse criteria (such as costs, risks, benefits, stakeholder values) are transformed (attempted) into one common dimensionless score (utility) or value (Keeney and Raiffa, 1993). It also relies on the assumptions that the decision-maker is rational (for example, more is preferred to less, preferences do no change), that the decision-maker has perfect knowledge, and has no personal biases that have not already been taken into account within the model. The goal of decision-makers in this process is to maximize the overall utility/value of each alternative (Kijak and Moy, 2004).

The first step in this type of analysis is the development of an attribute tree that summarizes the key objectives to be taken into account. The attribute tree splits top level objectives into finer attributes and criteria where the criteria at the lowest level should be measurable (Vreeker and Nijkamp, 2001). The second step is defining criteria and associated weights. The next question concerns the form of the multi-attribute utility function that adjusts the difference between possible criteria scores so that decision-maker's risk attitude is also encoded. The utility graphs could be created based on the data for each criterion. MAUT describes a system of assigning scores to individual indicators, which are then combined into overall aggregates on the basis of a perceived weighting of each score. It brings together different considerations in a structured way (Kijak and Moy, 2004). Differences in the importance of each criterion are attributed to the particular interests of the decision makers. The technique attempts to make these differences and similarities clear, by obtaining participants' subjective judgments about the importance of the various criteria and using these as a basis for comparison. Thus, by taking the decision-maker's preferences into consideration, criteria can be weighted by importance. MAUT ranks all the alternatives based on the decision-makers' preferences (Equation 6.1).

$$w_{ci} = \frac{r_{ci}}{\sum_{i=1}^{n} r_{ci}} \tag{6.1}$$

where

w_{ci} = the criterion's weight

r_{ci} = weight assigned the criteria (ordinal score)

n = number of different criteria

However, with this system the relative weight of one criterion to another is dependent on the number of criteria, as opposed to the relative importance of one criterion over another. This may not reflect the true preference of the participant and therefore give an incorrect result when aggregated (Barzilai, 2004).

5.1.5.1.3 *The Analytical Hierarchy Process*. The Analytical Hierarchy Process (AHP), developed by Thomas Saaty (Saaty, 1980), is a quantitative comparison method used to select the optimal alternative by comparing alternatives (e.g. cultivation methods) based on their relative performance on the criterion of interest (e.g. impact on ecological habitat, projected returns, etc.), after accounting for the decision-maker's relative weighting of these criteria. Similar to MAUT, AHP completely aggregates various facets of the decision problem into a single objective function (Janssen, 2001). The goal is to select the alternative that results in the greatest value of the objective function. Like MAUT, AHP is a compensatory optimization approach. However, AHP uses a different (more quantitative) comparison methodology that is based on pair-wise comparisons of decision criteria, rather than utility and weighting functions (Ramanathan, 2002). Evaluators express the intensity of a preference for one criterion versus another using a nine-point scale:

Example:

1 if the two elements have equal importance,

3 if one criterion is slightly/moderately more important over the other criterion,

5 if one criterion is significantly more important than the other criterion,

7 if one criterion is very strongly more important than the other criterion, and
9 if one criterion is absolutely more important than the other criterion.

All individual criteria must be paired against all others and the results compiled in matrix form. If criterion A is slightly more important compared to criterion B (i.e. a value of 3), then criterion B has a value of 1/3 compared to criterion A. Thus for each comparative score provided, the reciprocal score is awarded to the opposite relationship. The normalized weight is calculated for each criterion using the geometric mean of each row in the matrix (Equation 6.2) divided by the sum of the geometric means of all the criteria (Janssen, 2004).

$$X = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_i \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_i \\ \vdots & \vdots & & \vdots \\ w_i/w_1 & w_i/w_2 & \cdots & w_i/w_i \end{bmatrix} \tag{6.2}$$

However, similar to the multi-attribute theories, the weights are not correctly mapped to an empirical scale. For example, if criterion A is considered 5 times more important than B, and B is considered 5 times more important than C, then to provide a true weighting of the importance of A relative to C, the rating should be 25, which is not the case. Therefore, the aggregation will not provide a true representation of the system's weighting.

5.1.5.1.4 *Preference Function Modeling (PFM)*. Preference Function Modelling (PFM) is based on the premise of strong measurement, where the model generates the individual attribute units such that they all may be compared equally (Barzilai, 2003). In order to do so, three points of reference must be given such that the units are ratios of two comparisons not two points. These points are the scores of the two alternatives to be compared and a third baseline or reference point, which falls on the same scale (Tamara et al., 1999). Therefore, in the development of a model using this technique, participants' preferences need to have a point of reference when comparing criteria as opposed to subjective comparisons between non-commensurable indicators (Barzilai, 2004). Figure 6.9 provides a demonstration of how one would compare two alternatives within this mathematical framework. For example, a comparison can be made between two job alternatives: Manual's job and Rico's job. In order to properly rate one job against the other, a third reference point, defined as Eduard's job is used to provide the proper mathematical ratios.

<u>Statement:</u> Manuel's job is twice as good as Rico's

******

<u>Mathematical Representation</u>

Most MCE methodologies would treat this as:

$$\frac{Utility\_or\_Rating(Manuel's\_Job)}{Utility\_or\_Rating(Rico's\_Job)} = 2 \qquad (6.3)$$

However, this is a relative observation and is not related to a standardize unit of measurement. Therefore Barzilai's suggested methodology would be as follows:

$$\frac{(Utility\_or\_Rating(Manuel's\_Job) - Utility\_or\_Rating(Eduard's\_Job))}{(Utility\_or\_Rating(Rico's\_Job) - Utility\_or\_Rating(Eduard's\_Job))} = 2 \qquad (6.4)$$

where "Eduard's job" is defined as the mathematical reference to be used as a point of comparison on a number of pre-defined criteria. It is the difference between "Manuel's job" in reference to "Eduard's job" that is twice as much as the difference between "Rico's job" relative to "Eduard's job", thus providing an empirical scale that can be manipulated mathematically.

Figure 6.9. Description of proper empirical rating (adapted from Barzilai, 2004).

Barzilai (2003) reconstructed the foundations of decision theory based on a classification of model type by the mathematical operations that are applicable to the scales generated by the model. He demonstrated that addition and multiplication are not applicable to scales constructed by the standard models of measurement theory, including AHP and utility theory, when they are based on *weak scales* (i.e. measurement without units).

Barzilai (1998) indicates that much more care must be taken in the development of metrics for each individual criterion, as empirically specific scales are required if the criteria are to be compared in a mathematically correct fashion. The benefit is that is possible to mathematically compare quantitative and qualitative data in this way because each data set has been provided with an arbitrary, yet equivalent, unit of measure (between 0 and 100). This is similar to MAUT, but care is taken to ensure that the scales are relative to fixed points instead of each other, and as such, not unitless.

6.1.5.2 Applying MCE to Sustainability. Evaluation and/or decision-making in the sustainability arena can be very complex as it needs to involve weighing up a range of environmental, financial, social, stakeholder and other factors and determining the appropriate trade-offs (Rigby et al., 2001). MCE techniques have the advantage that they can assess a variety of options according to a variety of criteria that have different units (eg $, tonne, km, etc). This is a significant advantage over traditional decision support methods (for example cost-benefit analysis) where all criteria need to be converted to the same unit (ex. dollars).

Multiple criteria evaluation allows for the variety of scales to measure the criteria. Some criteria can be transformed into quantitative indicators, others use qualitative parameters presented in linguistic terms such as good, moderate, bad. Qualitative parameters can be used directly as ranking variables or can be transformed into cardinal ones and then used as quantitative variables (Munda et al. 1994).

When attempting to assess sustainability within an operational setting, it is important that any evaluation methodology allows for the system to be evaluated in terms of its relationship within local and regional boundaries as well as at the production and/or processing level (Bell and Morse, 2003; Marchettini et al., 2003; and Hall, 2000). MCE techniques are able to tackle environmental-economic-social integration, multiple use, inter-regional spatial links and trade-offs, families of conflicting criteria, qualitative information and uncertainty. As such, they present an appropriate tool to operationalize efficiency and sustainability criteria (Funtowicz et al., 2001) and. The concept of MCE is also compatible with the concept of ecological economics (Munda et al., 1994) as it leads away from neo-classical economics and cost/benefit analysis towards a multi-dimensional evaluation of aggregated realities. In the case of a multi-criteria problem, the concept of one optimal solution does not hold, as there is, in general, no action that dominates the others with respect to all criteria considered. Consequently, solving a multi-criteria problem does not necessarily mean searching for one single option, but instead, offer guidance towards bringing more transparency into the problem and thus aiding in a solution. The resulting evaluation outcome is a demonstration of compromise.

6.2 Model Approach

Barzilai (1998) stated that measurement without units is weak measurement and allows only for ordinal comparison and as such the mathematical processes preformed in AHP and MAUT can lead to invalid conclusions. This implies that neither can serve as a foundation for correct sustainability evaluation because they do not allow for the legitimate aggregation of the various indicators used to measure the system in question (Barzilai, 2004).

In addition to the mathematical problems highlighted, there is another barrier to the application of these methods as related to sustainability evaluation. In these methods the weights being assigned to the various criteria are completely dependent on participant's preferences (Ramanathan, 2002; Seppala et al., 2002). This is considered a valid methodology when trying to arrive at a decision that specifically meets with a decision maker's predetermined desires. However, in the evaluation of sustainability this kind of direct influence on the outcome is flawed. The whole point of using a multi-criteria evaluation to promote sustainable development is the integration of factors not normally considered in decision-making such as effect on biodiversity, soil erosion or social equality. In AHP or MAUT, the outcome is dependant on the attitudes demonstrated by the participants, as opposed to an evaluation based on empirical requirements for sustainability. For example, in the case of implementing a waste treatment system, choices may range from doing nothing to an elaborate treatment technology. By using this kind of system, it could be easily demonstrated that due to the participants' singular focus on short-term economic return (for example), that only criteria relating to immediate economic considerations receive significant weights, with the influence of other factors becoming negligible.

If a true evaluation of sustainability options is to be completed, subjective influences of participants should not be integrated into the evaluation methodology in such a crucial way. Instead, participants desires and concerns should be integrated into the evaluation process by incorporating specific criteria in the evaluation that reflect these desires, along with the criteria necessary to empirically represent the system being evaluated. The weighting of sub-criteria (criteria within each of the major sustainability objectives –e.g. economic, environment, social, and institutional) can be assisted by the input of participants as this will not negate the overall veracity of the "multi-criteria" aspect of the evaluation.

In this study, a modified methodology will be used. It will build on the hierarchal nature of AHP but will avoid the pair-wise comparisons of decision maker preferences and instead, integrate a more empirical structure into the development of the weights and indicator values as outlined in preference function modeling (PFM). It will provide a composite indicator of sustainability within a defined system that is based on scalable data and avoids the problems previously highlighted. For the remainder of this thesis, this methodology will be referred to as a Composite Sustainability Indicator (CSI) model. Figure 6.10 outlines the steps followed within the CSI methodology. Although, these are similar to those found for other MCE methodologies, it is in the details of each step that the differences lie.

6.2.1 Step One - Problem Definition (and Objectives).

A core element of any sustainability analysis is the identification and integration of the stakeholders concerns and desires. While these concerns should not override the fundamental requirements of a sustainable system (i.e. social considerations cannot be ignored, or ecological functions knowingly be degraded) the implementation of any sustainability strategy will need the support of the stakeholders. The evaluation can provide a platform for education and the dissemination of information in situations where

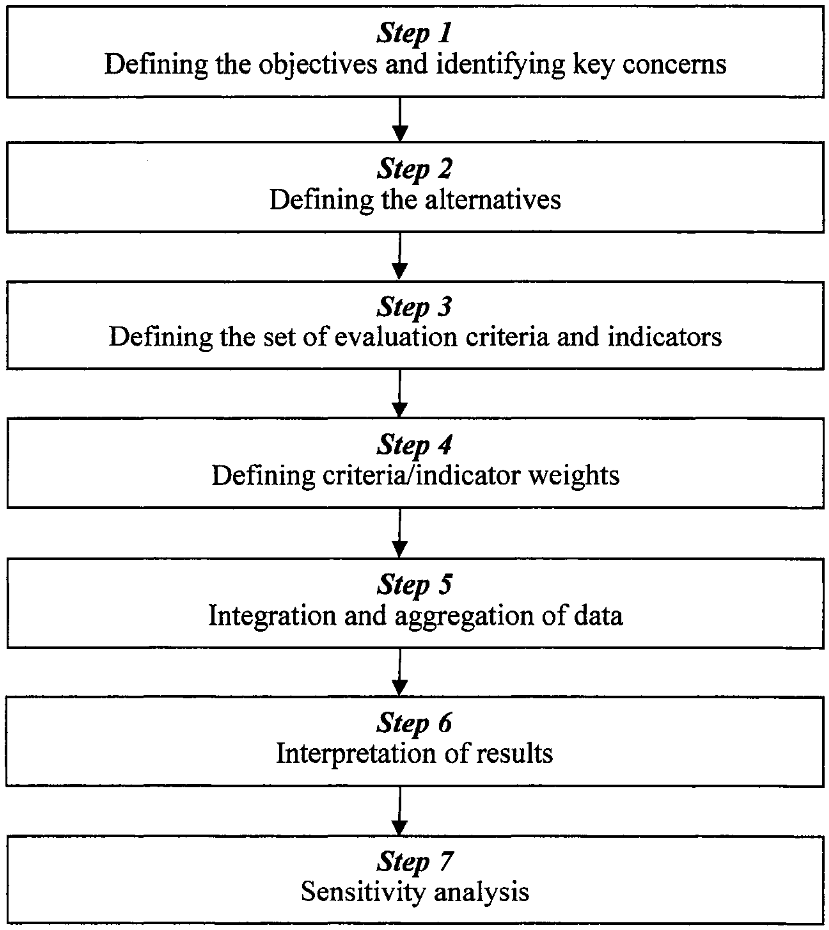


Figure 6.10. Steps in Development of Evaluation Model.

stakeholders are not truly familiar with the concepts of sustainable development and the necessary integration of the four major pillars: economic, environmental, social and institutional considerations.

6.2.2 Step Two - Identifying Alternatives.

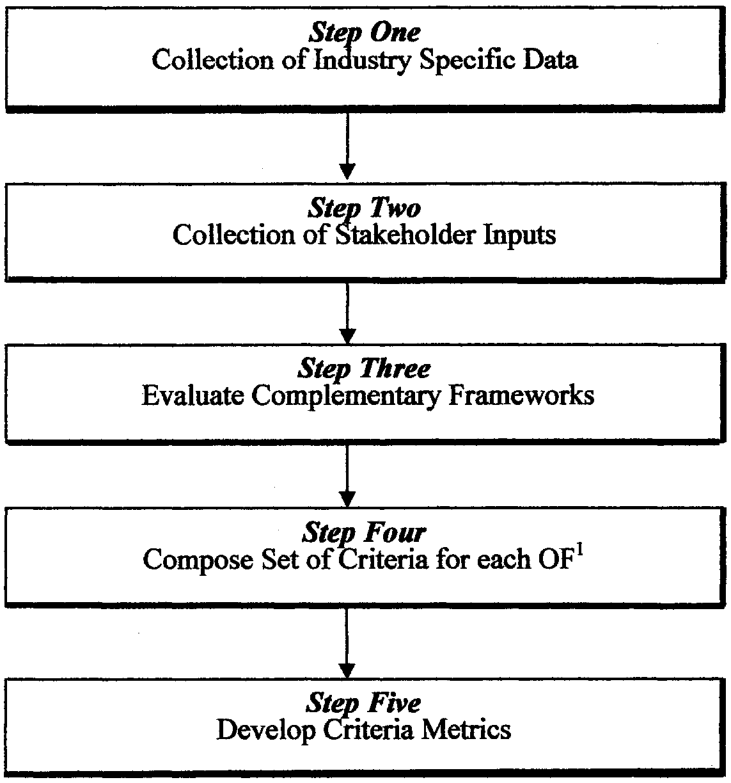
The aim of the framework is to identify technical, practical and management alternatives that are more sustainable than a present system condition. As such, the alternatives available to the stakeholder(s) need to be identified and adequately defined such that the evaluation criteria could be developed. In the case of complex systems that had a cascade of alternatives occurring at a variety of different decision points, it is necessary to map out the natural progression of each evaluation stage and the influence that each alternative has up and down the system chain. An example of this within the coffee industry is the various alternatives available for the heating/drying phase, as the desirability of some of the options would depend on a previous nodes where the alternative uses for coffee pulp or pruning biomass were evaluated (this will be further discussed in section 6.3).

6.2.3 Step Three - Developing Evaluation Criteria and Indicator Metrics

Defining criteria that can be assessed using indicators with measurable scales is a prerequisite towards the construction of an empirically-sound composite sustainability indicator. In addition, the set of indicators to be used should be based on a common understanding of the basic issues to be addressed. According to Klang et al. (2003), the formulation of the core set of sustainability indicators for industrial systems is a much-needed step in implementing a sustainability strategy for those systems. However, Nijkamp and Vreeker (2000) cautioned that the indicators should be developed with the specifics of the system in mind as opposed to designing static indicators to be rigidly applied in every evaluation situation. Therefore, this study was preceded by a broad analysis of the information needs, the goals of the stakeholders and the intended support to be provided by the framework. Given the complex nature of agro-industrial systems and the many stakeholders involved, such an analysis required a suitable methodology. With adaptation of some recommendations made by Wolter (2001) and Bell and Morse (2003), a five-step methodology (Figure 6.11) was used to develop the list of criteria for the evaluation of sustainability within industrial systems. Much of the specific information integrated into this process has already been discussed in Chapter 5.

The first step aimed at collecting industry specific data that helped identify the main issues that need to be addressed. An in-depth review of practices within the industry was conducted.

The second step entailed a careful process of communication and interaction with the various stakeholders in order to find out what items needed to be considered within the



1-OF stands for objective function – the mathematical representation of the process of maximizing benefit within all sustainability aspects (e.g. Economic, social, etc…) being considered

Figure 6.11. Criteria Development Methodology.

the framework. Understanding the stakeholders' goals and concerns is paramount when developing indicators that will actually be useful and understandable to the end-users. It was also important to determine the relationship between the various stakeholders and what positions of power they may hold within the system (ABCR, 2003; Wolters and Danse, 2003; and Schram, 2003).

The third step involved an analysis of existing indicators and frameworks that could offer relevant information concerning various aspects of sustainability and highlight problem areas within these frameworks. Such information may comprise standards such as ISO 14001, best practices and industry codes of conduct (Wolters, 2001) and other indices such as those developed by research institutions and government organizations (Velva et al., 2001; and UN, 2001). Also available instruments such as life cycle analysis (LCA) and social impact assessment (SIA) models were helpful in creating awareness of the things that matter and help compose a list of potentially relevant aspects of sustainability.

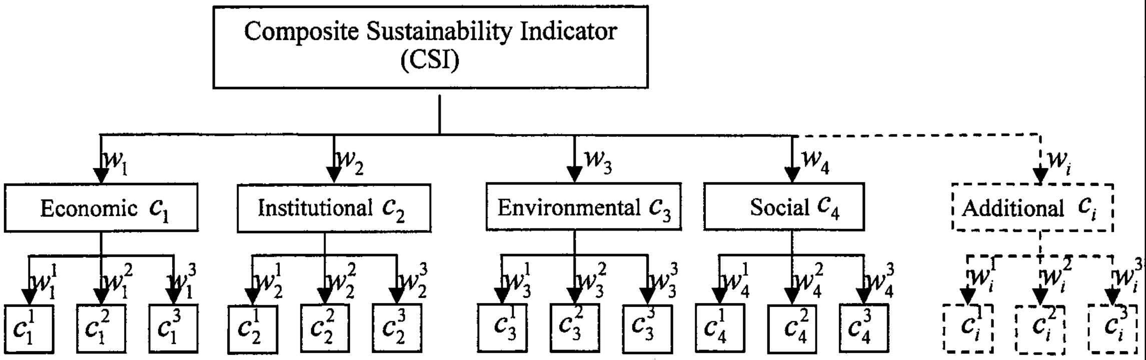
In the fourth step, an applicable set of sustainable indicators was composed (Appendix D). According to Bell and Morse (2003), the following factors should be considered when developing sustainability indicators:

1. Availability of information and/or feasibility of collection. Data needs to be accessible in order to be useful, so indicators that cannot be evaluated (directly or indirectly) are of little use. However, one must be careful not to fall into the trap of only using the most readily available data, as it is usually focused heavily on the economic considerations.
2. Considering the various goals of the stakeholders at all times as stakeholder input is vital. Indicators are as good as the effort put in monitoring and improving them.
3. The need for an understanding of the best approach to present the various indicators to the different stakeholders.

In the fifth step, the scaling metrics were developed such that they could permit the integration of quantitative and qualitative data. Each criteria will be measured either directly (has a defined unit), or indirectly, through the provision of a linguistically defined scale. Either measurement can then be converted to a scale of 0 to 100 sustainability indicator units (SIU), where the units can be used to represent an empirical state for any criteria. As such the final score for any evaluation will be between 0 and 100. Overall, the framework employed a hierarchal structure for the development of the composite sustainability indicator (CSI), which is outlined in Figure 6.7.

5.2.4 Step Four - Development of Weighted Evaluation.

As noted in Figure 6.12, each criterion and sub-criterion can be assigned a weight that would integrate its relative importance into the overall sustainability evaluation. Insight from research and (preferably) field data should be overlaid with the requirements for system sustainability. The development of weight followed the methodology outlined by



where :

c_i = weighted value of objective function i

w_i = weight assigned to objective i

c_i^n = measured value of sub-criterion n for c_i

w_i^n = relative weight assigned to sub-criterion n

and

$$\text{CSI} = \sum c_i w_i \quad \text{and } 100 > \text{CSI} > 0 \tag{6.5}$$

$$c_i = \sum c_i^n w_i^n \quad \text{and } 100 > c_i > 0 \tag{6.6}$$

where:

$$\sum_1^i w_i = 1 \tag{6.7}$$

$$\sum_1^n w_i^n = 1 \tag{6.8}$$

i = number of objective functions included in the CSI, and

n = number of sub-criteria assigned to each

Figure 6.12. Hierarchal structure of model.

Barzilai (2004) where a reference point (normally the criterion of least importance) was used to determine the relative weights of each criterion in relation to each other. Unlike AHP or MAUT, only sub-sets of criteria will be compared to each other, i.e. economic sub-criteria were not weighted against social sub-criteria.

6.2.5 Steps Five to Seven

These remaining steps involved the input of data and model analysis. The analysis itself does not result in final recommendations as it was necessary to interpret the results and look the outcomes for the various objective functions used to make up the main composite indicator function. A sensitivity analysis was necessary to increase the understanding of the results, their impacts and their potential support. The most common way to do this analysis was by means of variations of weights and preferences. This way it could be seen which criteria were crucial, and which could be neglected because of their minor influence on the result.

6.3 Model Framework

For all practical purposes, one cannot guarantee the sustainability of any system that is evaluated. However, a comparative assertion that the state of a system is moving towards sustainability more so than another, can be made. That was the aim of this model, which was developed based on data obtained from the research and field investigation of the coffee industry.

Due to the complexity of the industry, the model development is addressed according to the two major processes incorporated into coffee industry: (a) cultivation, and (b) processing. The reasoning for this is the necessity to incorporate additional sustainability aspect into the processing evaluation that may not need to be considered (or applicable in some cases) within a cultivation evaluation. Upon completion of the individual component development, the two were integrated.

6.3.1 Cultivation

This section deals with the sustainability evaluation of coffee cultivation practices.

6.3.1.1 Identification of Alternatives. After investigating the cultivation practices of 55 farmers in various regions of Costa Rica, three broad alternatives were identified. These systems are described as: (a) monoculture, (b) traditional polyculture, and (c) organic.

Monoculture coffee production follows a system of intensive chemical, is reliant on chemical fertilizers and pesticides, and has become the 'status quo' approach in recent years. It is, therefore, considered the natural benchmark against which to compare other alternatives. Traditional polyculture coffee production has historically used a system of intercropping coffee with shade trees and other cash crops, often employing leguminous (nitrogen-fixing) species to reduce the reliance of producers on supplemental nitrogen fertilizers. Despite the history and tradition of this method of coffee production, it offers new choices and combinations of secondary crops to suit changing market and production conditions. Organic production also follows the traditional approach of intercropping coffee, shade and cash crop species, yet disallows the use of chemical fertilizers and pesticides. Recommended supplemental nitrogen may be added from sources such as composted manure or plant wastes. Tables 6.1 - 6.3 highlight the major differences found in the systems evaluated. Figure 6.13 provides and overview of cultivation practices, in relation to time of year and intensity of rain.

6.3.1.2 Determining Criteria. Due to the relative simplicity (as compared to the available alternatives within processing) it was decided that the composite sustainability indicator could be evaluated through the optimizing of the standard four objective functions: (a) economic sustainability, (b) environmental sustainability, (c) social sustainability and (d) institutional sustainability as shown in Equations 6.9 - 6.13).

$$CSI_c = w_1F_{SI} + w_2E_{SI} + w_3S_{SI} + w_4I_{SI} \tag{6.9}$$

where:

CSI_c = Composite Sustainability Indicator

$W_{1\text{-}4}$ = weighting factor

F_{SI} = economic function

E_{SI} = environmetnal function

S_{SI} = social function

I_{SI} = institutional function

F_{SI} , E_{SI} , S_{SI} and I_{SI} are calculated as follows :

Table 6.1 Cultivation Practices (Production).

Parameter	Monoculture	Polyculture	
		With Agrochemicals	Organic
Plants/Hectare	3000-7000	1500-3000	1000-2000
Kg/Hct/Yr	1400-1800	1000-1500	800-1300
Lifetime of Plants	12-15 years	24-30 years	24-30 years
Flavor	More Bitter	Less Bitter	Less Bitter
Yield	Higher	45-70%	Lower (~25-40%)
Side Crops	Less/None	More	More

Table 6.2. Biological Parameters.

Parameter	Monoculture	Polyculture	
		With agrochemicals	Organic
No. of Bird Species	20-50	90-125	120-150
Proportion biodiversity (compared to natural)	10%	55-80%	75-90%
Mid-size Mammals	Almost none	20+ species	20+ species
Other (ants, beetles, epiphytes, amphibians, & other species)	Less species	More species than mono-cultivation but less than organic	More species

Table 6.3. Qualitative Inputs and Outputs .

Parameter	Monoculture	Polyculture	
		With agrochemicals	Organic
Yield	+	-	-
Weeding	+	-	--
Chemical Fertilizers	+	-	--
Pesticides	+	-	--
Soil Erosion	+	-	--
Soil Degradation	+	-	--
Toxic Leachate	+	-	--

+ = more
- = less
-- = significantly less

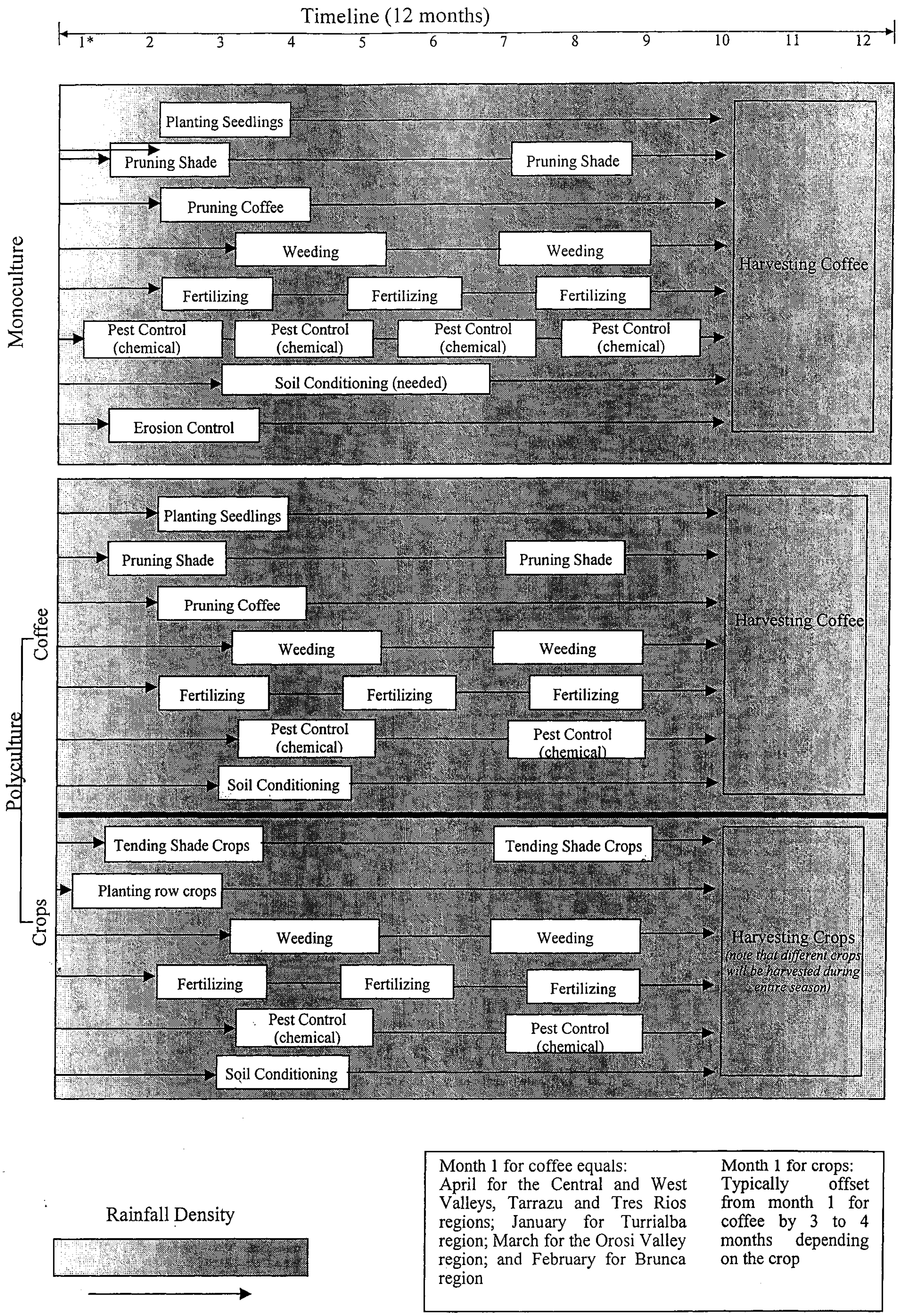


Figure 6.13. Activity Timeline for Coffee Cultivation.

$$F_{SI} = \Sigma w_{fi} c_{fi} \quad (6.10)$$

$$E_{SI} = \Sigma w_{ei} c_{ei} \quad (6.11)$$

$$S_{SI} = \Sigma w_{si} c_{si} \quad (6.12)$$

$$I_{SI} = \Sigma w_{ii} c_{ii} \quad (6.13)$$

where:

w_{fi-ii} = weighting factor for sub-criteria

c_{fi-ii} = sub-criteria values

For the purpose of this evaluation, vast arrays of indicators were initially proposed. However, any model must limit (to some extent) the number of input variable to a manageable level. Based on literature review and stakeholder responses during the field study, it was determined that those listed below are the most appropriate.

5.3.1.2.1 *Economic Indicators*. The economic objective function will optimize the economic costs, returns and economic risks. The total cost and economic return for each cultivation practice was determined and the economic risk was related to the dependence of the returns on market volatility. Table 6.4 gives a summary of the inputs and products that can be considered in the economic calculations. In any economic calculation, it is necessary to incorporate the effects of interest rates and inflation on the analysis. In order to make comparisons between dollar amounts that occur in different time periods, the currency devaluation must be taken into account in order to maintain the same buying power. In the case of a Costa Rican study, currency devaluation must also be incorporated to account for the changing value of the local currency as compared to the world market, where coffee prices are set. For example, using the consumer price index and currency devaluation rates outlined in chapter 5, it was determined that even with a fixed price for coffee, indexed against the inflation in the US dollar, farmers have been losing an average of 3.9% of their buying power every year since 1993.

The present value (PV) of future earnings and/or financing is calculated according to the following equation:

Table 6.4. Economic costs to be considered.

Description of Parameter	Units (per hectare)
General Fiscal Items	
Interest rate	%
Inflation rate	%
Currency devaluation	%
Variable Costs	
Agrochemical Inputs	
Pesticides – Material Purchase	$ ($/kg * kg/ha)
Pesticides – Application Costs	$ ($/hr * hr/ha)
Herbicides – Material Purchase	$ ($/kg * kg/ha)
Herbicides – Application Costs	$ ($/hr * hr/ha)
Fertilizers – Material Purchase	$ ($/kg * kg/ha)
Fertilizers – Application Costs	$ ($/hr * hr/ha)
Material Costs	
Soil Amendments (non-chemical)	$ ($/kg or vol * kg or vol//ha)
Organic Fertilizers	$ ($/kg or vol * kg or vol//ha)
Seedlings (coffee)	$ ($/unit * unit/ha)
Seedlings (trees)	$ ($/unit * unit/ha)
Crop Seeds	$ ($/unit * unit/ha)
Labour Costs	
Harvesting	$ ($/hr * hr/ha)
Pruning Shade	$ ($/hr * hr/ha)
Pruning Coffee/Berry Collection	$ ($/hr * hr/ha)
Planting Seedlings	$ ($/hr * hr/ha)
Planting Crops	$ ($/hr * hr/ha)
Weeding	$ ($/hr * hr/ha)
Erosion Control	$ ($/hr * hr/ha)
Soil Conditioning	$ ($/hr * hr/ha)
Harvesting Crops	$ ($/hr * hr/ha)
Fixed Costs	
Repair and maintenance of equipment	$ ($/year/ha)
Taxes	$ ($/year/ha)
Loan interest	$ ($/year/ha)
Revenue	
Coffee Yield	$ ($/kg * kg/ha)
Crops	$ ($/unit * unit/ha)
Timber	$ ($/unit * unit/ha)
Firewood (Prunings)	$ ($/unit * unit/ha)

$$PV = FV(1+i)^{-n} \tag{6.15}$$

where:

FV = future value of money ($)

i = interest rate (%)

n = number of years in the future (yrs)

Therefore, in order to determine the economic sustainability of a particularly cultivation system, the net present value (NPV) was calculated for the whole system as follows:

$$NPV = PVR - PVF - PVV \tag{6.16}$$

where:

PVR = Present value of revenues ($)

PVF = Present value of fixed costs ($)

PVV = Present value of variable costs ($)

This allowed for the comparison of costs and revenues for the system over a (user defined) time period *n* in present value (Marco and Horbolyk, 2001). The effects of variability in data used in the calculation, such as coffee prices, interest rates, and yield declines due to soil erosion, reductions in soil fertility or changes in cultivation practices, can be examined through the use of probability distributions for the main input and output variables to the economic evaluation. The significant variations required a sensitivity analysis to determine what various thresholds were needed to keep the NPV positive for each system and the probability that those conditions would be met. Where possible, to integrate this into the objective function, the NPV of each system (NPV_{sys}) was scored based on a relative scale from 0 to 100 using the following:

$$NPV_{score} = (NPV_{sys} - NPV_{min})/(NPV_{max} - NPV_{min}) \times 100 \tag{6.17}$$

where:

NPV_{score} = Score between 0 and 100 measured in CSI units

NPV_{max} = NPV for the most profitable system available to local conditions

NPV_{min} = NPV for the least profitable system

Economic risk (ER) was incorporated in the objective probability that the NPV was greater than zero using a Monte Carlo simulation to account for variability. Therefore, the final economic objective function for cultivation look as follows:

$$F_{SI} = w_{NPV} * NPV_{score} + w_{ER} * ER_{score} \tag{6.18}$$

where:

ER_{score} = Score between 0 and 100 measured in CSI units (for this measure - 1 % probability = 1 CSI unit)

w_{NPV} = weighting factor assigned to the NPV_{score}

w_{ER} = weighting factor assigned to ER_{score}

6.3.1.2.2 *Environmental Indicators.* Wolter and Danse (2003) suggested that environmental indicators be divided into two broad categories: condition and environmental performance (temporal indicators). For the purpose of evaluating cultivation practices, condition criteria evaluate the present state of the environment such as water and soil quality. These indicators would focus largely on the presents conditions, such as soil erosion or biodiversity levels, both on-site and in the immediate surroundings.

Performance criteria evaluate the actual operational mechanisms that influence sustainability such as the incorporation of active soil maintenance program, the incorporation of crops and/or timber into the system, or the use of agrochemicals. These indicators are also used to evaluate the performance of the present system on a day-to day basis. Level of chemical inputs, annual nitrogen leaching, impacts of emissions and other site /regional specific performance measures that have not been captured by other indicators, such as the importance of seasonal timing of agrochemical application in regards to the level of effect on wildlife, need to be considered. Relationships that changes over time such as percentage changes in yield vs percentage changes in inputs (materials or labour) are considered within this category. Table 6.5 presents a summary of the type of indicators that can be used to evaluate the environmental sustainability.

If soil erosion rates are not known, and more quantitative analysis is desired, the estimated erosion rates using the Revised Universal Soil Loss Equation (RUSLE) (Singer and Munns, 1999; and Schwab, et al., 1993) can easily be integrated into the evaluation as follows:

$$A = R*K*LS*P*C \tag{6.19}$$

where:

A = Soil erosion rate (tonnes/ha/year)

R = Rainfall factor

K = Soil erodibility

LS = Slope factor

P = Factor relating to conservation practices

C = Factor relating to amount of soil cover vs bare soil exposed

The C factor can be calculated as follows:

$$C = PLU * CC * SC * SR \tag{6.20}$$

where:

PLU = Prior land use (can influence baseline levels of factors such as organic matter, fertility, compaction, or soil contamination)

CC = Crop cover

SC = Surface cover

SR = Surface roughness

In general, the evaluated measures for each criteria against each cultivation practice will be normalized on a scale of 0 – 100 and then integrated in the CSI equation (6.9) to

Table 6.5. Environmental parameters for consideration in sustainability evaluation.

Description of Parameter	Units
Condtion	
Soil Erosion (A)	tonnes/yr/ha
Rainfall erosivity (R)	unitless
Soil erodibility (K)	unitless
Slope factor (LS)	unitless
Conservation Practices (P)	unitless
Soil Cover (C)	unitless
Prior Land Use (PLU)	unitless
Cover Crop (CC)	unitless
Surface Cover (SC)	unitless
Surface roughness (CR)	unitless
Biodiversity levels (compared to natural)	%
Soil nitrogen levels	Ppm or % of appropriate
Existence of agro-chemical residues	Ppm
Amount of available biomass (on-site)	kg/ha
Diversity of shade trees	# of different species
Performance	
Kg of agrochemicals/ha or kg of coffee	Kg/ha or kg/kg coffee
Kg of chemical fertilizer/ha or kg of coffee	Kg/ha or kg/kg coffee
Percent manhours on soil protection/maintenance	% or total manhours/ha
Crop nitrogen fixing potential	kg N/ha
Total biomass input	kg/ha
Percent of chemical vs non-chemical inputs	%
Performance of buffers (water)	Direct performance measure
External impacts	Direct performance measure
Input efficiency (+ or -) over time t	Δunit input/Δyield/unit time
Projected Nitrogen leaching	ppm in groundwater
Timing of chemical application (appriateness)	Direct performance measure

provide a composite score for the environmental sustainability of the practice in question. A sensitivity analysis was used to determine which factor's variability had the most significant effect on the outcome and to analyze the appropriateness of this influence.

5.3.1.2.3 *Social Indicators*. The social objective function optimizes the conditions of the various social criteria highlighted such as the number of manhours required from family members, amount of leisure time, treatment of employees, and community support. In addition to stakeholder input, numerous sustainability models, tools and concepts were reviewed, including the UN's Human Development Index (UNDP, 2004) the Dow Jones the Dow Jones Sustainability Indexes (SAM Indexes GmbH, 2004), and other social impact assessment (SIA) tools such as the World Banks Poverty ans Social Impact Analysis (PSIA) methodology (World Bank, 2003). Table 6.6 highlights those aspects applicable to this work that may be evaluated.

6.3.1.2.4 *Institutional Indicators*. The institutional factors often considered when evaluating institutional sustainability include: (a) capacity, and (b) framework (UN, 2001). Capacity includes indicators of access to financial institutional, public and private structures that permit the ongoing operations of agriculture and have the available depth to support sustainability within economic, social and environmental parameters. Effective sustainability guidelines that can be used to promote the well-being of stakeholders through appropriate social, environmental and economic legislation must exist.

The available institutional framework is an evaluation of the physical and logistical availability of financing, education and extension services. Educational programs, financing options, and opportunities for assistance need to be in place or developed as required. Indicators dealing with the ease of maneuvering through institutional bureaucracy are included, as well as a reflection on the system's flexibility and adaptability to change and development. Table 6.7 outlines the possible criteria.

Table 6.6. Examples of social parameters for consideration in sustainability evaluation.

Description of Parameter	**Units**
Total Labour Inputs	Man-hours
Coffee Related Labour	Man-hours
Crop Related Labour	Man-hours
Percent labour input versus leisure time	%
Equity of women's labour (farm vs home)	Direct value measure
Wage Parity	%
Use of family (child) labour inputs	Direct value measure
Cultural Acceptance	Direct value measure
Relative risk	Direct value measure
Access to stakeholder support networks	Direct value measure

Table 6.7. Institutional parameters for consideration in sustainability evaluation.

Description of Parameter	Units
Capacity	
Access to $$ support for improved practices	Direct value measure
Knowledge base about practice	Direct value measure
Demonstrable case studies/examples	Direct value measure
Framework	
Amount of bureaucracy	Direct value measure
Existence of extension services	Direct value measure
Cultural support for system	Direct value measure
Level of autonomy	Direct value measure

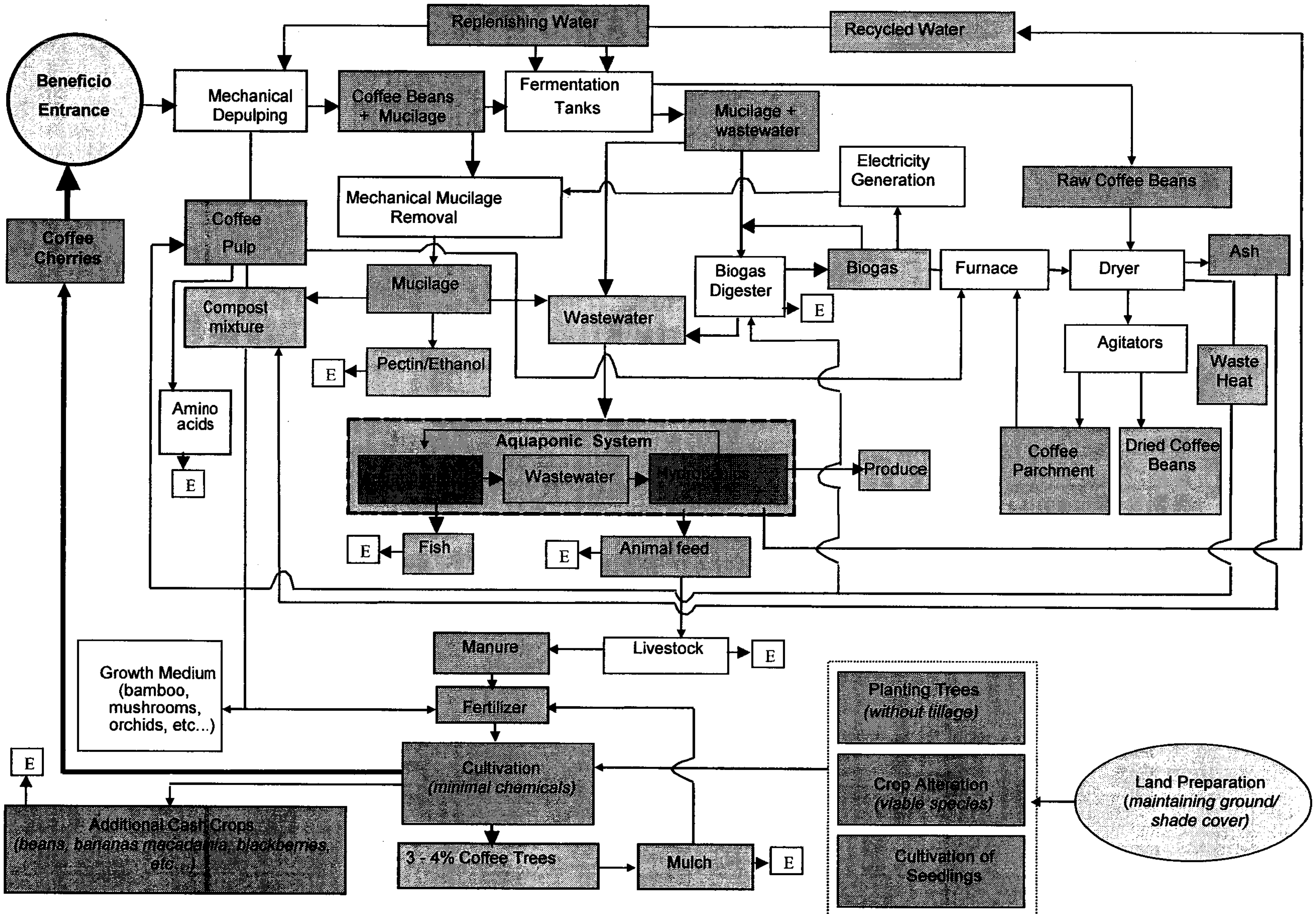
6.3.2 Processing

The investigation of a variety of sustainability evaluation models for industrial systems highlighted a number of gaps that needed to be accounted for (Adams and Ghaly, 2005). This was over and above the considerations made for sustainability within an agricultural setting. As such, the evaluation was expanded to include considerations not already addressed and these will be highlighted.

6.3.2.1 Identification of Alternatives. There are essentially two types of alternatives to be integrated into this framework: (a) global alternative, which incorporate changes that affect the entire operation and (b) local alternative, which incorporate changes to specific sub-sections of the overall process and can influence the options available in other sub-sections. Figure 6.14 provides an example of a theoretical system that incorporate the variety of options for improving eco-efficiency and making effective use of by-products. At each process node there are a variety of decision alternatives that need to be considered relative to the entire system. Table 6.8 outlines the various alternatives at each node and highlights (using superscripts) where decisions might have an effect on the alternatives available up-stream or down-stream. The systems to be evaluated in a particular situation result from the integration of stakeholder concerns, technical and economic feasibility, institutional support measures and cultural attitudes.

6.3.2.2 Determining Potential Criteria. Sustainability is to be evaluated in terms of the system's relationships within local and regional boundaries and not only at the production or processing level (Bell and Morse, 2003; Marchettini et al., 2003; and Hall, 2000). Therefore, this framework is based on the hypothesis that macro-system sustainability (national/global) can only be achieved if the micro and meso-systems within it are sustainable as well. It also draws from the idea that sustainability at the micro level does not include the necessary externalities required to guarantee a positive contribution to meso and macro-level sustainability (Hinterberger and Sinozic, 2002). Thus, the focus of this framework began with meso level criteria (industrial chain) and moved forwards and backwards using micro (facility specific) and macro (regional/national) level sustainability as considerations where applicable. Indicators were generated to evaluate the overall impact of the industrial system and then more narrowly defined to manage the information with regards to site and facility specific conditions.

Most frameworks divide the holistic concept of sustainability into three or four pillars as a starting point invariably runs the risk of the sum of the parts being less than the whole. This is particularly true if the interrelations between the three pillars are not adequately understood and clearly described, and consequently, sustainability is reduced to a consideration of separate factors, the sum of which is less than true sustainability. Therefore, the proposed framework incorporates the various aspects of sustainability by considering indicators that provide a description of the systemic nature of the industry. It includes two-dimensional indicators (where possible), instead of solely focusing on indicators that provide a one-dimensional, piecewise evaluation of economic, environmental, social and institutional sustainability. Evaluating the linkages at the boundaries of each arena provides a more comprehensive understanding of the system (Figure 6.15). These linkages reduce the overall number of indicators that need to be measured. This is important because the framework is also meant to have a practical application, so the number of indicators must be kept to a manageable number.



E = Possible Employment Opportunities

Figure 6.14. Integrated Coffee Processing System.

Table 6. 8. Stages and Alternatives of Sustainability Evaluation at the Facility Level.

Stage	Alternative
Whole Facility	Water Recycling
	Equipment Upgrade (Motors/Pumps)
	Implementation of Parallel Systems
	Mechanical Transport of Cherries
	Status Quo
Depulping	Compost
	Growth Substrate
	Amino Acid Substrate
	Fuel[a]
Mucilage Removal	Mechanical Removal[b]
	Fermentation
Mucilage Utilization	Pectin Production[b]
	Organic Loading (for other wastewater uses)
Wastewater Utilization	Separation of Solids
	Sedimentation of Residual Solids in Wastewater
	Production of Biogas[c]
	Aquaponic Ponds
Biogas Utilization[c]	Electricity Generation
	Fuel for Dryer System
Dryer System	High Efficiency Furnaced[d]
	High Efficiency Dryer[a]
	Use of Waste Heat[a]

Notes:

a – Coffee pulp can only (feasibly) be used as fuel if there is a opportunity to dry the pulp in an economical manner. The use of waste heat for this purpose may be necessary. As such, this can influence the decision to install a higher efficiency dryer

b – Pectin production depends upon mechanical removal of mucilage

c – Biogas utilization obviously is dependent on the integration of an anaerobic system.

d – The relationship between cultivation practices and beneficios processes will be part of the overall analysis; particularly in terms of the use of on-site biomass. Presently much of the beneficio firewood is pruning biomass. If farmer utilize this biomass as a source of organic matter for their farms the supply will be limited and will (may) affect the weighting provided the different drying alternatives.

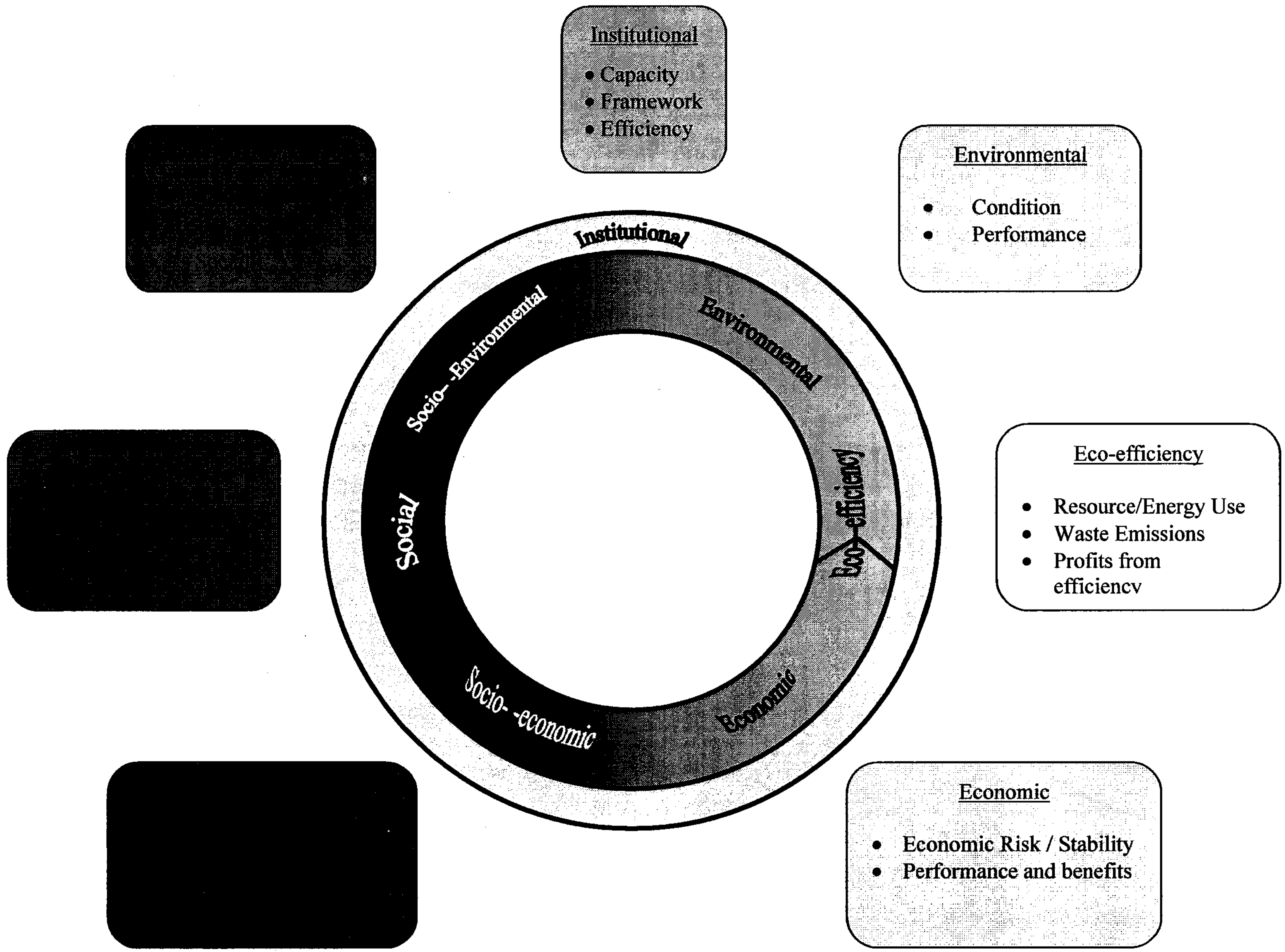


Figure 6.15. Sustainability Evaluation Framework (Adams and Ghaly, 2005)

6.3.2.3 Criteria for Evaluating Economic Conditions. For the purpose of this framework, those indicators found to be most appropriate to current industrial systems were drawn from various frameworks as well as the information gathered during interaction with stakeholders from within the system. The economic evaluation requires an analysis of the economic risk associated as well as the economic performance and benefits associated with it.

6.3.2.3.1 Economic Stability/Risk. Risk aversion is an important consideration for industry particularly in developing countries. As such, a condition must be evaluated for its contrition to the economic stability of the system. This should include issues such as location within the market place, competitive edge, access to institutional (financial) support, exposure to financial repercussions due to negative external impacts, such as economic impacts of soil erosion outside of agricultural productivity (disruption of hydro-electric operations, for example).

6.3.2.3.2 Economic Performance and Benefits. This criterion is one that is typical across frameworks and relies on standard accounting indicators such as income, debt reduction, availability of capital and cash flow. The influence of positive market positioning due to the promotion of sustainability would be included with these indicators. Benefits refer to the conditions that provide a positive economic environment which is not directly related to increasing gross income, such as access to subsidies, reduced innovation costs through eligibility for external funding and project support. These types of incentives can be very important in the promotion of sustainability within systems in developing countries, where sustainable and environmental technologies that seem reasonably priced in the developed world are beyond the economic reach of industries in a developing setting.

The key assumptions about the economic conditions surrounding sustainable innovation and technology is that the decisions about these investments, are taken just like any other decision about investment, where the present value ($) of benefits should outweigh that of the cost (Schram, 2000).

$$\text{Pr (AP)} + \text{Pr ([EC])} + \text{Pr ([LC])} \quad > \quad \text{C\&I} + \text{Pc (O\&M)} - \text{S} \qquad (6.21)$$

Benefits **Costs**

where:

Pr (AP) = Present return for the profit stream from alternative products and /or reduced operating costs ($)

Pr ([EC]) = Present return from the avoided environmental costs and taxes during the lifetime of the investment ($)

Pr ([LC]) = Present return from the avoided legal costs (environmental liability) ($)

C&I = Capital equipment and installation costs ($)

Pc (O&M) = Present cost operating and maintenance costs during the lifetime of the investment ($)

S = Subsidy or Foreign Aid provided for "sustainable innovation/technology" ($)

Therefore, for the purpose of the following economic value function, the NPV must be greater than 0.

$$\text{NPV} = \text{Pr (AP)} + \text{Pr ([EC])} + \text{Pr ([LC])} - \text{C\&I} - \text{Pc (O\&M)} + \text{S} \qquad (6.22)$$

It should be taken into account that interest rates in Costa Rica (as well as other developing countries) are often very high, reflecting inefficiencies in the economic system as well as the risks associated with investing in projects in this country. In some cases, an internal rate of more than 30% is needed for a project to be taken into consideration, in order to overcome interest being paid on the borrowed capital. High interest rates have a much greater adverse effect on the left hand side of equation 6.21 (the benefit side), while the right hand side is less affected. Therefore, Schram (2000) stated that subsidies or aid for sustainable innovations and technologies need to be paid out immediately.

6.3.2.4 Criteria for Evaluating Socio-Economic Conditions. Criteria related to this boundary condition investigate the inter-linkages between economic conditions of the system and the effects on social sustainability. Conversely, they capture the influence that the social conditions within the system can have on the economic sustainability. They incorporate the recognition of the importance of these interconnections, where a one-dimensional approach would not adequately realize the dependence of one on the other, which may possibly lead to inconclusive or misleading outcomes. Broad issues such as quality of life, stakeholder participation and community development are, therefore, evaluated in this framework. Table 6.10 outlines the specific indicators that will be included.

6.3.2.4.1 Quality of Life. This criterion will draw from indicators that evaluate the impacts that the economic conditions can have on the social sustainability and vis-versa. Issues such as the employment opportunities between harvests, the amount of leisure time available to stakeholders, gender related access to work and wage parity and wages are considered. Hiring practices that include third-parties are also addressed within this broad criterion.

6.3.2.4.2 Stakeholder Participation and Consideration. Most agro-industries have a very broad spectrum of stakeholder linkages ranging from farmer association and cooperatives to industrial associations and corporate vertical structures. Ramanathan (2002) and Pretty (1998) indicated that participation by stakeholders is a critical condition for success in sustainable agro-industrial development as stakeholders' capacity to innovate is paramount for the implementation of sustainable practices. Labuschagne et al. (2005) suggested that indicators evaluating the level of stakeholder empowerment provide important information regarding the probable success of any strategy or operational changes that are made to improve the economic condition. These ideas were echoed by both industry and farming associations (ABCR, 2003; and APOT, 2003). Additional indicators that evaluate the feasibility of cooperation based on the types of stakeholder connections are important. What is sustainable within a co-operative system may not apply to one that contains independent farmers and a privately owned facility.

6.3.2.4.3 Community Development. This criterion reflects on the contribution the industry makes to the socio-economic well-being of the region that supports its operations such as level of expenditure in local community (local based products), and granting the local population first access to employment.

6.3.2.5 Criteria for Evaluating Social Conditions. Based on the thorough analyses of the models and other tools reported in the literature, it was determined that those criteria that could not be represented by two-dimensional indicators fell into two main categories: human resources and community relations. Table 6.11 outlines the specific indicators that will be used in each of these two categories.

6.3.2.5.1 *Human Resources*. This refers to the indicators representing the condition of the present system with regards to its impact on its internal stakeholder (the industry's workforce). Employment condition indicators can include: stability, the presence of occupational health and safety (OHS) programs, treatment of workers, exploitation (illegal workers, child labour), physical working conditions, and the provision of services.

6.3.2.5.2 *Community Relations*. This criterion deals with the impact on the external social system. Indicators reflect the relationship the community has with the industrial system in terms of access to information and contribution to community well-being. In the case of the Costa Rican coffee industry for example, the industry has influenced the very cultural fabric of the communities involved in coffee production as much of Costa Rica's political stability arose from the way the coffee industry was organized in the late 1800s (Paiva, 2000). It has also contributed to the development of physical infrastructure that has impacted the c ommunity such as water systems, electrical distribution and roadways. Issues related to the community development such as security, social networks and cohesive forces need to be considered as part of the community relations' indicators.

6.3.2.6 Criteria for Evaluating Socio-Environmental Conditions. Socio-environmental indicators are linked with development of and compliance with applicable environmental management practices. They also evaluate the influence that environmental conditions have on the broader society, whether it be groundwater contamination at the local level, degradation of resources at the regional level, or greenhouse gas emissions at the national/global level. As such, this has been broken down into three main areas: compliance, training and management upgrades, and social constructs.

6.3.2.6.1 *Compliance*. According to de Simone and Popoff (1997), a sustainability framework that has a main focus on compliance can limit innovation and promote minimal incremental improvements that do not contribute to the overall sustainability. Instead of being the focus, it should only be considered as one condition. If an industry is to stay in operation, it has to comply with the applicable laws and regulations. Problems arise from satisfying these conditions as the end goal because the legal requirements may be far from a true reflection of protecting the surrounding environment. This criterion evaluates the industry attitude towards the society in which it operates. If an industry is routinely out of compliance, does not monitor its operational conditions (from an environmental point of view) or does not offer environmental training to employees, then its focus is not on total sustainability.

6.3.2.6.2 *Training and Management Upgrades.* Major research focus has been directed toward the technical and biophysical nature needed for sustainable agro-industrial development, but less studied is the need for alternative approaches to learning and training. Ramanathan (2002) noted that training, which can effectively transfer research methods and technologies to the end users, is as important as the message trying to be taught. Pretty (1998) suggested that training must be at a level that will: (a) facilitate the spread of sustainable behaviours and, (b) institutionalize these approaches. Environmental problems in the industry have been viewed as technical problems. However, technical solutions can only represent part of the solution. Environmental and social issues must be incorporated as part of the overall system management and as such embraced as the responsibility of management. In developing countries, management experience with documentation is often very limited and, therefore, are often operated with rudimentary strategies that do not analyze production and financial strategies beyond the bare minimum needed for survival. Therefore, indicators such as numbers and percentages of stakeholders who have received sustainability education and/or environmental training and the level of management dedication to the integration of environmental awareness are important.

5.3.2.6.3 Social Constructs. This criterion deals with the influence that environmental impacts will have on the social sustainability of society. Indicators dealing with the numbers affected by negative (or positive) environmental condition in terms of health, use of recreational areas and aesthetics can be included. Environmental actions taken by the industry that include community input, such as the development of reserves, protected areas, waterways, or species are considered. In addition, this considers issues that deal with the cultural acceptability and compatibility of an industry's initiative with the regional/national sustainability goals. Application of developed world ideals and beliefs cannot be automatically accepted.

5.3.2.7 Criteria for Evaluating Environmental Sustainability. The suggestions by the Institute of Sustainable Commodities (ISCOM) were the point of departure for the environmental indicators. However, the focus of their recommendations was based on the ISO 14000 EMS framework and as such was only considered a starting point. Experience gained in the field and the evaluation of other framework methodologies and conceptual models (such as industrial ecology and zero emissions) aided the development of additional indicators. However, the separation of indicators into condition and performance indicators proposed by Wolter and Danse (2003) was considered appropriate for this framework. Within each sub-criteria, aspects of the biophysical domain (air, water, land) are addressed.

5.3.2.7.1 Condition. This criterion evaluates the present state of the industry in relation to the environment including air, water and soil quality, biodiversity levels, and levels of soil erosion. Within the agro-industrial system, these indicators would focus largely on the conditions present on-site and in the affected surroundings.

6.3.2.7.2 Performance. The indicators used to evaluate this criterion will focus on the performance of the present system in its day-to-day operations. Quantity and type of chemicals used, percentage of energy coming from renewable (and sustainable) resources, impacts of emissions and other site /regional specific performance measures that have not been captured by other indicators, such as the importance of seasonal timing of agrochemical application in regards to the level of effect on wildlife. It also evaluates the actual operational mechanisms that influence sustainability such as the incorporation of active monitoring programs, the implementation of protection measures and the existence of a long-term plan that allows for continuous improvement not limited by compliance responsibilities.

6.3.2.8 Criteria for Evaluating Eco-Efficiency. These criteria investigate the inter-linkages between environmental conditions within the system and the effects on the economic bottom line. The World Business Council for Sustainable Development coined the phrase in 1992 after the Rio summit and included seven elements for eco-efficiency (NRTEE, 2001):

1. reduce the material intensity of goods and services
2. reduce the energy intensity of goods and services
3. reduce toxic dispersion
4. enhance material recyclability
5. maximise sustainable use of renewable resources
6. increase material durability
7. increase the service intensity of goods and services

For the most part, eco-efficiency indicators that have been developed for practical use in industry have largely focused on the first three conditions (NRTEE, 2001). In some industries, energy or material-use reduction may not be feasible; therefore the focus must be on the diversion of waste materials and energy to the production of value added products to improve the efficiency of use. Therefore, an additional focus was included specifically in order to provide a platform to demonstrate the promise contained within the technical application of industrial ecology to the overall system as suggested by de Simone and Popoff (1997).

In addition to standard measures of the amounts of inputs and the amounts and quality of waste emissions, this framework included criteria whose focus are to provide indicators of efficiency of resource use in terms of the level of profits that can be generated by using by-products to produce value added products, and the amount of saving generated through the use and diversion of these by-products. This can be evaluated in terms of the economic value per unit of resource or energy efficiency increase, the percentage of inputs diverted to productive outputs, the overall percentage of inputs that is eventually discharge as waste, the number of jobs created per unit of resource or energy efficiency increase. In general, measures linked to system resources, energy and emissions/by-products as they relate to the economic conditions are the foundations for these criteria. It is understood that these indicators should not be expected to measure and communicate all aspects and details of performance, and that the credibility of the indicators when communicating with external audiences is an important issue (NRTEE, 2001).

6.3.2.9 Criteria for Evaluating Institutional Sustainability. Although Spangenberg et al. (2002) highlighted the linkages between institutional sustainability the other elements and Labuschagne et al. (2005) integrated some institutional aspects as a pre-requisite for sustainability, they have not sufficiently dealt with it.. The United Nations (UN, 2001) divided institutional sustainability into two sub-sections: institutional framework and institutional capacity. Due to its primary application to the sustainable development in developing countries, elements of the UN framework were included. However, it was expanded to include efficacy. The presence of a stable infrastructure (government, financial, education) is captured with institutional framework indicators. The scope to which that infrastructure can provide support for sustainable development is captured in institutional capacity. However, the ability of that infrastructure to perform the usefulness of its programs and the effectiveness of its strategies is evaluated. The presence of a geographically available education or health system, for example, demonstrates a positive contribution towards sustainable development. However, there is no indication of the quality, effectiveness and efficiency of the service being provided. For that reason, institutional efficacy is determined to be a necessary criterion as well.

6.3.2.9.1 Capacity. This criterion includes indicators of access to sustainable and green technologies, financial institutions, and public and private structures that permit the ongoing operations of industry, and have the available depth to support sustainability within economic, social and environmental parameters. The effectiveness of regulations that can be used to protect the well-being of stakeholders through appropriate social, environmental and economic legislation are considered.

6.3.2.9.2 Framework. The physical and logistical availability of financing, education, training are important. Educational programs, financing options, and opportunities for technical assistance need to be in place or developed as required. Indicators dealing with the ease of maneuvering through institutional bureaucracy are included, as well are reflection on the system's flexibility and adaptability to change and development.

6.3.2.9.3 *Efficacy*. This criterion focuses on the efficiency of the infrastructure and the narrowing of the gap between institutions and industry. This issue was highlighted in the survey of coffee industry stakeholders as to the obstacles to sustainable development. It was reported by many facility operators that the government and research institutions had no concept of the real problems facing the industry and were finding solutions to problems that did not necessarily broadly exist (ABCR, 2003). Alternatively, this gap took the form of the dissemination of obsolete information. For example, it was noted that may ICAFE extension officers were still promoting mono-culture practices despite the international support to the contrary (i.e. Traditional Shade) available to individual growers through aid agencies (Rainforest Alliance, 2004b).

6.4 Model Implementation

There were multiple purposes for this evaluation model, the applicability of each was: (a) to monitor ongoing progress towards sustainability within a specific system, (b) to provide comparison between two or more present, operational systems, and (c) to provide decision making support when choosing between a number of new theoretical alternatives. In each instance the criteria being used in the evaluation were the same. However, subtle differences in data measurement and interpretation were needed. For example, the first situation of ongoing monitoring of an evolving system permitted a direct comparison between spatially identical system data that contained only temporal differences. In the other two situations, an increased level of interpretation was needed to provide consistent evaluation metrics for different systems with a myriad of possible sub-system combinations.

6.4.1 Determination of Alternatives

As noted by Ramanathan (2002), multi-criteria evaluation methods are most practical for use with a reasonable number of alternatives. When the number of alternatives fed into the evaluation model gets too large it can lose its authenticity as a projection of the user's reality. In this case, the user is forced to put complete faith in the model without the ability to properly grasp how the results were produced (Janssen, 2001). If the user has to be able to rationalize the final outcome as potentially logical, this can be difficult in the face of unlimited alternatives. In appears that in developed countries, this tactile connection with the generated output is not as necessary (i.e. we have faith in the outputs of abstract models produced by "authorities" in the subject area). However, one of the major obstacles noted by Ramanathan (2002) to any kind of technological or methodological transfer within developing countries was the inability of the end-users to put their faith in concepts developed outside a frame of reference for which they did not have the skill set to easily understand. Faith in "experts" to provide meaningful solutions to their problems was not abundant (Horton and MacKay, 2003). As such, it was necessary to include in the composite sustainable indicator (CSI) evaluation model, considerations of stakeholder concerns, physical and biophysical restrictions of the system, as well as likely cultural/institutional impediments and highlight the system strategies, practices and technologies that could possibly be applied in a particular situation. The aim was to look at the present system's constraints (e.g. availability of land, limits to water resources, etc...) and evaluate only those options whose set of criteria could either: (a) be met within the system's boundaries (e.g. alternative required resources which are available or accessible to the present system), or (b) were not so obviously unsustainable in comparison to other options that they did not warrant the effort (e.g. increase use of pesticides to protect yields over the long term).

6.4.2 Model Assumptions and Constraints.

The model was developed with the following assumptions:

1. Each technology had certain mandatory requirements that had to be met for them to continue being a part of the overall evaluation.
2. Monte Carlo simulation was used to incorporate the probability distributions related to stochastic data (i.e. could not be empirically calculated or varies over time).
3. The weights were based on collected data, stakeholder inputs and an evaluation of the indicators relevance to sustainability concerns within the system.

The model was based on the following constraints:

1. Practical number of indicators developed from available data, stakeholder inputs and literature.
2. Weights were varied for the different criteria and sub-criteria to determine the CSI outcome sensitivity to particular facets of sustainability.

6.4.3 Model Indicators.

System-specific indicators were developed following the outlined framework with the incorporation of considerations for the necessary evaluation parameter of both the cultivation and processing aspects of the overall system. Both state and driving force related conditions were included in the development. All the indicators are not applicable to all systems in each situation. However, the aim of this model is to provide a platform useful across a myriad of systems; in situations where a particular indicator is not applicable, the weighting effects of the other indicators will be normalized to provide an equal basis for comparison.

6.4.3.1 Indicator Definitions. The decision regarding the indicator selection was based on the evaluation of data availability, existing sustainability models, opinions of stakeholders and industry experts, and the indicator's applicability to the system based on the observations made during field research. The following highlight specific indicators that the author believed required further clarification, beyond the general discussion found in the previous section.

6.4.3.1.1 Economic. The specific economic indicators are found in Table 6.9. Net Present Value (NPV) is a useful description of a system's profitability over a specified length of time. It was set up to include external factors such as availability of subsidies, is inclusive of costs, savings and revenue streams, and can integrate probability functions that reflect possible future variabilities in economic data. NPV can also be used to compare the economic feasibility of different systems by tracking the change in costs/revenues as compared to a baseline system or subsystem. Another benefit is that the timeline for the analysis can be changed in order to demonstrate the effects of the various input factors over time. For example the NPV of a system taken over three years (NPV(3)) would demonstrate the shorter term profitability of a system, whereas the NPV (12) (or the NPV of the system taken over 12 years) could be calculated to demonstrate the longer term feasibility of the same system.

The incorporation of risk provides an evaluation of the likelihood that a user will be willing to accept the economic risks associated with the operation of a particular system. Brealey and Myers (1996) provides an empirical method to use the standard deviations around an estimated economic outcome and convert that into a probability function of user likelihood that this outcome will be acceptable to a certain distribution of people.

In the absence of quantitative data for the calculations of NPV and probability of risk acceptance, it was deemed justified to integrate qualitative data in the model in the form of a direct worth value based on the perceptions and traditional knowledge of the stakeholders. Particularly in agro-industrial systems that have been in existence for extended periods of time, considerable knowledge (albeit disaggregated) has accumulated amongst stakeholders regarding the economic feasibility associated with different types of industrial systems. Unfortunately this knowledge normally exists in silos with

Table 6.9 Economic Indicators.

Parameters	Description
NPV (i)	Net Present Value (NPV) provides an indication of the system's profitability over time. Related measures such as "pay-back period" and initial investment can be used in the place of NPV where it is not realistic to calculate due to limited data
Perceived Economic Performance	In the absence of quantitative data regarding system costs, it is necessary to permit the inclusion of stakeholder perception regarding the economic performance of a system based on anecdotal evidence (traditional knowledge, farmer and processor qualitative input).
Risk Factor (i)	Probability that a decision maker would accept level of economic risk associated with a particular system. This can be related to the Monte Carlo determination of the % probability that the NPV is >0 over a specified period of time.
Perceived level of Risk	In the absence of quantitative data, risk perception can be evaluated as a direct value measure based on the input of stakeholders

individuals (or groups) and is not readily disseminated through the whole industry. However, this knowledge has merit and can be integrated in the absence of (and/or perhaps complementary to) deterministic economic data.

6.4.3.1.2 Socio-Economic. Table 6.10 highlights the four indicators used for this evaluation. Of particular note are the temporal aspects of the indicators dealing with community stability and balance of time. One of the major concerns is the seasonality of the coffee industry and the resulting necessity of stakeholders to live on "borrowed" monies that accumulate interest over the course of the cultivation period. Therefore, any innovation that provides a more stable employment environment (off-season crops, secondary product systems) was considered positive in regards to these indicators. The

Table 6.10 Socio-economic indicators

Parameters	Description
Level of community stability	Percentage contribution to local employment (throughout the year)
	Percentage workforce made up by transients or "out of town" laborers
Level of bargaining power held by industry stakeholders	A direct value measurement of the workers ability to extert some control over their own destiny (labour unions, cooperatives, marketing boards)
Access to (credible) credit	Availability of credit at a reasonable interest rate
Pay rate compared to living costs	Change (Δ) buying power (% +/-)

other concern is the influx of outside workers who can be hired at lower wages and can have a disruptive affect on the community fabric due to their transient nature.

6.4.3.1.3 *Social.* An analysis of gender equity beyond pay parity was specifically not included. Deeply ingrained cultural attitudes play a role regarding women integration into society such that it could not be evaluated within the scope of this investigation. For example, the question was asked, 'is it sustainable to have higher numbers of women in the labour force (indicating the integration of women into society as wage earners) or fewer (indicating the ability or desire of women to remain home as primary caregivers to family and children)?' While it was recognized that the drops in coffee prices have dramatically increased the burden on women's time in some cases, the difficulty in establishing an accurate scale to evaluate the "sustainability" of the different types of contributions that women make to society was noted. A more detailed analysis of the number of hours worked per day according to gender may offer better observation for future analysis. Parameters that were included are presented in Table 6.11.

Table 6.11 Social indicators.

Parameters	Description
Availability of industry support of worker's well-being	Existence of social support network to aid workers in times of injury, illness and familial stresses
Injury rate amongst workers	Injury rate as compared to rate considered "acceptable" or normal by international (developed world) standards.
Access to adequate social needs	Workers (particularly transient) should have access to adequate housing, education and medical services.
Balance of work and leisure	Average number of hours worked per day

6.4.3.1.4 *Socio-Environmental.* The indicators chosen for this criterion stem almost directly from the input of stakeholders regarding their views on how social and environmental considerations should be integrated and what was of importance. The indicator dealing with the availability of data was included in this section because there were numerous complaints from processors about the fact that they had 'heard stories' about a particular technology or sustainability practice, but could not access the appropriate data to make an educated decision. The problem was not their attitude about sustainability issues, simply the inability to secure reliable information.

Health related issues (beyond specific industry related injuries) were not included in this model at this time, although it is foreseeable that it could be integrated when data became available. At this time there is no mechanism in place to assess the overall health of various industry stakeholders as compared to other groups. The data is aggregated by region and by occupation but not by industry. As such it is difficult to draw any conclusion about the specific health of those in the coffee industry in general, and in different system configurations, specifically. Table 6.12 outlines the parameters that were included.

Table 6.12. Socio-Environmental Indicators.

Parameters	Description
Compliance	Efficiency of present systems to meet compliance standards or (in theoretical cases) the ability to meet said standards.
Training requirements	Deals with the existence of training programs for system stakeholders focused on the sustainability practices.
Stakeholder attitudes towards environmental issues	Deals with the level of ownership of environmental stewardship found within stakeholder community; includes industry contribution to environmental protection beyond their own boundaries.
Alignment with national sustainability policies	To what degree does the system positively contribute to present national policies external to the industry, e.g. protection of biodiversity, GHG emission reduction.
Availability of reliable data	Ease of access to existing data from researchers, NGOs and other industrial organizations regarding sustainability alternatives. Existence of information silos can frustrate innovation.

6.4.3.1.5 *Environmental and Eco-Efficiency.* The indicators for these sub-criteria, found in Tables 6.13 and 6.14, were largely developed from a mass/energy balance of the system found in Figure 6.10. By varying the system design through the inclusion of different technologies and/or processing systems, the various material and energy outputs, efficiencies and operating conditions could be determined and their sustainability as a contribution to the total analyzed. With regards to waste generation, each type of waste was weighted according to the intensity of the negative impact associated with each in consideration of current environmental concerns (Wolters, 2001). In addition, it was determined that a direct value measure of the level of monitoring that had been integrated (or was required to be integrated) should be included as a constraint variable because in the absence of monitoring, some sub-system alternatives could not be implemented.

Table 6.13. Environmental indicators.

Parameters	Description
Level of System Monitoring	Reflects how well management has integrated the monitoring of system inputs and outputs and/or the likelihood that the necessary monitoring would be integrated.
Resource Consumption	Water, electricity, firewood (or other external fuel source), soil, nutrients.
Impacts of Wastes	Unit measures of wastewater, waste heat, unused biomass, etc., multiplied by the impact weight for each waste
Management's Response	Level of response to environmental issues
Soil Health	Direct Value Measure based on the structure, fertility and amount of soil in the system.
System Resilience	Direct value measure related to ability of the system to handle change
Biodiversity levels	Percent of biodiversity as compared to a natural (representative) ecosystem

Table 6.14 Eco-efficiency indicators.

Parameters	Description
Material Intensity	Calculation of the overall material usage within the system. Presented as resource-use efficiency.
Energy Intensity	Calculation of the overall energy usage within the system and is presented as the amount of waste heat released and overall energy efficiency.
Return on Resource Input	ROR is calculated as the sum of the percentage use of the by-product multiplied by its eco-efficiency factor divided by the sum of percentage use multiplied by the maximum usage factor that is technically feasible for the resource.

6.4.3.1.6 Institutional. Those items of specific interest to this model revolve around the elimination of institutional barriers to innovation approaches. While the generic issues discussed previously will be taken into consideration, the long term sustainability of any system will be directly affected by: (a) ICAFE's attitude towards any system innovations, and/or (b) whether there is a strong proponent in favour of the system alterations that holds a level of respect amongst the industry stakeholders. Novel approaches and strategies outside of ICAFE's present mandate will require: (a) the support of an external organization (NCPCs[4], universities, NGOs) and/or (b) the ability of the system stakeholders to undertake the integration of sustainability alternatives without external support (i.e. they have enough $$, they have the resource to integrate the changes themselves, etc). Table 6.15 presents these parameters.

Table 6.15. Institutional indicators.

Parameters	Description
Level of institutional support	Regards the availability of specific subsidies/in-kind expert support, the amount of express support by organizations credible among stakeholders and financial institutions, and the willingness of government departments to allow the introduction of practices differing from passed policy mandates.
Demonstrable case studies/examples	Related to the existence of case studies to provide demonstrable successes.
Availability of appropriate technology transfer expertise	Related to the feasibility of providing the necessary infrastructure needed for appropriate technology transfer (i.e. in-country capacity building)
Efficiency of communication networks	Ability of industry networks to effectively "get the word out" about new practices and strategies
Ease of market access for resulting product	Availability of market recognition for sustainability efforts. Specifically included here (and not economic) due to ICAFE's strict control over the product pricing.

6.4.3.2 Criteria Weighting. One of the major complexities when aggregating information into indices, is how to establish a weighting system that integrates data without loosing its meaning or becoming too subjective. In this instance, a Monte Carlo simulation was used to provide a sensitivity analysis of the CSI's output to variations in the weights of the main criteria. The range of possible weighting was determined, based on scientific data (where possible) and on the predominate attitudes found amongst stakeholders. However, this was balanced against the necessity of maintaining a certain level of equity between the main criteria. The same methodology was employed to determine the sensitivity of each main criterion's score to the weighting of the various individual indicators (where applicable).

[4] NCPC - National Cleaner Production Center funded by the UNIDO.

6.5 Data Integration

Based on the systems description and constraints, the initial economic performance of the system and the material and energy balance are calculated. Then, the economic, eco-efficiency and environmental indicator are derived. The other indicator values (social, socio-economic, socio-environmental and institutional) are then incorporated into the model and the calculation of the composite sustainability indicator (CSI) score is completed. In the situation that data is not known for the system, average values are input based on the system's operational parameters and constraints, which are elucidated in a separate section of the evaluation program. Figure 6.16 demonstrates the overall flow of data input and calculations.

6.5.1 Input Data

The basic data used for production costs, production per hectare, replanting costs, sales prices and agrochemical inputs used in the economic calculation for the cultivation systems were obtained from ICAFE (2003). With regards to labour costs, this data was modified to reflect the results of the farmer surveys. Data related to income generated from additional products, coffee yield variabilities due to the different cropping systems and the reduction in agrochemical input due to different cropping systems were gathered from literature, communications with coffee researchers and farmers, and personal observations during field research and will be highlighted as is appropriate throughout the chapter. The general data source used in addition to field data are outlined in Table 6.16.

Economic data used to calculate the NPV contribution of the various components within the coffee processing system were collected from: (a) the beneficio managers in situations where a particular system had already been applied, (b) the Asociacion del Beneficidores de Costa Rica (ABCR), who had conducted cost benefit analyses on a variety of environmental technologies in order to determine their individual economic feasibility, (c) technology vendors, and (d) calculations generated

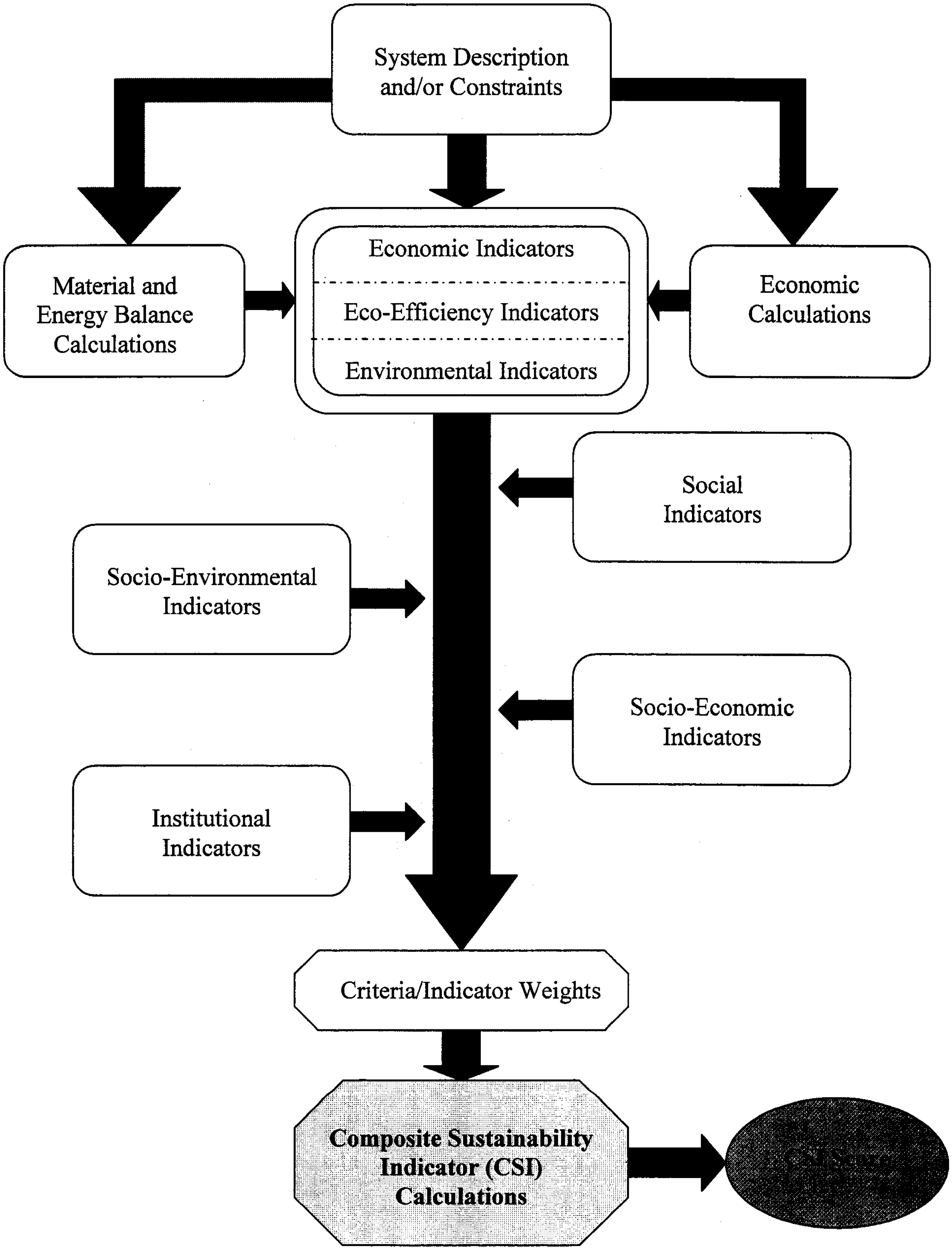


Figure 6.16. Flow of data input and calculations.

Table 6.16. Data sources.

Data Type	Reference or source
Coffee Yields	Romero-Alvarado et al (2002) Lyngbaek et al. (2001)
Production Costs (cultivation)	ICAFE (2003a) APOT (2003) Gobbi (2000)
Operational Costs (processing)	ABCR (2003) Schram (2000, 2003) Volcafe (2003)
Material Inputs (cultivation)	ICAFE (2003a) MAG (2004) Rainforest Alliance (2004) Ramirez (2004)
Material Inputs (processing)	Wolters and Danse (2003) Echeverri (2003) Segura and Reynolds (1993)
Material outputs (cultivation)	APOT (2003) Lyngbaek et al. (2001)
Material Outputs (processing)	Aguilar (2004) ABCR (2003) Echeverri (2003) NCPC (2003) Danse (2002)
Energy Usage (processing)	Schram (2003) Danse (2002) Echeverri (2003)
Labour Inputs (cultivation)	ICAFE (2003a) Ramirez (2004)
Soil Quality	Rubin and Hyman (2000) Babbar and Zak (1995) Perfecto and Snelling (1995) Lal (1995)
Social Factors	van den Elzen (2002) Courville (2000) Lyngbaek et al. (2001)

Table 6.16. Continued.

Data Type	Reference or source
Social Factors (Cont'd)	Aguilar and Klocker (2000)
	Sikdar (2003)
	Pratt and Harner (1997)
Cultural Factors	Ramanathan (2002)
	Vargas et al. (2000)
	Sikdar (2003)
	Winson (1989)
Technology Costs (processing)	Mata (2004)
	Scott (2004)
	Todd et al. (2003)
	Ellenbroek (2003)

from observations made during field research. The same sources were used to generate the necessary data for material balance and energy efficiency calculations within the beneficio operations.

Direct value measures for the various social, environmental and institutional parameters being used in the evaluation were based on input of stakeholders and field observations (found in Chapter Five). Quantitative data related to soil parameters such as erosion, nitrogen leaching potential, and soil quality were gathered from literature, although in a few cases farmers had some estimates. The most common form of data related to soil erosion and health came in quantitative forms. This was used in combination with the qualitative data to provide a balance between scientific data and the deep bench of anecdotal (but still valid) knowledge held by the farmers themselves. This knowledge was applied though a series of qualitative evaluations designed to give a quantifiable output of "relative" soil quality (as a comparison between different cultivation practices and conditions).

6.5.1.1 Metrics. As noted by Barzilai (2003), the metrics used for indicator measurement must be based on empirical scales in order to provide units comparable across the various indicators, whether they be quantitative or qualitative in origin. At least three points on the scale between 0 and 100 were defined, one as a base for comparison and two others, to provide the necessary ratio that permitted the comparison of two relationship vectors as opposed to the comparison of two random points. The scale was established as a linear scale for the purpose of this thesis. However, the possibility for integrating logarithmic or exponential scales is discussed later.

6.5.1.2 Variable Inputs and Distribution Functions. Probability and/or stochastic functions were built into the model where: (a) there was uncertainty in the input value or, (b) the input value was known to change overtime. Representative regression equations were calculated and input to represent data that changed according to a temporal or situational function. Probability functions were used in the instance where the value was unknown and the predictor data did not fluctuate in a consistent manner, such as interest rates for example. Table 6.17 shows the indicators whose values within the CSI model were generated using either a distribution function or an equation. The data ranges and functions that were used were generated from data that was highlighted in chapter five or (in the absence of coffee industry specific data) was adapted from research conducted in similar situations. Data uncertainly dealt primarily with economic calculations where farm productivity, coffee pricing and future energy costs could not be calculated with certainty and instead were based on what was most probable within 95% confidence. The same situation arose when providing decision support for theoretical system modifications, so uncertainty was built in to these calculations as well. The probable ranges were integrated into the data analysis as part of the sensitivity analyses of the overall CSI output values.

Table 6. 17. Indicator values generated by distribution functions or regression equations

Input Parameter	Input function
Coffee Pricing	Probability distribution
Coffee and Crop Yield	Regression equation (where possible)
	Probability distribution (literature)
Revenue received from other crops	Probability distribution
Pesticide Application	Regression equation (field data)
	Probability distribution (literature)
Fertilizer Application (inorganic)	Regression equation (field data)
	Probability distribution (literature)
Changes in Labour Inputs	Regression equation
Inflation rate	Probability distribution
Interest rate	Probability distribution

6.5.2 Indicator Description

A detailed description of the individual indicator metrics was developed, including all considerations used in the evaluations and the associated scoring mechanisms. Tables 6.18 to 6. 27 present the metrics for the indicators used within the CSI methodology. In Table 6.19, a number of the environmental criteria are made up of sub-indicators, each with its own scoring metric. The influence on the total score of the main criteria will be weighted according to the present conditions and applicable concerns. For ease of reading the sub-indicators, soil quality and system resilience were placed in separate tables (Tables 6.20 and 6.21). They were presented separately because they could be used independently by farmers as a simple sustainability overview of their present agricultural systems and would also be applicable to a variety of agricultural systems, in a variety of different social and geographical settings. These indicators are an expansion of those offered by Nicholls et al. (2004).

Table 6.18. Socio-Economic Criteria.

Indicator	Characteristic	Indicator Score
Compliance	On-going compliance issues, regular fines and/or sanctions (3+)	*0*
	Averages two non-compliance warnings within the season	*25*
	Averages one non-compliance warning within the season	*75*
	Fully compliant with national guidelines and regulations	*100*
Training	No training offered to stakeholders at any level	*0*
	Basic environmental, OHS training to limited, senior personnel	*25*
	Technology/strategy transfer training to operational stakeholders	*60*
	Ongoing training related to continuous environmental / efficiency improvement offered to general staff	*85*
Stakeholder attitudes towards environmental issues	Not a consideration	*0*
	Seen as peripheral to overall system operations (end-of-pipe or reactionary view)	*15*
	Considered to be important but remains an external construct	*60*
	Important to integrate environmental considerations into overall system operations (85 → 100 related to level of integration)	*85*
Alignment with national sustainability policies	Strategy/technology is contrary to national policies/focus	*0*
	Strategy/technology does not conflict nor is supported by national policies/focus	*50*
	Strategy is fully in-line with national policies and compliments their integration	*90*
Availability of reliable data	No data readily accessible to stakeholders regarding strategy or technology	*10*
	Data available only through for profit companies/organizations	*30*
	Data available through external not for profit agencies	*45*
	Data available through stakeholder networks (i.e. in-country/region pilot project with demonstrable results)	*75*
	Data actively disseminated by government	*85*

Table 6.19. Environmental Criteria.

Indicator	Sub-Indicator	Characteristic	Indicator Score
Level of System Monitoring		No monitoring	*0*
		Seasonal monitoring of basic inputs / outputs	*10*
		Seasonal monitoring of all inputs / outputs	*20*
		Monthly interval monitoring of input / outputs at system level	*40*
		Regular interval monitoring of all throughputs at the subsystem level	*85*
		Continuous monitoring of all throughputs at the subsystem level	*100*
Response to Potential Problems		Avoidance	*10*
		Makeshift response – limited to short term avoidance of legal or societal pressures	*20*
		Longer term solution but met with end-of-pipe treatment and/or reactionary thinking.	*50*
		Basic investment in cleaner production strategies	*75*
		Proactive attitude towards eco-efficiency and broader strategies that recognize the $$ benefit and stability of environmental protection	*100*
Impact of Resource Consumption	*Electrical Energy Usage*	Percentage from renewable sources – biogas, hydroelectric)	Percentage
	Heat Energy Usage	Percentage from sustainable supply	Percentage
	Water usage	Creates regular shortage for surrounding ecosystems	0
		Create shortages only during unanticipated dry periods	40
		Abundant water available – self sufficiency without posing negative effects associated with withdrawal	85
	Pesticides	Overuse – wide-scale destruction of non threatening flora and fauna	0
		Application of targeted IPM strategies – i.e. no influence on anything but target species	50
		Not used	100

Table 6.19. Continued.

Indicator	Sub-Indicator	Characteristic	Indicator Score
Impacts of Wastes and Emissions	*Wastewater*	High organic loading with measurable effect on receiving ecosystem	0
		High organic loading introduced to waterway with sufficient carrying capacity to avoid immediate problems	25
		Compliance	50
		Clean water – reintroduced into the local ecosystem with minimal disruption	85
	Air Emissions	Low-efficiency furnaces without management of exhaust quality	10
	(minas up to 10 from the final score based on air quality of surrounding area)	Functional scrubber to remove particulate (non-sustainable fuel)	45
		Functional scrubber to remove particulate (renewable/sustainable fuel)	60
		High-efficiency furnaces with minimal emissions	90
	Pulp	Discharge to local waterways or ecosystems untreated	15
		Burned as fuel, or disposed of in non-harmful way (example: mixed into livestock feed – it doesn't contribute any benefit to the animal but its use does not pose environmental hazard)	50
		Fully composted and reintroduced at farm level or sold	100
	Agrochemicals	Off-site negative environmental impacts or influences on human health	0
		Measured migration off-site, but no measured impacts	25
		Fully integrated IPM or sustainability regime that is monitored by an external agency	75
		No use	100
Biodiversity		Biodiversity as a percentage of natural forest	*x% → X*

Table 6.20 Soil Quality Sub-Indicators.

Sub-Indicator	Characteristic	Indicator Score
Structure	Loose, powdery soil without visible aggregates	*10*
	Few aggregates that break with little pressure	*50*
	Well formed aggregates difficult to break	*100*
Compaction	Compacted soil, penetrating wire bends readily	*10*
	Thin compacted layer, some restrictions to a penetrating wire	*50*
	No compaction, wire can penetrate all the way into the soil	*100*
Soil depth	Exposed subsoil	*10*
	Thin superficial soil	*50*
	Superficial soil (> 10 cms)	*100*
Colour, odour and organic matter	Pale, chemical odor and no presence of humus	*10*
	Light brown, odorless, some presence of humus	*50*
	Dark brown, fresh odor and abundant humus	*100*
Water retention after irrigation or rain	Dry soil, does not hold water	*10*
	Limited moisture level available for short time	*50*
	Reasonable moisture level for a reasonable period of time	*100*
Soil cover	Bare soil between hedgerows	*10*
	Less than 50% soil covered by detritus or live cover	*50*
	More than 50% soil covered by detritus or live cover	*100*
*Erosion**	Severe erosion, presence of small gullies	*10*
	Evident but low erosion signs	*50*
	No visible signs of erosion	*100*
(RUSLE eqn, or erosion is known use the following:	High levels of erosion as compared to local standards (>50 t/ha/yr)	*10*
	Medium levels of erosion as compared to local standards (20 t/ha/yr)	*30*
	Calculated level are similar to virgin forest (<100kg/ha/yr)	*100*
Presence of invertebrates	No signs of invertebrate presence or activity	*10*
	A few earthworms and arthropods present	*50*
	Abundant presence of invertebrate organisms	*100*
Average Score	*Average of the scores for each sub-indicator*	

Table 6.21. System Resilience Sub-Indicators.

Sub-Indicator	Characteristic	Indicator Score
System Health – Coffee Appearance	Discolored foliage with signs of disease or deficiency	*10*
	Light green foliage with some discoloring	*50*
	Dark green foliage, no signs of deficiency	*100*
System Health – Coffee Growth	Sparse clusters, limited new shots, minimal leaf area	*10*
	Taller shoots, some new growth, more abundant blossom clusters	*50*
	Abundant shoots and foliage area.Vigorous growth, tight clusters, abundant on most branches	*100*
Weed competition/pressure	Crops stressed, overwhelmed by weeds	*10*
	Medium presence of weeds, some level of competition	*50*
	Vigorous crop, minimal weeds or has ability to overcome those present	*100*
Actual/Potential Yield	In relation to local average	*Percentage level*
Level of Intercropping	Monoculture	*0*
	Uneven cover crop or intermittent cropping rows	*Percentage level*
	Full cover crop with regular placement of cropping rows	*100*
Number of Shade Trees	None	*0*
	80 (with < 6 species)	*35*
	80 (with < 12 species)	*50*
	> 160 (with > 12 species)	*100*
Management System	Conventional Monoculture (no shade)	*0*
	Conventional Monoculture (some shade)	*10*
	In transition to organic (using IPM) or stable traditional shade with minimal agrochemical input	*60*
	Organic, complete diversified with low external inputs	*100*
Average Score	*Average of the scores for each sub-indicator*	

The methodology allows for measuring sustainability in a *comparative or relative* way, either by comparing the same system over time, or by comparing two or more cultivation systems under different management practices or transitional stages. The comparison of various systems allows stakeholders to identify the more sustainable system from a biophysical perspective. This is then integrated into the overall evaluation CSI evaluation. The benefit is that in the absence of quantitative data to describe soil health and fertility, basic, easily understood and identifiable criteria can be used instead. Biodiversity was not included in the systems resilience for the specific reason that biodiversity is a major policy issue within the Ministry of the Environment in Costa Rica. As such it was treated as a separate indicator so not to dilute its overall contribution to system sustainability.

Table 6.22 provides the indicators used for eco-efficiency evaluation. The eco-efficiency (EE) factor will be explained further on.

For the purpose of this exercise the NPV of the processing system was scored according to whether it was greater than, equal to, or less than zero, as compared to the original operation. This was due to the limited empirical data relating to the economic performance of these systems. Within the cultivation system the NPV was calculated

Table 6.22. Eco-Efficiency Criteria.

Indicator	Characteristic	Indicator Score
Material Usage	Normalized inverse of comparison between actual usage and theoretical industry expressed as a percentage, e.g. value of 1 = 100, 0.5=50, etc..	*Percentage*
Energy Usage	Normalized inverse of comparison between actual usage and theoretical industry expressed as a percentage, e.g. value of 1 = 100, 0.5=50, etc..	*Percentage*
Output Efficiency	$[\sum (EEfactor_x_\%use) / \sum (\%use^{mas} x_EEfactor^{max})]$x 100	*Percentage*

directly and scored in a similar manner (Table 6.23). The main purpose was to avoid interdependences of the systems' score. In future scenarios, a theoretical NPV could be used as an ideal for the purpose of comparison in the instance that a specific economic outcome is either (a) desired or (b) known. The risk assessment was based on a Monte Carlo simulation that included yield, price and interest rate fluctuations and calculated the percent probability that the outcome would be positive.

Table 6.23. Economic Criteria.

Indicator	Characteristic		Indicator Score
NPV (i)	Cultivation (absolute values)	- <0	*0*
		- =0	*50*
		- >0	*100*
	Processing (as compared to original operation)	- <0	*0*
		- =0	*50*
		- >0	*100*
Perceived Economic Performance	Perceived negative impact on economic performance/stability		*0*
	Not perceived to have a significant impact		*50*
	Perceived positive impact on economic performance/stability		*100*
Risk Factor (i)	Percentage probability of the system having an positive NPV according to Monte Carlo simulation		Percentage
Perceived level of Risk	Perceived high risk to economic security/stability		*0*
	Not perceived to have a significant risk		*50*
	Perceived to minimize risk to financial security/stability		*100*

Table 6.24. Socio-Economic Criteria.

Indicator	Sub-Indicator	Characteristic	Indicator Score
Contribution to community stability	*Local employment*	Use of employment brokers	*0*
		X = %local (1) + %regional (0.5) + %transient (0.2) - % illegal (1.5)	*X →score*
	Investment in community	No local investment	*0*
		~ 25% of operational purchases made through local vendors and resources provided by local sources	*40*
		> 50% operational purchases made through local vendors and resources provided by local sources	*80*
	Contribution to community	No involvement	*0*
		Active presence within stakeholder community (e.g. availability of social, economic or natural resources, or provision of services, to stakeholders). Respect for stakeholders resources.	*60*
		Active community presence with a high level of philanthropic contribution (e.g. availability of social, economic or natural resources, or provision of services, to broader community members). Respect for community resources	*85*
	Contribution to professional development	None. Absence of training or career opportunities. Hire only menial, unskilled labour with no chance to excel	*10*
		Limited training opportunities strictly focused on site-specific needs. Hire workers with some skills training	*45*
		Hire higher skilled workers. Actively recruiting local population for skills training.	*80*
Level of bargaining power (stakeholders)		Exploitive industry structure – absence of stakeholder rights	*0*
		Informal stakeholder organizations – some recognition granted by others in the industry chain and external institutions (e.g. sustainable coffee marketing boards)	*60*
		Formalized organizations – co-operatives, unions, etc…with high level of self determination.	*80*

Table 6.24. Continued.

Indicator	Sub-Indicator	Characteristic	Indicator Score
Access to credit		No credit	*0*
		Limited credit from local high interest moneylenders	*10*
		Available credit through credible financial, government or industrial institutions at interest rates 20+%	*35*
		Available credit through credible financial, government or industrial institutions at interest rates 10-20%	*65*
		Fully available credit through credible financial, government or industrial institutions at interest rates <10%	*90*
Pay rate compared to living costs		Exploited or indentured workers – pay is insufficient to maintain basic standard of living	*0*
		Sufficient pay to meet basic food, housing, clothing needs.	*35*
		Approximately 10% disposable income once average living expenses are covered	*65*

6.5.3 Aggregation

Novak and Ragsdale (2003) demonstrated the usefulness of spreadsheets when aggregating decision support system data. In this instance the spreadsheet program has been integrated with probabilistic mathematical software @RISK (Palisade Corporation, Ithaca, New York, USA) that allows for the integration of functions, unknown variables and Monte Carlo simulations into the evaluation calculations. This permited more realistic representations of the systems involved. Such operations are not static in nature and the software permits the direct integration of probability functions in place of static data. As well, it allows for a more transparent analysis of the various model sensitivities to data changes. The final aggregation was a weighted summation of the main objective functions (social → institutional) that contributed to the final CSI equation.

Table 6. 25. Social Criteria.

Indicator	Characteristic	Indicator Score
Availability of industry support of worker's well-being	No social support net - simply whatever support offered by familial ties	*0*
	Established yet informal community support structure to assist workers and families in times of illness and injury	*50*
	Basic industry or government supported benefits plan to support injured and ill workers (sick time, disability, and employment guarantee)	*70*
	Full coverage benefits plan for workers and their families	*100*
Injury rate	More than 15 workers injured per hundred	*0*
	National average for agro-industry workers (11.4 per 100 workers)	*35*
	OECD average for agro-industry workers (7.0 per 100 workers)	*50*
	Less than 4 workers injured per hundred	*75*
Balance of work and leisure	Excessive working hours with little time for leisure (>3500 hr or +70 hr/wk)	*25*
	Mildly excessive working hours (up to ~3000 hr or 60 hr/wk)	*50*
	Moderately balanced work and leisure time (~2500 hr or 50 hr/wk)	*80*
	Well-balanced work and leisure time (~2000 hr or 40 hr/wk)	*100*
Level of child labour	Extensive use of child labour resulting in interference with education	*10*
	Limited child labour (over 14) that permits continuation of education	*35*
	No child labour (according to local definitions)	*70*
	No child labour (according to UN definition)	*100*

Table 6. 26. Institutional Criteria.

Indicator	Characteristic	Indicator Score
Level of institutional support	Institutional structure is opposed to proposed sustainability measures	*0*
	Limited support structure from institutional organizations (banks, government departments, industry organizations)	*25*
	Strong external support (NGOs), but little internal support measures	*50*
	Strong internal institutional support for sustainability efforts	*85*
Demonstrable case studies/examples	No demonstrated success – strictly a pilot/theoretical strategy/project	*10*
	Demonstrated success with foreign application in a different industry	*45*
	Demonstrated success with foreign application in the same (or parallel) industry	*65*
	Demonstrated success with in-country application in a different industry	*70*
	Demonstrated success with in-country application within the same industry	*90*
Availability of appropriate technology transfer expertise	Cookie cutter application of foreign technologies	10
	Foreign expertise with basic understanding of cultural and societal strengths and gaps	50
	In-country expertise with deep understanding of potential barriers	75
	In-country training program – technology transfer is in progress	90
Efficiency of communication networks	Information silos prevent efficient communication	10
	Unidirectional government network disseminating national policy	35
	Bi-directional network between stakeholders and government but little connection with external support agencies, industry associations and or research communities	60
	Well established industry association with strong stakeholder participation and linked to the various levels of government and research institutions (e.g. petroleum industry)	100

Table 6. 26. Continued.

Indicator	Characteristic	Indicator Score
Ease of market access	Poor access to even basic commodity market (poor quality or excessive restrictions)	25
	No recognition or market access beyond commodity	50
	Recognition but hampered by inadequate access (lack of processing facilities) or inadequate market share for specialize product (sales difficulty)	60
	Established market niche with recognition	90

6.6 Model Evaluation – Costa Rican Case Study

Figure 6.17 presents the algorithm used in complete the data aggregations. The solid black lines represent the data flow when the model is being used to provide a comparative evaluation of two or more systems. In this instance, the user already has the necessary input data to describe the various system conditions (both qualitative and quantitative) and is using the model to evaluate either: (a) the change in relative sustainability of the system(s) over time or (b) to compare the relative sustainability of two different operations/systems. The dashed red lines represent the data flow when the model is being used as a decision support tool to aid the user in evaluating the relative sustainability of potential technological modifications or changes in operational practices. The description of the model programming and input can be found in Appendix E.

For the purpose of demonstrating the usefulness and applicability of this methodology, two evaluation scenarios were included in this thesis. The first was a comparative evaluation of the sustainability of two different systems and how it changed over time as a result of changes in practices. The second was a decision assistance operation aimed at providing an analysis of the relative sustainability for a number of theoretical system modifications available to a co-operative wishing to improve their economic and environmental performance. These scenarios were completed using data primarily collected during the fieldwork. However, in the absence of data specific to the Costa

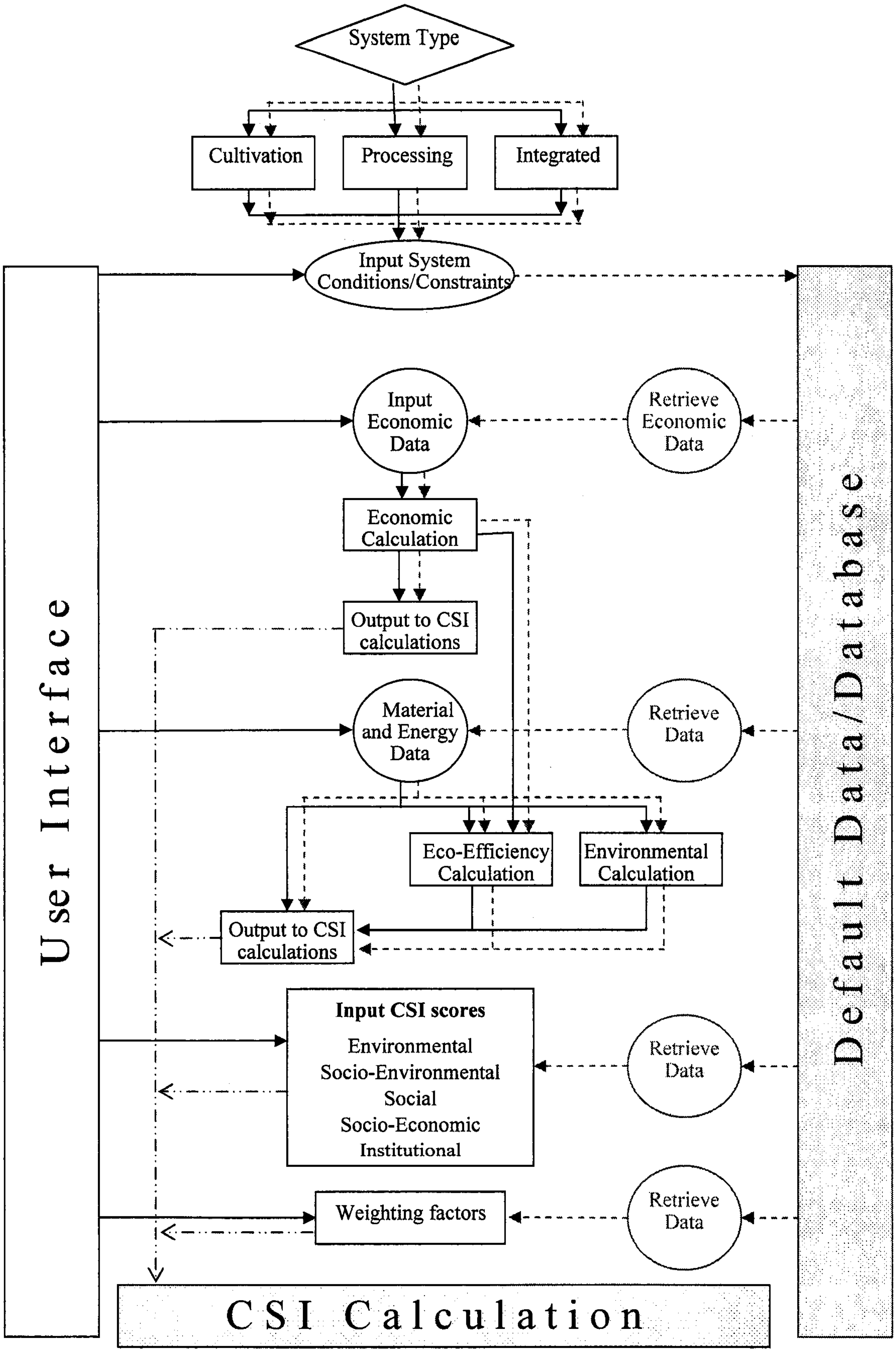


Figure 6.17. Program algorithm.

Rican coffee industry, source data was obtained from: (a) applicable studies related to the coffee industry, (b) applicable literature related to agro-industrial systems in Costa Rica, and (c) applicable literature related to agro-industrial systems in developing countries.

6.6.1 Case #1: Co-operative Sustainability Evaluation

A number of co-operatives were involved in a European funded program intended to improve their sustainability. The program was based on the application of ISO 14000 standards to beneficio operation and the Utz Kapeh Code of Conduct[†] to farming practices. The beneficios' participation in this program made available data that described systems actively trying to incorporate sustainability into their mandate. Some data was available from literature, others were produced by the program administrator and associated researchers (Danse, 2003; Wolters and Danse, 2003 and Schram, 2003). The balance of the data was collected directly from two of the co-operatives.

Co-operative #1 was located in the Puntarenas province. It was made up of ~450 member farmers and produces between 500 and 600 tonnes of dry green coffee per year. The co-operative was primarily monoculture plantations without shade at the outset of the project. Co-operative #2 was located in the Guanacaste province and was made up of approximately 140 farmers. They produce between 125-160 tonnes of dry green coffee per year. Similar to Co-operative #1, the plantations were largely monoculture plantation, but approximately 50% of the acreage was grown with some sparse shade trees (~35 trees per hectare). Farms with ground cover, cover crops or intercropping were not noted in significant number at the outset for either one of the operations.

The beneficio facilities for both co-operatives were standard wet processing operations. There was little to no monitoring of inputs or outputs beyond seasonally aggregated data regarding production, firewood consumption, electricity usage and water use. Both co-ops had to supplement the firewood supply available to the beneficio from coffee bush

[†] Utz Kapeh was developed four years ago by a consortium of Guatemalan grower-exporters together with the Ahold Coffee Company. It was intended as a consumer-driven, grower-accepted standard for responsibly grown coffee and was based on the EUREPGAP Protocol for Fruits and Vegetables. Eurepgap was developed by European retailers to provide basic assurance for food safety and environmentally and socially appropriate growing practices.

and shade tree prunings with wood of questionable origin particularly Co-op #1, due to the lack of shade trees. Parchment was used as an additional supplement. Both facilities operated aerobic lagoons as a wastewater treatment option, although the manager of Co-op#2 noted that the system was not monitored and there had been complaints associated with fouls smells and high mosquito populations originating from the lagoons. Both facilities had compliance issues with their wastewater at the beginning of the program.

Figure 6.18 presents an example the initial model input page that solicits information regarding the processing operations and the type of linkage to the farming systems. From the input data, the system constraints and conditions can be linked to calculations and indicator scoring used in the balance of the model.

6.6.1.1 Material and Energy Analysis. An analysis of the material and energy throughputs was conducted for the two co-operatives in order to provide comparison as well as evaluate changes over time. Table 6.27 presents the intensity of resource use and the changes that occurred over time. Figures 6.19, 6.20 and 6.21 present the change in water consumption, electricity usage and firewood consumption over the transition period between the two co-operatives. It should be noted that, the co-operatives could not produce data about the use of agrochemical during the transition period. All that was available was the previous average usage, approximate usage for the 2002/2003 season and anecdotal indications of regarding the intensity of use.

6.6.1.2 Financial Analysis. A cost benefit analysis was completed for the two co-operative beneficios evaluating the projected economic performance of the original system, the economic performance during the transition and the new projections based on the modifications. Figures 6.22 present an example input page from within the model used for the economic analysis within the cultivation stage. For each of the systems, the data related to cultivation (inputs, outputs, yields, etc) were taken as the average of the overall co-operative as reported by the co-operative managers (whom in both cases were all the beneficio managers). Beneficio data was used directly.

System Considerations

Is there any system of monitoring inputs and outputs?

If yes, what is the water usage per tonne of coffee?
- fire wood (cubic meters)?
- kwh/tonne depulping?
- kwh/tonne mucilage removal?
- amount of parchment used in furnaces (percentage of total produced)?
- amount of other fuel?
- amount of BOD (mg/L) in wastewater?
  - COD (mg/L)?

What is the average annual capacity of the mill (fanegas)?

What is the maximum daily capacity?

What is the average daily capacity? — Input

Does the depulping system operate in parallel or series?
- If series, how many lines?
- If parallel - how many receiving hoppers?
  - how many 1st grade depulpers?

Present use of waste heat?

Type of wastewater treatment system? (AL, AEL, AED, other)

Any revenue generated/saved through use of by-products?

Are there any environmental concerns or complaints that need immediate attention?
- What to they involve? (wastewater, pulp, air quality, firewood, other) — Input

How much space/land is available for upgrades and/or technology installations?
A=none, B=<0.5 hectare, C=0.5-1 hectare, D=>1 hectare

What is the beneficio's linkage with coffee farmers? (Regional, Local, Coop)

Is there an in-house OHS or environmental training program for workers?
- If yes, how many hours per quarter are spent training?

Percentage of workers the are from the local community?

Number of workers with specific educational backgrounds or skill sets:
- Unskilled labour (in a technical sense)
- Some vocational training
- Completed technical training
- University educated (business or technical)

Minimum age permited to work in mill?

Injury rate last five years? (if available) — Input

Average Rainfall during harvest season — Input

Inputs are linked to other equations and functions throughout the model.

Figure 6.18. Input table for processing system considerations.

Table 6.27. Material and Energy Intensity (per tonne of green coffee except where noted).

Description	Co-op#1		Co-op#2	
	Original	Modified	Original	Modified
Electricity (kwh)	283	152	256	196
Water Consumption (m^3)	26.1	16.3	15.9	10.2
Firewood (m^3)	1.52	0.22	1.74	1.09
Inorganic Fertilizer	228	151†	370	290†
Nemacides/Fungicides (kg / ha)	50-80	25-40	50-80	25-40
Herbicdes (L / ha)	4	1	4	1

† - these number are based the use fertilizer per unit output of coffee. However if one calculates fertilizer use based on the output of all crops, the efficiency of fertilizer use per unit output improves another 10-30%.

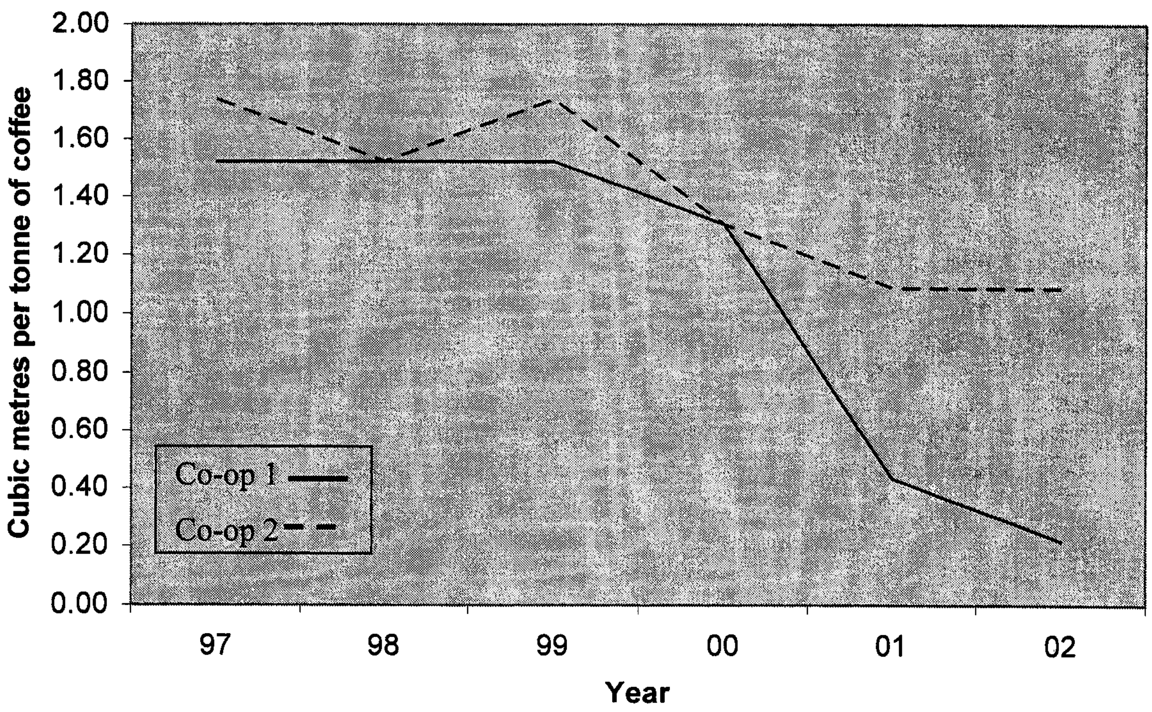


Figure 6.19. Water consumption during transition

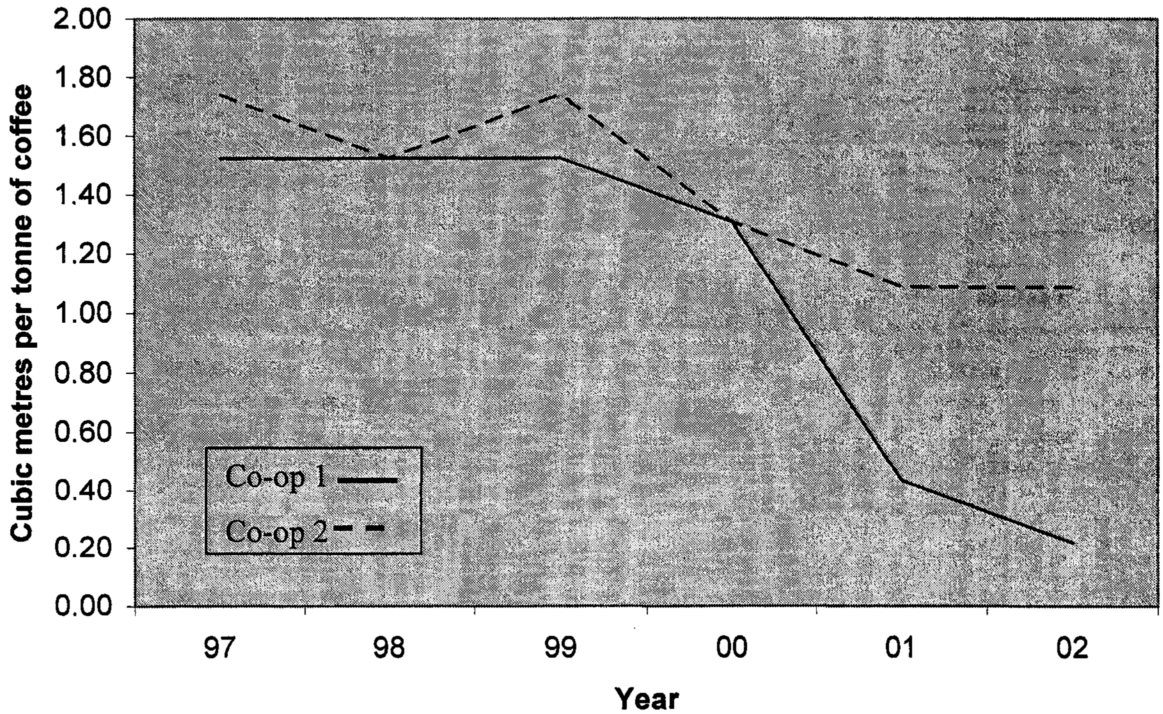


Figure 6.20. Electricity consumption during transition.

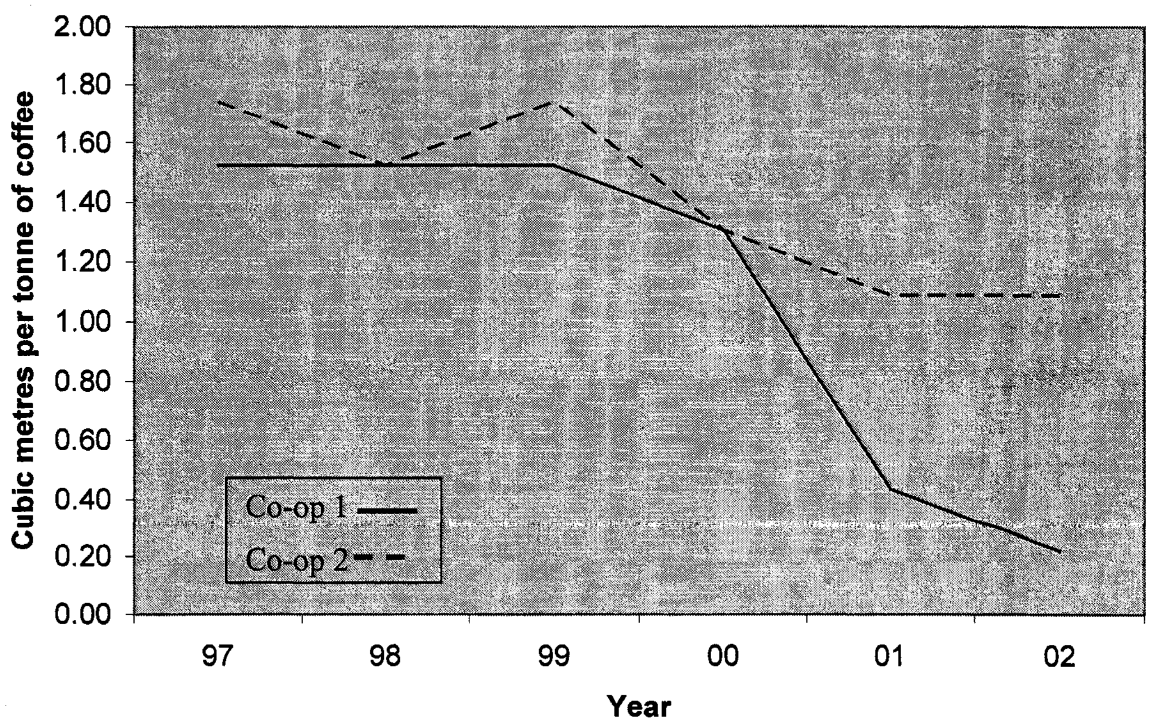


Figure 6.21. Firewood consumption during transition.

Cultivation
Economic Calculations

	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8
Material Input								
Soil Amendments								
Fertilizer								
Organic								
Inorganic								
Pesticides								
Fungicides								
Herbicides								
Pesticides								
Nematicides								
Seedlings								
Alternative Crops								
Labour Costs								
Fertilizer Application								
Pesticide Application								
Harvesting								
Planting Shade trees[1]								
Maintaining Shade Tree[2]								
Pruning Shade Trees								
Pruning Coffee Coffee								
Planting Seedlings								
Planting Crops								
Weeding								
Erosion Control								
Soil Conditioning								
Harvesting Crops								
1 - only for systems being converted to polyculture								
2 - only for first three years after planting								
Fixed Costs								
Repair and maintenance								
Taxes								
Loan interests								
Revenue								
CoffeeYield								
Multiplier (based on niche)								
Crops								
Timber								
Firewood (Prunings)								
Present Value of System								

Net Present Value Calculations

Number of years into the future?								
Interest rate								
Coffee Yield distribution function								
Coffee pricing distribution function								
Crop Yield distribution function								
Crop pricing distribution function								

System 1	NPV (	0	) =
System 2	NPV (	0	) =
System 3	NPV (	0	) =
System 4	NPV (	0	) =
System 5	NPV (	0	) =
System 6	NPV (	0	) =
System 7	NPV (	0	) =
System 8	NPV (	0	) =

CSI Inputs for Cultivation Systems
CSI Inputs for Integrated Systems

Figure 6.22. Input for economic data (cultivation).

directly. Both sets of economic data were modified to reflect present value.

For each system the data was used to: (a) estimate parameters for inputs, outputs, costs, etc… of the overall operation, (b) compute investments needed to make the transition to "sustainable production" as defined by the project (Danse, 2003), (c) create a cash flow over a 10 year period, (d) incorporate the risk for production, price and interest rate variations using a Monte Carlo approach, (e) calculate the estimated NPV for the two systems, and (f) calculate the probability of having an NPV greater than 0. For the economic analysis of the beneficio operations, the NPV was calculated as a relative comparison against the original operation, such that the NPV for the original operation is considered zero. Therefore, all modifications (which are a part of the sustainability program) were assessed as being more or less profitable than the original state, i.e. NPV > or < 0. It should also be noted that for the purpose of this calculation, interest on loans taken by farmers to cover production costs were not considered. In most cases, the loans were supplied by the co-operative and interest rates were kept to a minimum, unlike farmers that borrow from privately owned or TNC beneficios where the loan interests are normally 10% (after inflation).

6.6.1.2.1 *Cultivation.* Coffee production costs result form inputs of materials, labour, administration, transportation, repairs and maintenance. The expenditure categories are the same as those presented in Table 5.13, but varied for the two systems in question for this evaluation. Table 6.28 highlights the production costs before becoming involved in the sustainability project. Table 6.29 shows the initial investments and incremental costs incurred by farmers to transition under this program. Costs include planting shade trees (leguminous and fruit trees), maintaining the shade trees, and training farmers and their workers on the proper handling and application of agrochemicals in line with an "integrated pest management" program developed in collaboration with local researchers and the European "Good Agricultural Practices" standards organization (EurepGAP) (Danse,2003). Table 6.30 displays the average production costs in 2003/2004, the point at which the system was considered to be stable.

Table 6.28. Coffee production costs per hectare in 1997 (average using the 2003 CRC:US$ exchange rate)

Description	Direct Cost (US$/ha)[a]	
	Co-op #1	Co-op#2
Harvesting Coffee	570	495
Post Harvest Berry Collection	46	37
Pruning Coffee Trees	52	62
Pruning Shade	0	35
Fertilization	310	265
Agrochemical Application	194	177
Weeding	0	0
Cultivation/Planting of Seedlings	70	65
Soil Management	30	23
Social Security (26.7%) - incl family labour	339	310
Subtotal (A)	**1611**	**1,471**
	Indirect Costs ($/ha)	
Transportation	55	97
Other Costs[b]	417	472
Subtotal (B)	**472**	**569**
Total per hectare	**2083**	**2040**
Kg of coffee per hectare	1840	1656
Cost per kilogram of coffee	**1.13**	**1.23**

a – includes labour + materials
b-includes maintenance and depreciation of equipment, taxes and license fees

Table 6.29. Initial Investments and incremental costs associated with transition ($/ha).

Description	Co-op#1	Co-op#2
Planting Shade Trees (@$1.50/tree)[a]	240	186
Maintaining Shade Tree (@1.20/tree)[b]	192	148.80
Training workers on handling and applying agrochemicals	150[c]	150

a- only in the first year of transition
b-only in the second and third years of transition
c- The cost was ~$150 per farm. While the size of farm ranged dramatically the average farm size was 1 ha for both co-operatives.

Table 6.30. Resulting coffee production costs per hectare (as of 2003 harvest)

Description	Direct Cost (US$/ha)[a]	
	Co-op #1	Co-op#2
Harvesting coffee	520	495
Harvesting Crops[a]	*80*	*96*
Post Harvest Berry Collection	37	34
Pruning Coffee Trees	52	62
Pruning Shade	64	55
Maintaining Crops[a]	*40*	*48*
Fertilization	260	243
Agrochemical Application	97	84
Weeding	28	32
Cultivation/Planting of Seedlings	70	65
Soil Management	45	36
Social Security (26.7%) - incl family labour	313	295
Subtotal (A)[b]	**1486** ***(120)***	**1401*(144)***
	Indirect Costs ($/ha)	
Transportation	55	97
Other Costs[c]	417	472
Subtotal (B)	**472**	**569**
Total per hectare	**1958** ***(120)***	**1970** ***(144)***
Kg of coffee per hectare	1656	1564
Cost per kilogram of coffee[d]	**1.18**	**1.25**

a- Includes labour and materials
b-This cost does not include harvesting and maintaining of other crops.
c-These costs (maintenance, depreciation, etc…) largely remained the same.
d- This calculation does not include costs for harvesting and maintaining other crops.

Due to the limited time scale there was insufficient yield data to empirically determine the revenue generated by the additional crops. Co-op #1 interspersed orange trees with nitrogen fixing varieties and these became ready for harvesting in 2002. Co-op #2 introduced cocoa, bananas and avocados as part of the shade trees. At the time of data collection, the banana and avocado trees were producing, while the cocoa trees were still too small to produce a crop of any significance. The other most popular crops (beans and tomatoes) were largely used for farm consumption or sold intermittently at the local markets. As such, the literature data which indicated that fruit sales generated within coffee agroforestry systems can constitute between 11 and 30% of the coffee revenue was used (Philpott and Dietsch, 2003; and Lyngbaek et al, 2001). The deviation in possible coffee pricing was incorporated into the model using a probability functions generated from an analysis of historical coffee pricing (ICO, 2004). Gobbi (2000) suggested that the possible decline of the coffee yield due to increased shade be incorporated using a triangular probability function (minimum, most likely, maximum) after the second year of (-5,-2,0) and after the six year point, a function of (-15%, -10%, 0%).

The other minor sources of income for the farmers included the sale of the coffee bush prunings (and later the shade prunings) to the beneficio for use within the coffee drying system. This, however, was left out of the revenue calculations for two reasons: (a) the amount was so small, and (b) most of the firewood would be sold to the co-operative's beneficio and as such was an internal transaction that would result in a net revenue of zero. As well, the dividend paid to the farmers by the co-operative was not included as it also was considered a net revenue of zero.

6.6.1.2.2 Processing. Due to the lack of disaggregated data available regarding detailed operational costs at the system level, the financial analysis of the operations was completed at a higher level. The NPV of the systems were calculated based on investments in new technologies or system improvements (Table 6.31), new revenue streams and the change in economic performance of the system. As such a NPV of 0 was given the CSI score of 50, which indicated no economic change (i.e. economically neutral). NPV values of greater than or less than zero were scored accordingly and were considered to be a weighted average between the short term NPV of the system vs the long term NPV. This was to reflect the importance of short pay-back period, balanced against possible longer term economic sustainability. The individual weight given to short-term vs long-term outcomes reflected the position of the co-operative's management in this regard. Risk was scored in a way similar to that performed within the cultivation analysis, where the score was considered to be the percentage that the NPV of the system was greater than zero, i.e. profitable. The risk data was aggregated using the same weighted summation as used for the long-term and short-term economic performance.

6.6.1.2.3 Output. Table 6.32 presents the financial analysis for the two scenarios within each of the co-operative operations. The NPV calculations were based on the annual costs and revenues of each system as a result of participation in the sustainability project and the predicted costs and revenues if the systems had remained the same. Within the cultivation calculations, the most significant change was in the balance between labour and material costs. With the implementation of changes in cultivation practices, there was a reduction in the expenditures on agrochemicals and fertilizers, while at the same time there were significant increases in the labour requirements for fertilizer application, weeding and pruning of shade trees. The production price per kg of coffee increased due to slightly reduced yields and increased labour costs. The reduction in yields contributed to a gradual decrease in net income in the first three years. In year four, however, the co-operatives were able to secure a premium price for their coffee and Co-op #1 began receiving revenue from the orange crops.

In year five, Co-op #2 began receiving income from the banana and avocado crops. In both co-operatives, the managers also expressed an improved stability (albeit immeasurable) due to the ability of the farmers to secure a percentage of subsistence foodstuffs from the sale and bartering of the cover and inter-row crops introduced to the coffee fields.

Table 6.31. Initial Investments and incremental costs associated with new system and subsidies†.

Description	Co-op#1	Co-op#2
Implementation of Monitoring[a]	1500	500
	(1200[b] +300[c])	(200[b]+ 300[c])
System Reconfiguration – Water (Recycling)	2200	500
- Mechanical Mucilage removal	0	400
- Solar Dryer Installation	40000	0
- Automated Parchment Feeders	0	1600
Labour changes (1 additional full-time @ 1.20$US/hr)	1200	n/a
Subsidies (-)	31200	400
Total Initial Investment	**13700**	**2600**

† - approximate values
a – cost of dedicated employee and equipment
b – employee costs will continue
c – equipment costs are a one time investment for flow meters, scales, and other equipment used for monitoring

Table 6.32. Financial Analysis.

Description		Co-op#1		Co-op#2	
		Original	Modified	Original	Modified
Cultivation (per ha)	NPV (5) mean	$3,592.65	$3,478.74	$2460.86	$2259.40
	% Probability ≥ 0 (risk)	90.5%	89.7%	80.2%	77.0%
	NPV (10) mean	$6,328.52	$7,240.85	$4,334.86	$5188.81
	% Probability ≥ 0 (risk)	90.5%	96.3%	80.2%	86.5%
Processing[a]	NPV (5) mean	$3,785.20		$1,065.97	
	~ per tonne	$6.30		$7.10	
	% Probability ≥ 0 (risk)	100		100	
	NPV (10) mean	$33,989.10		$6,921.26	
	~ per tonne	$56.65		$46.14	
	% Probability ≥ 0 (risk)	100		100	

a – as compared to original operation

6.6.1.3 Eco-Efficiency. Data related to material and energy-use, financial performance and system parameters were used to complete an eco–efficiency evaluation of the two system. The three indicators used for eco-efficiency (Table 6.14) were material-use intensity, energy-use intensity and return on resource (or by-product) use (ROR). This can be presented as the change in intensity over time if temporal data is available, the documented percentage of recycling within the operation or as a comparison to the theoretical/ideal minimum possible, depending on what user data is available. In this case, the material and energy use intensities were calculated as the percent increase over the theoretical ideal within the coffee industry. In regards to the ROR, an eco-efficiency (EE) factor was used, which represented the multiplier assigned to a particularly usage which captures its level of "value-added" contribution ranging from 0 (unused and untreated) to 4 (full usage creating value at a tertiary level). Table 6.33 presents a better description of this factor and Table 6.34 presents the evaluation of the two co-operatives in this case study and includes the eco-efficiency (EE) factors assigned to each, where applicable. The scale for input-use intensity was established as the inverse relationship between the ideal situation and the existing state (normalized to 100), and each input being assigned weighting factor to represent its impact as compared to the others. The scale for ROR was calculated as the sum of the percentage use of the by-product multiplied by it factor divided by the sum of percentage use multiplied by the maximum usage factor that is technically feasible for the resource.

6.6.1.4 Discussion. Table 6.35 presents the indicator scores for the two co-operatives from the model, with the predicted scores based on maintaining the status quo and the scores associated with changes made as a result of stakeholder sustainability decisions and participation in the project.

As a result of their sustainability efforts, Co-operative # 1 generated their own brand to capitalize on market niche and as such no longer depends on institutional factors from market access (see the score of 100 for "ease of market access"). The brand received additional recognition from implementing ISO 14000 and committing to eliminating the use of illegal workers (children and illegal migrants). This market niche also opened up

Table 6.33. Eco-Efficiency Factors.

Description	Factor
Unused - untreated and discharged to the environment	0
Unused - primary treatment	1
Used - primary fashion (recycled, basic fuel, compost)	2
Used - secondary fashion (secondary cascade[a])	3
Used - tertiary fashion (implementation of renewable energy or higher level cascade [b])	4

a – secondary cascade refers to a process that provides benefits on two levels – e.g. use pulp as growth substrate for maximum nutrient extraction and then apply as compost.

b –higher level cascade refers to a process that provides higher level benefits such as production of biogas, electricity or value-added products of higher $ values (alcohol, pectins or other compounds)

Table 6.34. Eco-efficiency calculations.

Description	Co-op#1		Co-op#2	
	Original	Modified	Original	Modified
Water-use Intensity[a]	653%	408%	398%	255%
Firewood-use Intensity[a]	760%	110%	870%	495%
Electrical Intensity[a]	257%	138%	233%	178%
Agrochemical Usage - Fertilizer	228%	151%	370%	290%
- Herbicides	400%	100%	400%	100%
- Pesticides	500-800%	250-400%	500-800%	250-400%
Return on Resource (By-products) Use[b]				
Wastewater (EE factor)	100% (0.5)	25% (2) 75% (0.5)	25% (2) 75% (1)	40% (2) 60%(1)
Waste heat	100% (0)	90% (4) 10% (0)	100% (0)	100% (0)
Mucilage	100% (0.5)	100%(0.5)	100% (0.5)	100%(2)
Pulp	40% (2) 60%(0.5)	100% (2)	100%(1)	100% (2)
Parchment	100% (2)	100% (2)	100% (2)	100% (2)

a - as compared to theoretical ideal
b - actual use will be highlighted in discussion.

Table 6.35. CSI indicator value tables from model.

Indicator	Wt	Co-op #1 Original	Co-op #1 Modified	Co-op #2 Original	Co-op #2 Modified
Socio-Environmental Criteria					
Compliance	0.2	0	25	0	50
Training requirements	0.1	45	60	25	70
Stakeholder attitudes towards environmental issues	0.4	50	85	30	70
Alignment with national sustainability policies	0.1	40	50	50	60
Availability of reliable data	0.2	45	45	45	65
Environmental Criteria					
Level of System Monitoring	0.2	10	85	25	75
Resource Consumption	0.1	50	75	45	65
Impacts of Wastes	0.2	36	59	36	51
Response	0.1	35	85	40	80
Soil Health	0.2	61	73	65	79
System Resilience	0.1	34	62	43	68
Biodiversity levels	0.1	10	50	15	60
Eco-Efficiency Criteria					
Material-Use Intensity	0.25	26	53	25	51
Energy-Use Intensity	0.25	26	82	27	38
Return on Resource Input	0.5	39	64	43	56
Economic Criteria					
NPV (i)	0.5	75	100	75	100
Perceived Economic Performance		n/a	n/a	n/a	n/a
Risk Factor (i)	0.5	71	93	65	82
Perceived level of Risk		n/a	n/a	n/a	n/a

Table 6.35. Continued.

Indicator	Wt	Co-op #1		Co-op #2	
		Original	Modified	Original	Modified
Socio-economic Criteria					
Level of community stability	0.25	45	68	65	97
Level of bargaining power held by industry stakeholders	0.2	65	85	65	85
Access to credit	0.3	50	65	50	90
Pay rate compared to living costs	0.25	50	55	50	55
Social Criteria					
Availability of industry support of worker's well-being	0.25	70	75	70	95
Injury rate amongst workers	0.25	35	50	35	50
Balance of work and leisure	0.25	80	80	80	85
Child Labour	0.25	35	70	35	70
Institutional Criteria					
Level of institutional support	0.2	50	65	50	75
Demonstrable case studies/examples	0.2	90	65	90	90
Availability of appropriate technology transfer expertise	0.2	n/a	50	n/a	n/a
Efficiency of communication networks	0.2	20	65	20	65
Ease of market access for resulting product	0.2	50	100	50	85

improved credit from local financial structures. This allows members access to lower interest loans that are not typically available (although the loans are still with the local institution, not held by the co-operative). The co-operative also used its large numbers to negotiate for better pricing on farm equipment and materials. However, while the co-operative contributes positively to their stakeholders there is little interaction with the co-operative beyond its own boundaries. Community stability is supported indirectly by the stability of the local coffee co-operative simply due to its influence on local economy.

Technically, the most profound change to the processing system was the installation of a solar powered drying system that has virtually eliminated the need for firewood within Cooperative #1. In addition, the older dryer system required substantial electrical input; eliminating it dramatically reduced the electricity consumption. In this instance, the technology transfer was undertaken at the local level supported by an international NGO in the form of a subsidy and provision of staff training. This provided a positive balance for the system's NPV. Without the subsidy it would have taken ~8.5 years to get a positive return on investment by the cooperative.

There has been some improvement in the reduction of water consumption through improved monitoring and the installation of basic recycling systems. However, the co-operative uses water as a transportation mechanism (to move the product through the system) and still removes all mucilage using fermentation, both high water consuming activities. Wastewater is still an issue, although it is now meeting compliance. However, there is no exploitation of the high biological and nutrient loading for the production of value added products.

Shade tree density increased to ~160 trees/hectare and >50 % of soil was directly covered during rainy season (intercropping and specific ground cover leguminous plants). As such, soil erosion has been reduced anecdotally and soil health has been increased due to increase in biomass and a reduction in agrochemical inputs. Workers have all been trained in the use of pesticides and chemicals are used on a situational-specific basis. With increases in shade and intercropping, much pulp is used ineffectually. Influence on women is unknown, although children have benefited. There is now a strict policy for employment and the working conditions and basic rights of workers are now monitored.

Within Co-operative #2 much of the increase in sustainability resulted from the increased focus regarding socially related issues. The co-operative offers many services to their members including technical assistance and advice regarding sustainable coffee production, and soil conservation and has taken an active role in the surrounding community, such as forestation projects, educational programs, land-redistribution initiatives. The co-operative is also one of the larger contributors to the local development committee. It has has created various storefronts, which provide wholesale prices on hardware, agricultural products, and general goods. It also now offers credit to for all of its members.

A recycling system was already in place, however, co-operative #2 was able to improve water consumption through improved monitoring. In addition, a mucilage removal system was installed in 2000 to process approximately 50% of coffee and reduced water consumption even further. This coincided with a slight increase in electricity consumption. However the time of day usage limited the negative impacts associated with this increase. During times of peak electricity, Costa Rica turns to the combustion of imported fossil fuels to provide the excess requirements. During the balance, Costa Rica's electricity is produced by a significant number of small to medium size hydroelectric generators, wind power and geothermal based electrical generation. By operating the mechanical removal system in off-peak hours, it ensures that the system makes use of electricity that is being generated sustainably (hydro, geothermal or wind). The continued monitoring of electricity consumption by equipment, and implementing a program to replace failed pumps and motors with properly sized higher efficiency models reduced electricity consumption. An additional strategy that was suggested during the site visits was the installation of variable-speed motors to operate the depulping machines such that the last half of the series could be decoupled. It is presently being considered.

The addition of an automated parchment feed to the drying furnaces was calculated to have reduced the firewood consumption by 37%. This was due to a more consistent production of heat energy as the system would release a continuous amount of parchment in relation to the heat requirements, with the firewood added to maintain an ideal temperature. Optimizing parchment use reduced the input of firewood. An additional suggestion was made to stockpile a year's supply in advance such that the wood was seasoned (as opposed to green) thus maximizing the heating value.

In the fields, shade tree density averaged at ~160 trees/hectare and ~40 % of soil was directly covered during rainy season by intercropping and specific ground cover leguminous plants. Therefore, soil erosion had been reduced and soil health had been improved, but the many years of intense sun coffee cultivation has left the soil in worse condition than was found within the farms of Co-operative # 1. However, the increased biomass and reduction in agrochemical inputs has improved the evaluated condition of the samples gathered in the region. Similar to Co-operative #1, workers have all been trained in the use of pesticides, chemicals are used on a situational-specific basis and coffee compost is returned to fields thus closing the cycle.

Table 6.36 presents the outputs scores for the two systems. Both co-operatives demonstrated a significant improvement in overall sustainability over the time period evaluated, although the gains were made in different areas. One point that is highlighted is that there is stillroom for significant improvement, particularly in the area of eco-efficiency and returns from resource use (i.e. by-products). There is very little integration of by-product wastes into a value-added system structure. The model has been created to preferentially reward the integration of such strategies and as such, promotes its inclusion in any environmental management plan.

Table 6.36. Model output of CSI evaluation scores.

Indicators	Weights	Co-op #1		Co-op #2	
		Original	Modified	Original	Modified
		Indicator Values			
Social	0.14	55.0	68.8	55.0	75.0
Socio-economic	0.14	52.8	67.2	56.8	81.4
Economic	0.15	73.0	96.5	70.0	91.0
Eco-efficiency	0.14	31.2	66.1	32.8	49.1
Environmental	0.15	34.3	70.6	39.5	68.3
Socio-environmental	0.14	37.5	59.0	28.5	64.0
Institutional	0.14	52.5	69.0	52.5	78.8
Total Score		48.2	71.3	48.0	72.7

It should be noted that the fact that the composite sustainability scores were similar for both operations was an expected outcome. Anecdotally, during the time spent with the co-operatives, the qualitative assessment showed that, while each had different specific objectives with regards to the anticipated improvement, the operations were comparable in terms of holistic sustainability. This conclusion was supported by the outcome of the model, despite the significant variability in some of the individual criteria. As such, it demonstrates the efficacy and usefulness of the model to evaluate sustainability (in this case over time) and obtain a realistic assessment, particularly if it is being used by an untrained person.

6.6.2 Case #2: Decision Assistance Evaluation

This simulation was designed to assist a co-operative east of San Jose with the development of a sustainability plan for their operations. The focus of the evaluation was primarily the processing operations. However the cultivation practices were included with the operational boundaries so that uses for coffee pulp and farm biomass that would result from a transformation from sun-coffee monoculture operations to shade-coffee, intercropping operations could be demonstrated. It was not the aim of the evaluation to provide a detailed outline of how to implement sustainable practices on the farms, only the costs and benefits of doing so were highlighted.

Originally the beneficio was built as a farm based operation to process the coffee onsite instead of taking it to the next closest facility, which was 20 km away and difficult to access at the time of construction in the early 1960s. The same individual who built the beneficio owned the farm. Since it came into operation, the original owner had expanded the operation to include ~90 other local farmers and 200 hectares of monoculture sun-grown coffee, and is now operated as a co-operative. Total production is approximately 300 tonnes per year. Presently the coffee pulp is largely unused. Farmers rely on chemical inputs for fertilization and most of the pulp degrades slowly in piles behind the beneficio. Due to its distance away from San Jose, this co-operative does not take its pulp to any of the centralized composting facilities in the Central Valley.

There is limited wastewater treatment. The beneficio presently uses an aerobic lagoon system which are not well kept and thus result in compliance failures at least once a season. There have also been complaints from local area residents about smells and mosquito problems in the vicinity of the systems.

The evaluation of possible alternatives was based on the theoretical system proposed in Figure 6.10. For any other industrial systems to be evaluated using this model, there will need to be an assessment of available cleaner production strategies and possible resource-use options conducted on a case by case basis such that the variety of possible alternative system designs can be integrated directly into the evaluation.

6.6.2.1 Theoretical Alternatives. Table 6.37 presents the input data and distribution functions used in the evaluation. The series of questions posed to the user was used to define the system constraints. In this instance the most significant points to be noted were as follows: (a) there was no system monitoring, (b) the average daily throughput was less than 50% of the mill's capacity for 4 out of 6 months of operation, (c) the depulping system operated in series, (d) as a co-operative, the beneficio had access to land for facility expansions, (e) the availability of firewood was of concern, (f) erosion was a significant concern, particularly due to the intensity of rainfall events even during the "dry season", (g) compliance with wastewater regulations was an issue, (h) most workers were local resident farmers and as such there were strong ties between the mill's operations and the surrounding farms, and (j) the surrounding community was almost solely dependant on the coffee co-operative and one other sugar co-operative for employment and economic well-being. The material and energy usages were input as well. The system constraints and conditions were then applied to a predetermined list of possible sustainability options as presented earlier in figure 6.10. Table 6.38 provides the model output of "proposed" options that could be implemented. These are the options that were then evaluated using the CSI model.

Table 6.37. Input Considerations for Decision Support.

System Considerations

Is there any system of monitoring inputs and outputs?	N	
If yes, what is the water usage per tonne of coffee?	18.4	
fire wood (cubic meters)?	1.78	
kwh/tonne depulping?	267	
kwh/tonne mucilage removal?	0	
amount of parchment used in furnaces (percentage of total produced)?	100	
amount of other fuel?		
amount of BOD (mg/L) in wastewater?	1800	
COD (mg/L)?	2000	
What is the average annual capacity of the mill (fanegas)?	60000	
What is the maximum daily capacity?	1000	
What is the average daily capacity?	Input	See graph over time
Does the depulping system operate in parallel or series?		
If series, how many lines?		
If parallel - how many receiving hoppers?	4	
how many 1st grade depulpers?	4	
Present use of waste heat?	none	
Type of wastewater treatment system? (AL, AEL, AED, other)	AL	
Any revenue generated/saved through use of by-products?	no	use of pulp
Are there any environmental concerns or complaints that need immediate attention?	Y	
What to they involve? (wastewater, pulp, air quality, firewood, other)	Input	See CSI (Sen)
How much space/land is available for upgrades and/or technology installations? A=none, B=<0.5 hectare, C=0.5-1 hectare, D=>1 hectare	D	
What is the beneficio's linkage with coffee farmers? (Regional, Local, Coop)	C	
Is there an in-house OHS or environmental training program for workers?	N	
If yes, how many hours per quarter are spent training?	0	
Percentage of workers the are from the local community?	95	
Number of workers with specific educational backgrounds or skill sets:		
Unskilled labour (in a technical sense)	27	
Some vocational training	1	
Completed technical training	2	
University educated (business or technical)	2	
Minimum age permited to work in mill?	15	
Injury rate last five years? (if available)	Input	
Average Rainfall during harvest season	Input	

Table 6.38. Sustainability Options for Theoretical System.

Potentially Suitable Options	Non-suitable options
Processing	
Monitoring and system reconfigeration †	
Anaerobic digestion (heat production)	
Anaerobic digestion (electricity production)	Solar dryers
High efficiency furnace (fluidized bed)	
Aquaponic operation	Pectin/alcohol production
On-site composting	Mushroom production
Mulch production from shade cultivation	

† - recycling, decoupling pulping lines, mechanical mucilage removal and automated parchment feed.

Table 6.38 also presents those options that were not considered suitable. In this case solar dryers were not feasible to the regions climate, which was characterized by extensive period of rain and cloud cover even during the "dry" season. Pectin and alcohol production were not considered feasible. This was due to: (a) that there would be insufficient mucilage available to make it viable as an independent operation, and (b) the relatively remote location of the facility in relation to a larger industrial center where there could be a multiple feedstock that make the option more attractive. Finally, mushroom production was deemed unsuitable at this time due to a complete lack of any available market. Mushroom consumption is extremely limited in the Costa Rican diet, although the possibility of using waste heat to dry a mushroom crop and make it available internationally should be investigated in the future. As well, due to financial conditions of the present Costa Rican industry, it was not suggested that both furnace and anaerobic digestion be installed. In the present economic market it would be very difficult to generate the necessary funding to pay for both systems in anything other than a foreign funded pilot project.

From these theoretical alternatives, the various system integrations that were evaluated are described in Table 6.39. The data requirements for these calculations are outlined in Appendix E.

Table 6.39. Evaluated Systems.

System Number	Description
System 1	Shade production and composting with monitoring and system reconfiguration.
System 2	System 1 plus anaerobic digestion (biogas used as heating source)
System 3	Same as above with electricity generation in addition to heat source
System 4	System 1 plus high-efficiency furnace
System 5	System 1 plus aquaponic operations

6.6.2.2 Financial Analysis. Tables 6.40 and 6.41 provide an economic forecast of the costs and benefits associated with the selected options. The @RISK program (Palisade Corporation, Ithaca, New York, USA) was used to create a Monte Carlo simulation that input a range of values for interest rates, funding probabilities, coffee revenues, and coffee yields. The estimates used in the evaluation were derived from information collected from technology vendors such as BTG (Hensen, 1998) and Bioflame (Buchanan, 2004), the performance data of the sustainable coffee project (Danse, 2001, 2002 and 2003), input from the Asociacion de Beneficiadores del Costa Rica (ABCR, 2003) and the Asociacion de Productores Organico de Turrialba (APOT, 2003), coffee industry researchers (Schram, 2001 and Schram, 2003) and the general input regarding operations costs and expenditure from the various mill managers interviewed over the course of the field study.

Tables 6.40 and 6.41 provide the average operational cost of the co-operative farmers and the projected cost resulting from a transition to shade-grown coffee with an average of 160 trees/hectare and intercropping. It is estimated the costs per kg of coffee will go down with a transformation to shade-grown coffee, due to the abnormally high costs of fertilization in relation to the coffee yield. Soil erosion and nutrient leaching are exacerbated by intense rain events that characterize the region and a higher than industry average level of chemical input is required

Table 6.40. Estimated changes in cultivation costs.

Description	Direct Cost (US$/ha)[a]	
	Present	Estimated[b]
Harvesting Coffee	382	382
Harvesting Crops	0	*80*
Post Harvest Berry Collection	46	46
Pruning Coffee Trees	52	52
Pruning Shade	0	60
Maintaining Crops	0	*40*
Fertilization	410	200
Agrochemical Application	221	100
Weeding	0	60
Cultivation/Planting of Seedlings	70	70
Soil Management	31	60
Social Security (26.7%) - incl family labour	324	307
Subtotal (A)	**1536**	**1337(*120*)**
	Indirect Costs ($/ha)	
Transportation	37	37
Oher Costs[c]	384	384
Subtotal (B)	**421**	**421**
Total per hectare	**1957**	**1758 (*120)***
Kg of coffee per hectare	1426	1355
Cost per kilogram of coffee	**1.37**	**1.28**

a – includes labour + materials
b – based on cost averages from the sustainable coffee project (Danse, 2003) and on limited shade farm data
c-includes maintenance and depreciation of equipment, taxes and license fees

Table 6.41. Initial Investments and incremental costs associated with transition ($/ha).

Description	Cost of Conversion
Planting Shade Trees (@$1.50/tree)[a]	240
Maintaining Shade Tree (@1.20/tree)[b]	192
Training workers on handling and applying agrochemicals	150[c]

a- only in the first year of transition
b-only in the second and third years of transition
c- The cost was ~$150 per farm. While the size of farm ranged dramatically the average farm size was 1 ha for both co-operatives.

to maintain a reasonable level of soil fertility. The introduction of ground cover and nitrogen fixing species of crops and trees are predicted to have a dramatic effect on the soil quality and fertility in a relatively short period of time. The scores for soil health and system resilience resulting from a transition in practices were estimated with a normal distribution ranging from $\pm$ 10%. However, if a more detailed analysis was desired, the output from a RUSLE equation could easily be incorporated at this juncture if data was available.

Table 6.42 provides the estimated costs associated with the implementation of the proposed changes, the amount of subsidy possibly available under the present conditions ,the probability of getting the subsidy and whether financing is available from non-financial institutions (i.e. vendors). The information regarding subsidies was largely anecdotal information gathered from Schram (2003), Rusillo (2004), Danse (2003) and the director of the United Nations National Cleaner Production Centre in San Jose (Musmanni, 2003). Beyond that, no comprehensive source related to the availability of subsidies was available at the time of data collection. However, due to the long history these individuals had with the institutional structure of the Costa Rican coffee industry it was felt their estimates could be meaningfully incorporated into this evaluation until such a time that this type of data is more easily obtained. This data was incorporated into the Net Present Value (NPV) as probability distributions that will affect the likelihood that a particular option is profitable (or at least economically feasible) over time. With regards to the financing option listed in the table, the net present value was calculated with an annual cost for a loan for the capital expenditure at 8%. This is the typical interest rate charged to the operation by the vendors to make the technology more available. Present interest rates available from Costa Rican financial institution are, if available, as high as 20 to 25%.

Table 6.43 presents the NPV and probability of risk for various options. The first two lines presents the absolute economic performance of the original cultivation practice and of that projected for the transition to shade-grown coffee. The NPV for the rest of the

Table 6.42. Initial Investments and incremental costs associated with new system and subsidies†.

Description	Total Cost (US$)	Possible Subsidies	Probability of Subsidy
Implementation of Monitoring[a]	1500 (1200[b] +300[c])	80%	25%
System Reconfiguration			
- Water (Recycling)	1800	50%	50%
- Alteration of Depulping Lines	1600		
- Automated Parchment Feeders	1600	100%	20%
Anaerobic Digestion (heat production)	40,000	50% + financing	50%
- 2 additional employees	2400	50%	25%
Anaerobic Digestion (electricity)	65,000	20%+ financing	50%
- 3 additional employees	3600	33%	25%
High Efficiency Furnace	50,000	financing	
Aquaponic Operations	25,000	50%	50%
- 2 additional employees	2400	50%	25%
Mulch production	7.5$/hectare[d]		
On-site composting[b]	1200	100%	25%

† - approximate values
a – cost of dedicated employ and equipment
b – employee costs (1 additional full-time @ 1.20$US/hr) will continue indefinitely
c – equipment costs are a one time investment in flow meters, scales, etc.. used for monitoring
d – cost to mulch coffee and shade tree prunings = ~ 4$/tonne at 1.5 tonnes per hectare

Table 6.43. Financial Analysis.

Description	NPV (5) mean	% Probability ≥ 0 (risk)	NPV (10) mean	% Probability ≥ 0 (risk)
Original Cultivation Practices	$2586.21	81.7%	$4427.36	80.6%
Implement Shade Coffee Practices (per hectare)	$2399.02	73.6%	$4631.94	84.9%
System 1	$400.52	100%	$16,141.11	100%
System 2	-$6,839	52.6%	$7,564.83	54.9%
System 3	-$4665.78	51.7%	-$12603.72	50.2%
System 4	-$28,242.24	0%	-$44,667.55	0%
System 5	-$270.54	73.9%	$10,029.32	100%

options are calculated as comparisons to the original state, i.e. more or lest costly over time that the present operation. This was due to the absence of reliable data regarding the systems and sub-system operating costs within a standard beneficio. The influence of the subsidies and financing were incorporated in the level of risk associated with each of the scenarios.

6.6.2.3 Material and Energy Balances. The evaluation of the systems' material and energy balances and the eco-efficiency calculations were conducted for each option individually and then aggregated where appropriate. It was built into the programming of the spreadsheet what options were mutually inclusive and which options were mutually exclusive. If the user wished to score an individual technology, this is possible. However, for the purpose of demonstration, the balance of the calculations were completed for various integrated systems possible.

Table 6.44 presents the existing material and energy balance at the time of the evaluation as well as the theoretical changes to these values resulting from the implementation of each of the options. Table 6.45 presents the calculations for the eco-efficiency indicators using this material and energy data and the eco-efficiency factor calculations discussed in Case #1.

6.6.2.4 Discussion. Improved monitoring and system reconfiguration, including the installation of an automated parchment feeder similar to that in Case #1 and mechanical mucilage removal system can save of ~2000$ per year in electricity and an additional 1200$/year in reduction in firewood use. ABCR (2003) estimated that approximately 20-25% reductions in electricity consumption by changing incorrectly sized and inefficient motors and pumps during regular maintenance and monitoring of sub-subsystems. The additional ~60 kwh/tonne savings is the calculated savings if the depulping system was decoupled such that at times when throughput is less than 50% of

Table 6.44. Material and Energy Intensity (per tonne of green coffee accept where noted).

Description	Original Operation
Water Consumption (m^3)	23.8
Firewood (m^3)	1.76
Electricity (kwh)	267
Inorganic Fertilizer	324
Nemacides/Fungicides (kg per ha)	80
Herbicdes (L per ha)	5

† - these number are based the use fertilizer per unit output of coffee. However if one calculates fertilizer use based on the output of all crops, the efficiency of fertilizer use per unit output improves another 10-30%.

Table 6.45. Eco-efficiency calculations.

Description	Original	System 1	System 2	System 3	System 4	System 5
Water-use Intensity[a]	595%	257%	257%	257%	257%	125%
Firewood-use Intensity[a]	880%	500%	440%	430%	200%	500%
Electrical Intensity[a]	243%	141%	141%	100%	113%	141%
Agrochemical Usage - Fertilizer	324%	150%	150%	150%	150%	150%
- Herbicides	500%	150%	150%	150%	150%	150%
- Pesticides	800%	300%	300%	300%	300%	300%
Return on Resource (By-products) Use[b]						
Wastewater (EE factor)	100 (0.5)	40 (2) 60 (1)	100(2)	100(4)	40 (2) 60(1)	100 (4)
Waste heat	100(0)	100(0)	20 (2) 80(0)	40(0) 60(2)	100(0)	10(2) 90(0)
Farm Biomass	100(0)	100(2)	100(2)	100(2)	100(2)	100(2)
Mucilage	100(0.5)	100 (1)	100(3)	100(3)	100(1)	100(3)
Pulp	100(0.5)	100(2)	100(2)	100(2)	100(2)	100(2)
Parchment	100(2)	100(2)	100(2)	100(2)	100(2)	100(2)

a - as compared to theoretical ideal
b - actual use will be highlighted in discussion.

maximum capacity (approximately 3 months) half of the line could be shut down. There was no definable economic benefits related to possible decreases in water consumption as the water is free and the present treatment is simply an aerobic pond. While there will be operational savings associated with decreased water use, it cannot be easily calculated.

Mulching of coffee and shade prunings can be done by mobile mulching operations that charge 5 – 7 $/tonne (APOT, 2003). The mulch created can be returned to the fields in areas stressed by soil erosion where it can offer protection from rain events and improve soil structure. Alternatively, it can be burned in a high-efficiency furnace. It should be noted that present high-efficiency furnaces cannot accept wood fuel in a form other that chips or sawdust and as such the mulching of farm wastes can provide a renewable fuel sufficient to operate the beneficio without input of other forest products. Present fuel wood costs approximately 8$/$m^3$ delivered or 16$/tonne (@ density of ~500kg/m^3). Assuming a transportation cost of 5.3$/tonne (based on similar transportation costs of a tonne of coffee pulp–Section 5.7.6) to collect the mulch from the farms and take it to the beneficio, the total cost for a tonne of wood mulch is ~10$/tonne or 35% cheaper. At an average wood waste production of 1.5 tonnes per hectare in a shade plantation once the plantations have been transformed to shade operations, there should be sufficient fuel for the beneficio without contribution to deforestation, even with a low efficiency furnace. It will also translate into an operation savings of $5.28 per tonne of green coffee. This was included as a cost savings beginning in year four to account for the lag between planting of shade trees and the beginning of shade tree pruning.

Presently the beneficio averages one to two 250,000 CRC (588$) fines for non – compliance per season. For systems' 2 and 3 (anaerobic digestion) the payback periods without subsidies are 13.2 years for system 2 and 14.4 years for system 3, the payback resulting from reduced fuel wood expenditures (system 2), electricity costs (system 3) and a "theoretical elimination of these fines (both). The revenues (or in this case cost savings) associated with the decrease in electricity purchased from the national utility is significantly more than the saving due to reduced wood fuel purchases. However, the lengthy payback period of System 3 is due to the increased expenditure required for the installation of an electrical generations system. However, Costa Rica's as electricity rates increase this payback period could be significant reduced.

System 5 is difficult to support economically due to the relative low cost of wood. However, in the presence of a wood shortage, this economical hurdle may be overcome by the necessity to maintain operations.

Based on estimated production levels and local costs it is estimated that the net revenue (after operations not including employee salary) for System 6 would be approximately \$2000. This is reflective of an operating cost of ~\$10,000 and a gross income of \$12,000 from 10,000kg of produce (@ 450 CRC/kg or 1.06 \$US/kg) and 500 kg of tilapia (@1200 CRC/kg or 2.82 \$US/kg).

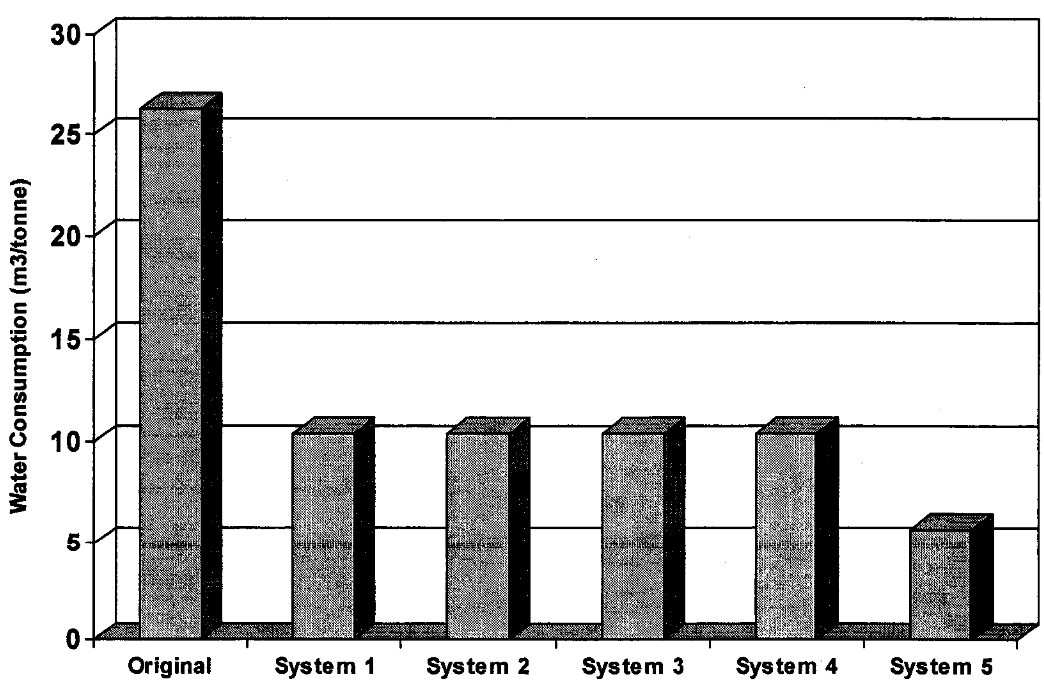


Figure 6.23. Water consumption.

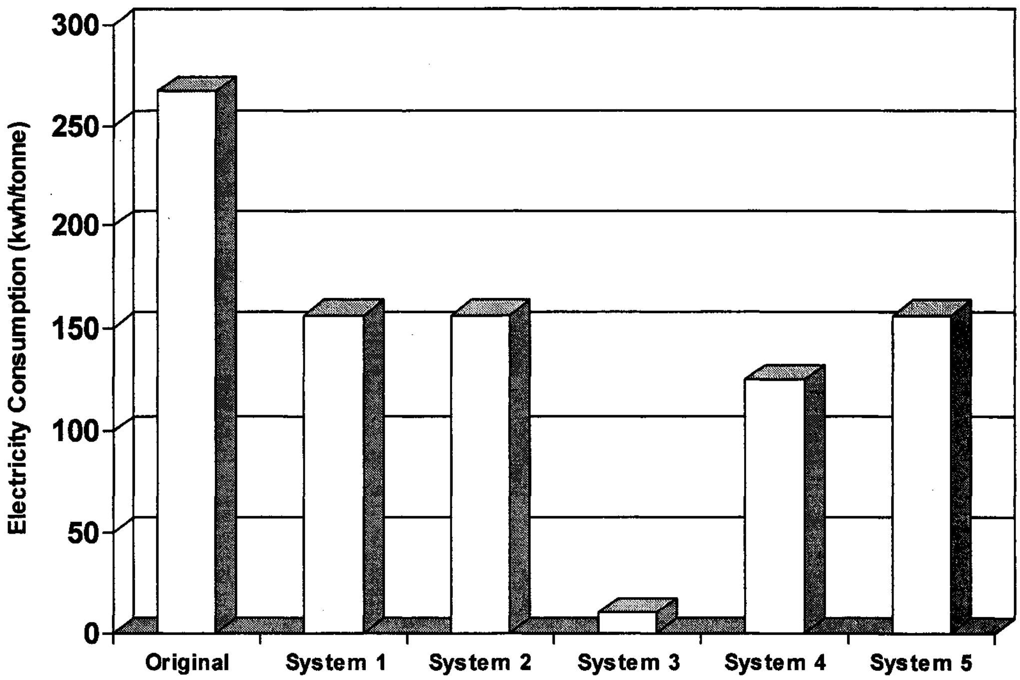


Figure 6.24. Electricity Consumption.

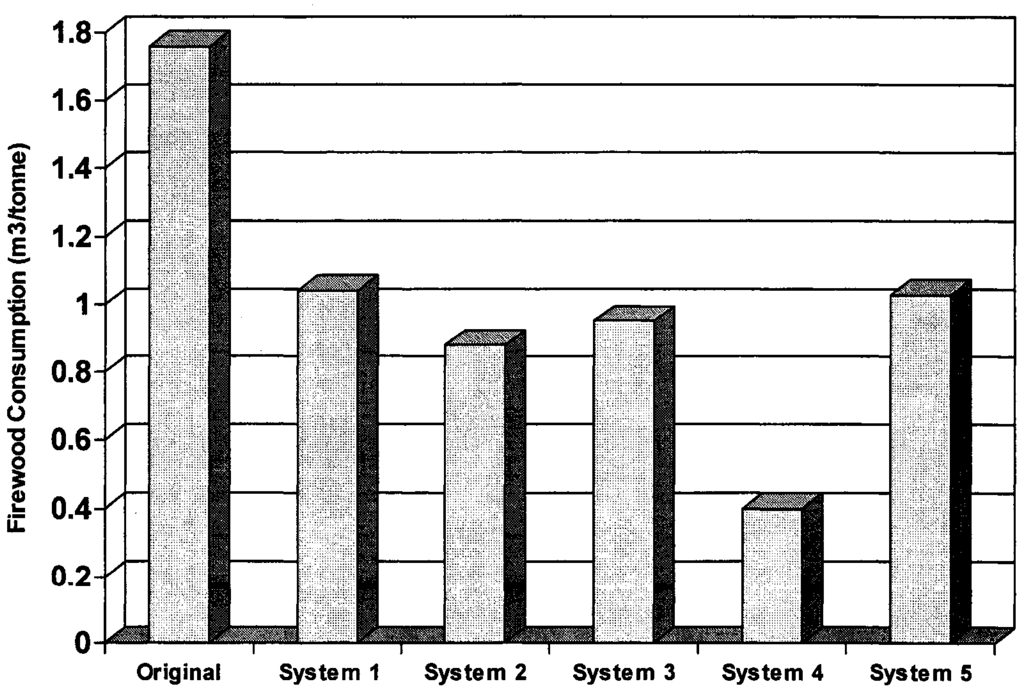


Figure 6.25. Firewood Consumption.

Figures 6.23 - 6.25 provide graphical representation of the theoretical water, electricity and firewood consumption. Firewood and electricity reductions related to the implementation of anaerobic digestion were calculated based on a recovery of 28 L of methane per kg of coffee produced. This translates into 196 kwh or ~1000 MJ of heat energy per tonne of coffee, depending on how it is used. In the case of System 3, the electricity generated could supply the mill its electrical power requirement and reduces load on the distribution system. This can be very important in an area plagued by power outages.

Table 6.46 shows the individual scores used in the calculations and Table 6.47 presents the main output table from the simulation. System 6 and System 1 received the top two scores, largely due to their improved economic performance as compared to the other systems and their equitable score for other aspects.

System monitoring and reconfiguration promotes the most change in this instance due to the inefficiency of the present operational setup and the lack of disaggregated data that would allow beneficio managers to determine where inefficiencies lay and how best to handle them. Aquaponics can have positive effect on the local region due to an increase in food sustainability in an area that depends on money from cash crops to purchase food from surrounding communities. Food deficit can be reduced by aquaponics.

There was limited material and energy balance completed for the farming operations. In depth analysis was required at a level beyond the scope of this study. To demonstrate the economic viability of changing to shade-grown coffee with intercropping, income averages from the various operations that had already done so were collected or referenced. There is significant specific research focusing on the nuance of Integrated Pest Management (IPM) and organic farming strategies, that it was not included here in as part of the decision support subsection. However, it should be noted that the composting and effective use of coffee pulp can reduce the purchased fertilizer ~10$/hectare once a shade-grown strategy has been implemented. Mulching wood for

Table 6.46. CSI indicator value tables from model.

Indicator	Wt	Original	System 1	System 2	System 3	System 4	System 5
Socio-Environmental Criteria							
Compliance	0.2	0	50	100	100	50	100
Training requirements	0.1	0	50	60	60	50	60
Stakeholder attitudes towards environmental issues	0.4	35	50	50	50	50	50
Alignment with national sustainability policies	0.1	25	75	75	65	25	50
Availability of reliable data	0.2	35	85	50	50	50	35
Environmental Criteria							
Level of System Monitoring	0.2	10	75	85	85	75	75
Resource Consumption	0.1	40	65	71	76	71	74
Impacts of Wastes	0.2	32	50	65	70	60	85
Response	0.1	35	75	75	75	75	75
Soil Health	0.2	53	75	75	75	75	75
System Resilience	0.1	34	65	65	65	65	65
Biodiversity levels	0.1	10	60	60	60	60	65
Eco-Efficiency Criteria							
Material-Use Intensity	0.25	23	45	45	76	52	64
Energy-Use Intensity	0.25	26	46	47	62	69	45
Return on Resource Input	0.5	17	54	76	92	54	82
Economic Criteria							
NPV (i)	0.5	75	75	50	0	0	100
Perceived Economic Performance							
Risk Factor (i)	0.5	90.4	100	53.7	50.9	0	86.9
Perceived level of Risk							
Socio-economic Criteria							
Level of community stability	*0.25*	50	60	60	60	60	65
Level of bargaining power held by industry stakeholders	*0.2*	65	65	65	65	65	65
Access to credit	*0.3*	50	50	50	50	50	50
Pay rate compared to living costs	*0.25*	50	60	60	60	60	65

Table 6.46. Continued.

Indicator	Wt	Original	System 1	System 2	System 3	System 4	System 5
Social Criteria							
Availability of industry support of worker's well-being	0.25	70	70	70	70	70	70
Injury rate amongst workers	0.25	42	65	65	65	65	65
Balance of work and leisure	0.25	75	75	75	75	75	75
Child Labour	0.25	40	50	50	50	50	50
Institutional Criteria							
Level of institutional support	0.2	50	75	60	55	55	35
Demonstrable case studies/examples	0.2	100	90	60	55	85	45
Availability of appropriate technology transfer expertise	0.2	n/a	90	85	70	85	65
Efficiency of communication networks	0.2	25	40	40	40	40	40
Ease of market access for resulting product	0.2	50	75	75	75	80	75

Table 6.47. Model output of CSI evaluation scores.

Indicators	Weights	Original	System 1	System 2	System 3	System 4	System 5
Social	0.14	56.8	65.0	65.0	65.0	65.0	65.0
Socio-economic	0.14	53.0	58.0	58.0	58.0	58.0	60.5
Economic	0.15	82.7	87.5	51.9	25.5	0.0	93.5
Eco-efficiency	0.14	20.8	49.8	61.0	80.5	57.3	68.3
Environmental	0.15	30.9	66.5	72.1	73.6	69.1	74.9
Socio-environmental	0.14	23.5	59.5	63.5	62.5	47.5	58
Institutional	0.14	45.0	74.0	64.0	59.0	69.0	52.0
Total Score		44.9	66.0	62.2	60.4	51.9	67.8

soil structure can be used where needed and the rest used in the beneficios. Improving shade increases renewable biomass availability.

The usefulness of the model to assist with decision making is largely dependent on the users ability to gather sound information about the various options available at the time of the evaluation. As well, shifts in government policy, improvements in program efficiency and availability of support will influence the scoring outcome as weights and scores associated with specific options will need to reflect these changes. For example, a particular technology may become a more feasible choice due to expansions in the educational system (provision of qualified labour) or increase support from an external institution. In this case the input data was based on the conditions present within the Costa Rican coffee industry in 2004. Like any evaluation system, it can only be useful if it is based on circumstances that are pertinent to the specific user.

6.6.3 Sensitivity Analysis

Sensitivity analysis was completed for the economic calculations using a Monte Carlo simulation that altered the change in coffee yields, yields of fruit crops, and price and interest rate variability according to the distribution function that represented each variable. For each of the systems evaluated, a simulation of 1000 iterations was run. Each iteration generated an output NPV value reflecting a random change in one of the input values. A regression model of these output data points is automatically created by the @RISK program, generating tornado graphs representing the regression coefficients for the inputs. As well, a sensitivity graphs demonstrating the percent change in NPV output as compared to the variable inputs was generated.

In the case of the decision assistance simulation, the effect of each criteria on the alternatives' scoring was evaluated by changing the weighting factors associated with each criterion to determine if this altered the resulting decision. This was considered of greatest importance as it could influence the user's decision outcome.

Figures 6.26 and 6.27 provide a graphical view of the sensitivity analysis performed on the financial analysis. Figure 6.26 presents the regression coefficients of the financial analysis of Case #1 as it is related to price fluctuations, coffee yield and fruit yields as a tornado graph of the sensitivity. As expected, the economic performance was

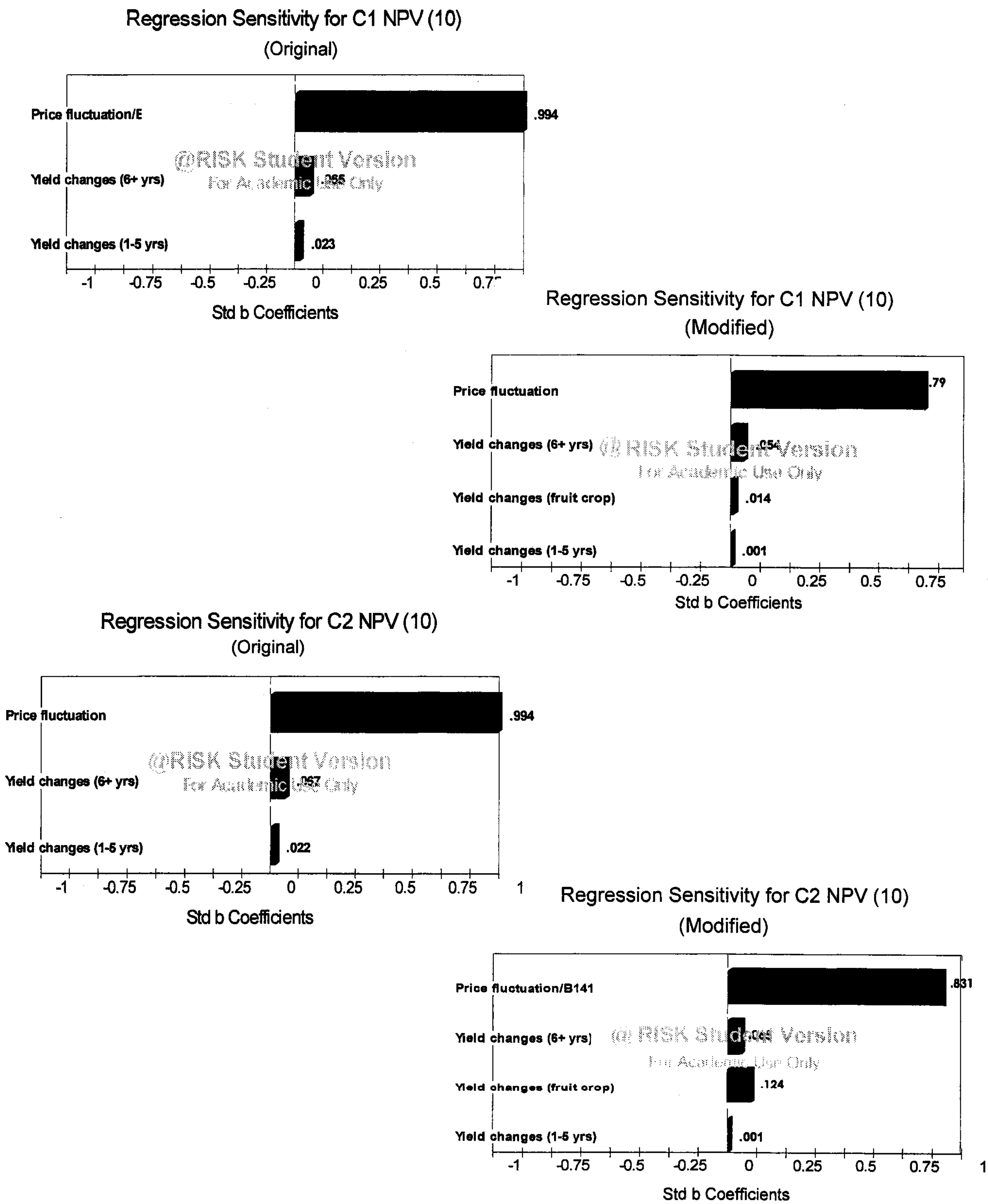


Figure 6.26. Tornado graphs of NPV sensitivity.

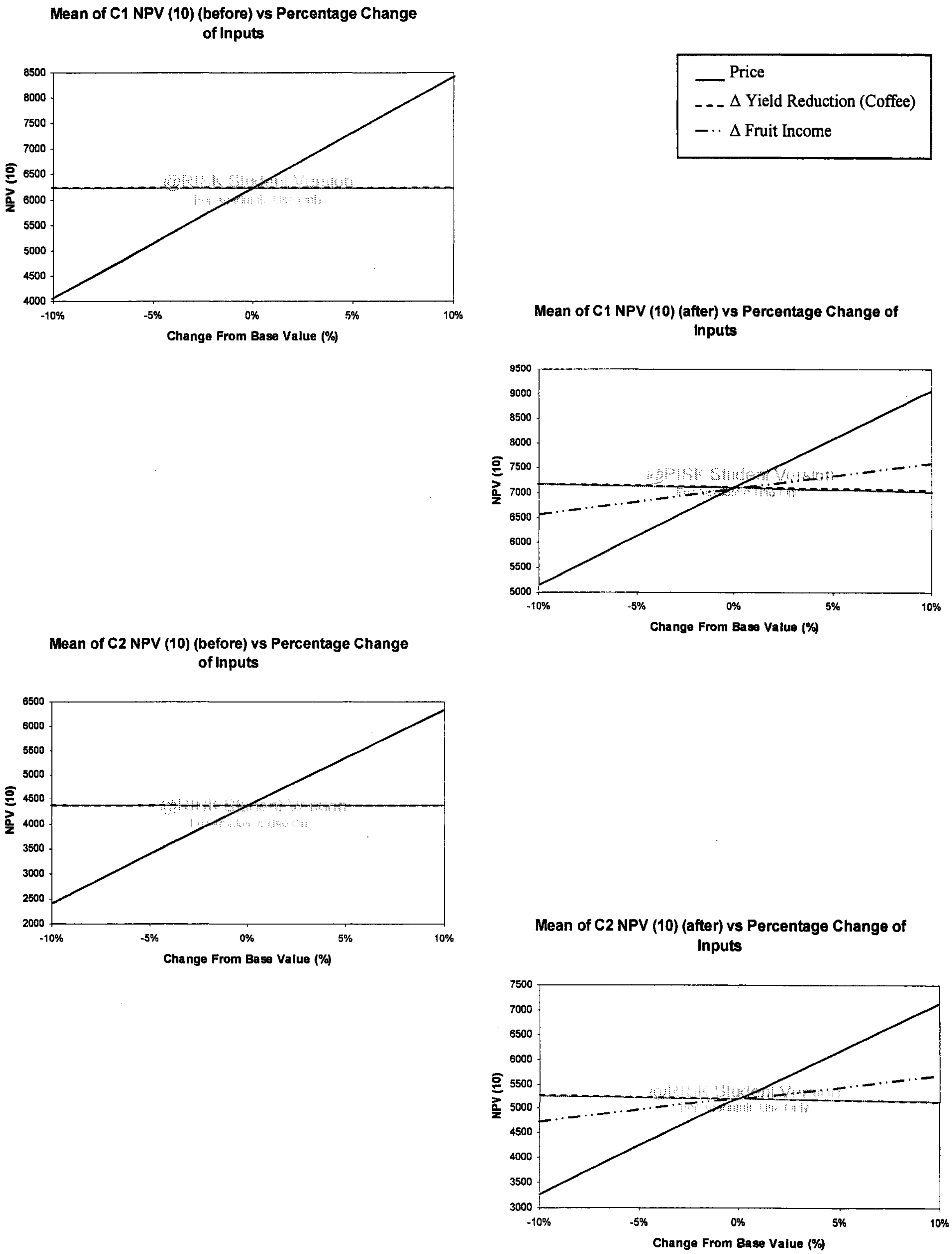


Figure .6.27. Revenue sensitivity to input variabilities.

more highly influence by price fluctuations, however there is a noticeable reduction in sensitivity when fruit yield are taken into account. This is an expected result as the predominant reasoning for farmers to make the transition to shade coffee farming (beyond environmental considerations) was to limit their risk related to the present coffee crisis. It is theorized that this variability would become even less pronounced if it was possible to take the revenue (either cash or in-kind, i.e. bartering, trading or offsetting household food costs) from the ground crops into consideration. Figure 6.27 presents the sensitivity graphs for the four systems by showing the change in the output NPV as compared to changes in the coffee and fruit yields and price. As can be seen, the price of coffee has the most influence on the output NPV, with less influence contributed by alterations in the yields of coffee and fruit. However, it can be noted in the sensitivity graphs of the two resulting systems that the influence of price is reduced when other crops are introduced to the economic equations.

As the other criteria were based on linear inputs, sensitivity analyses were not formally completed. As this type of model is refined and the input equations are based on functions that are not linear, the sensitivity of each input will have to be carefully determined before it is incorporated into such a system, to ensure the influence on the output scores are not unrealistic.

Tornado graphs and sensitivity graphs were generated for the NPV (cultivation) calculations in Case #2. However, as the distribution functions used in the calculations were the same as in the previous evaluation they will not be presented to avoid repetition.

In Case #2, it was noted that each objective function had an effect on the overall CSI score for each possible system. As such this could effect which alternative received the highest score. As such, it was necessary to investigate the influence of the weighting of the various criteria on the individual systems' scores.

Figures 6.28 to 6.31 presents the output CSI score as the weighting factors assigned to the main criteria are changed from being of equal weighting (Figure 6.28) to a situation where the weighting for the economic, eco-efficiency and environmental scores are four times greater than the other factors, respectively. Tables 6.48 – 6.50 provides the output data of these graphs.

It is easily seen what solutions become more attractive depending on the emphasis placed on the various aspects of sustainability. In this case the emphasis on economic, eco-efficiency and environmental issues were altered. As can be seen, System 1 (monitoring and system reconfiguration alone) and System 5 (aquaponics) consistently scored above the over options. This was only markedly different in the case of the heavy emphasis on eco-efficiency. In the absence of the economic constraints, the System 3 (anaerobic digestion with electricity generation) scored highest. This demonstrates the importance of access to subsidies within developing countries to assist overcoming the initial economic boundaries to sustainable technologies.

6.6.4 Model Strengths

This model assists in providing another measuring stick for easy initial comparison of sustainability within systems. Present systems such as the "dashboard" and "distance to target" evaluations typically offer a visual display of an indicator's performance against a predetermined end-point. Such tools could easily be enhanced through the application of the CSI methodology such that the user would be able to view the sustainability of the system from an overall standpoint and also to see what factors are contributing positively to sustainability and what areas need improvement. Previous composite indicators have been either based on ordinal scales where the relative score of a system will change depending on which other system it is being compared to, instead of fixed standards (Seppalai and Hamalainen, 2001), or are designed for more global indices and are difficult to apply to sustainability at the systems level.

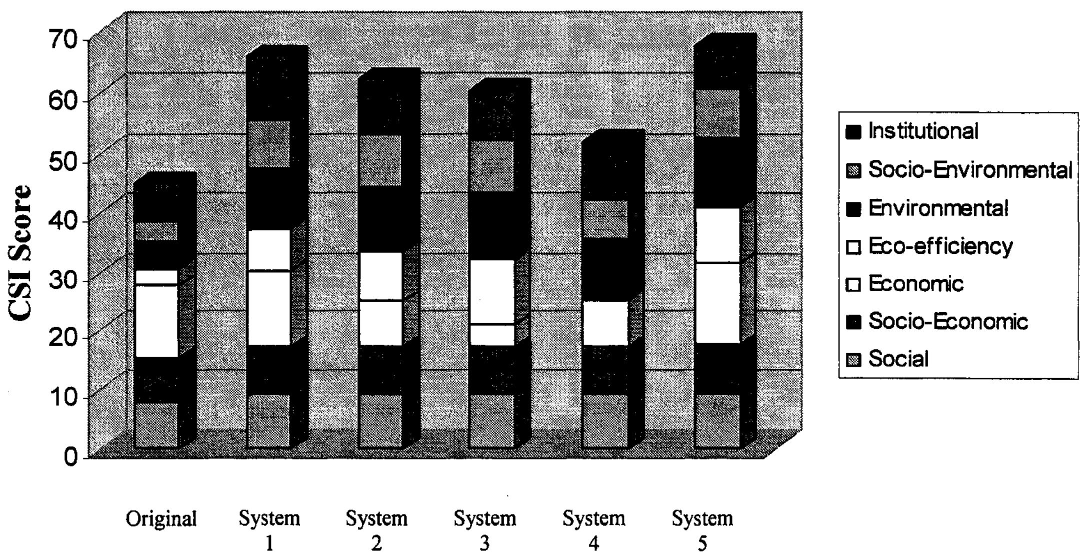


Figure 6.28. Total score for alternative systems when all criteria are equally weighted.

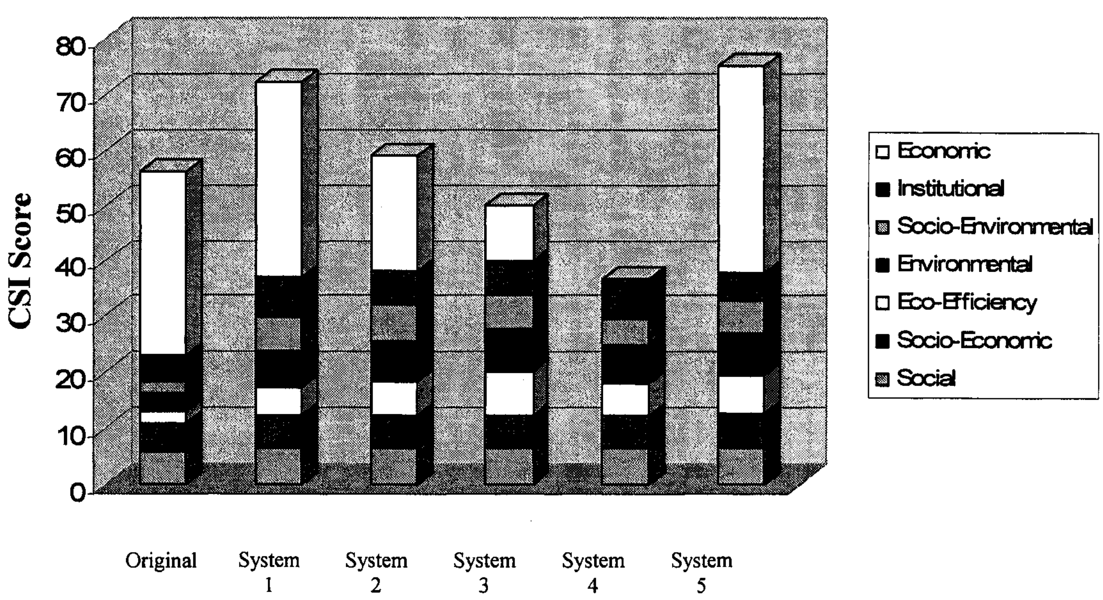


Figure 6.29. Total score when a higher weighting is assigned to economic criteria.

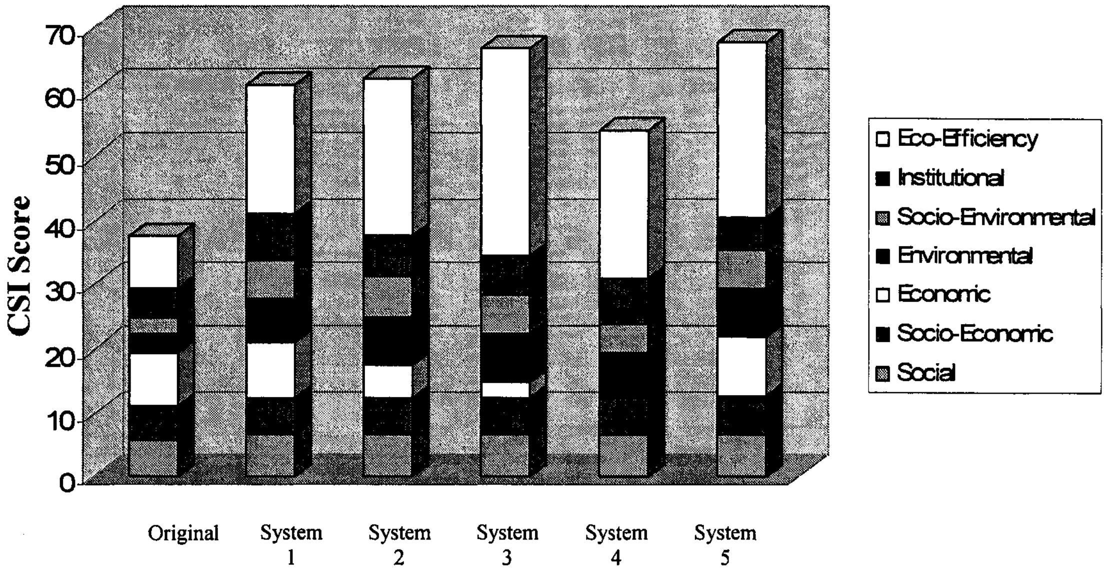


Figure 6.30. Total score when a higher weighting is assigned to eco-efficiency criteria.

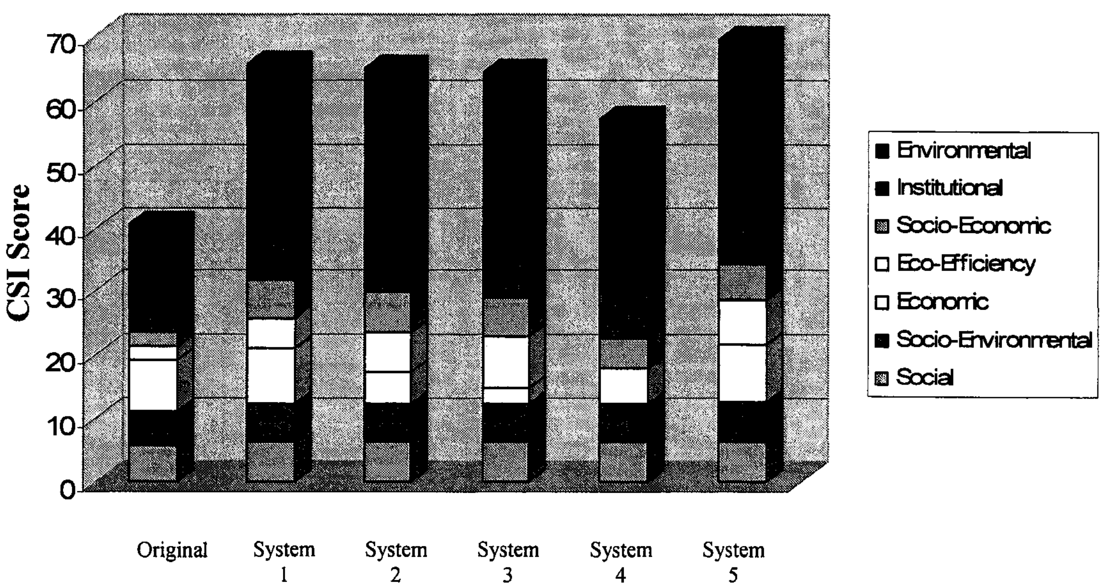


Figure 6.31. Total score when a higher weighting is assigned to environmental criteria.

Table 6.48. Score sensitivity to increased economic weights.

Criteria	Original	System 1	System 2	System 3	System 4	System 5
Social	5.7	6.5	6.5	6.5	6.5	6.5
Socio-economic	5.3	5.8	5.8	5.8	5.8	6.1
Economic	33.1	35.0	20.7	10.2	0.0	37.4
Eco-efficiency	2.1	5.0	6.1	8.1	5.7	6.8
Environmental	3.1	6.7	7.2	7.4	6.9	7.5
Socio-environmental	2.4	6.0	6.4	6.3	4.8	5.8
Institutional	4.5	7.4	6.4	5.9	6.9	5.2
Total	56.1	72.3	59.1	50.0	36.6	75.2

Table 6.49. Score sensitivity to increased eco-efficiency weight.

Criteria	Original	System 1	System 2	System 3	System 4	System 5
Social	5.7	6.5	6.5	6.5	6.5	6.5
Socio-economic	5.3	5.8	5.8	5.8	5.8	6.1
Economic	8.3	8.8	5.2	2.5	0.0	9.3
Eco-efficiency	8.3	19.9	24.4	32.2	22.9	27.3
Environmental	3.1	6.7	7.2	7.4	6.9	7.5
Socio-environmental	2.4	6.0	6.4	6.3	4.8	5.8
Institutional	4.5	7.4	6.4	5.9	6.9	5.2
Total	37.5	61.0	61.8	66.6	53.8	67.7

Table 6.50. Score sensitivity to increased environmental weight.

Criteria	Original	System 1	System 2	System 3	System 4	System 5
Social	5.7	6.5	6.5	6.5	6.5	6.5
Socio-economic	5.3	5.8	5.8	5.8	5.8	6.1
Economic	16.5	17.5	10.4	5.1	0.0	18.7
Eco-efficiency	4.2	10.0	12.2	16.1	11.5	13.7
Environmental	6.2	13.3	14.4	14.7	13.8	15.0
Socio-environmental	2.4	6.0	6.4	6.3	4.8	5.8
Institutional	4.5	7.4	6.4	5.9	6.9	5.2
Total	44.7	66.4	62.0	60.4	49.2	70.9

Without a composite index, the interpretation or the use of radar plots and dashboard type displays are limited for users who wish to evaluate the changes in sustainability in a holistic manner. Figure 6.32 demonstrates a visual comparison of sustainability between two (non-coffee related) hypothetical systems. The diagram shows that system A needs improvement in socio-economic stability and social sustainability and system B needs improvement in the areas involving environmental considerations, but it is difficult to compare the systems in a holistic manner, which is what is needed if it is to be of use in a decision analysis setting. This methodology allows for an aggregation of data that, in the case of a "distance to target" evaluation for example, would already be available. It then provides an opportunity to aggregate this data to one number that give an overall impression. The analysis of the breakdown of components can then help the user see where the gaps are while keeping the overall system in mind and avoid a piece-meal approach. The CSI methodology can be upgraded to include external database input, evaluation of interdependences of indicators, and more complex mathematical functions as new data or understanding about a system is gained along with the empirical data that reflects it.

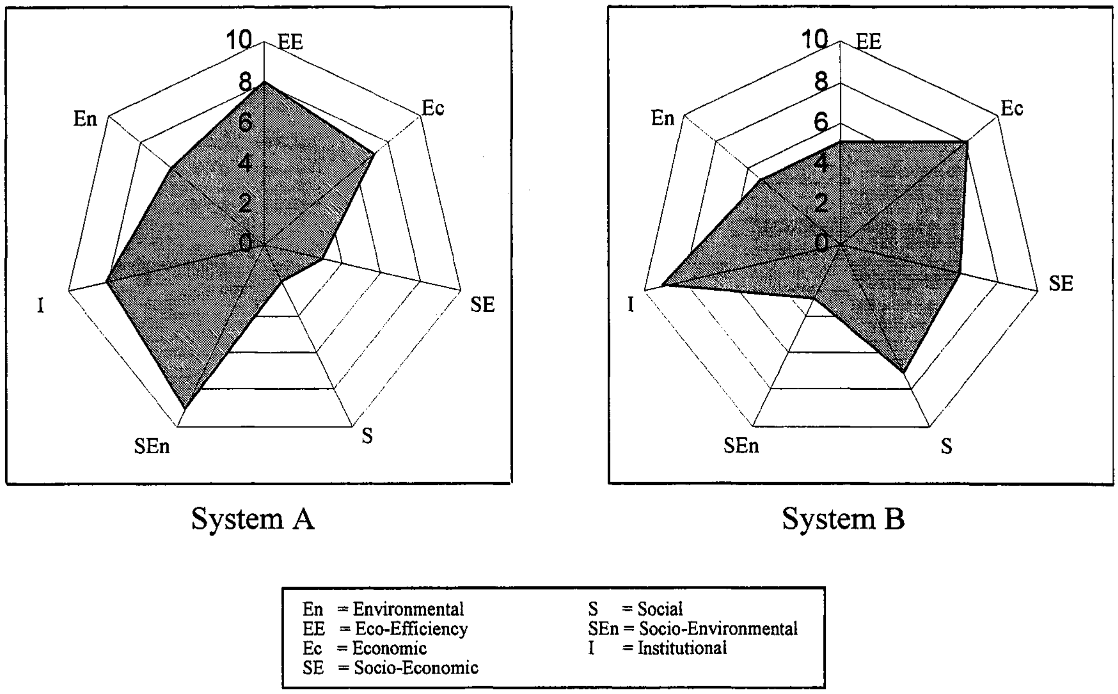


Figure 6.32. Radar plots for two hypothetical systems.

7 CONCLUSIONS

This study has provided an analysis of the present condition of the Costa Rican coffee industry and outlined opportunities to improve its sustainability. As well, it has highlighted some of the significant barriers to sustainability identified by stakeholders. This analysis lead to the development of a methodology aimed at filling some of the gaps found in sustainability evaluation methods available to assist the industry incorporate the necessary factors to promote sustainability in a holistic manner. The conclusions reached during this research are as follows:

1. The present Costa Rican coffee industry is, as a whole, inherently unsustainable.
   (a) Soil erosion and excessive quantities of agrochemical inputs are the norm within the conventional coffee cultivation methods.
   (b) Soil erosion has been reduced by some conscientious farmers by integrating better soil management practices, but the level of agrochemical inputs across the industry do not appear to be significantly lower.

2. Sustainable coffee programs promoted by ICAFE and Rain Forest Alliance (RFA) are considered insular and do not use a systems approach.
   (a) ICAFE is mainly focused on how to improve the soil fertility within coffee cultivation and ignore pesticide accumulation.
   (b) ICAFE has a singular focus of sustaining maximum yields.
   (c) ICAFE and RFA have minimal impact in assisting farmers become more sustainable from an overall standpoint through the cultivation of alternative products.
   (d) ICAFE and RFA do not actively promote the integration of the significant quantities of organic wastes produced by the beneficios into the system such that it can aid the farmer and increase revenue to the community.

3. Sustainability within the processing facilities is largely ignored, with the exception of a limited number of facilities progressing towards ISO14000 certification (which has its own set of limitations).

   (a) There is a lack of social considerations when developing sustainability strategies for industry and a significant gap between research and development organization and industry stakeholders with regards to the application of sustainability strategies.

   (b) Examples of successful integration of cleaner production and/or industrial ecology have not been capitalized on to their maximum benefit in terms of changing the outlook of the industry towards their resources, both raw materials and by-products.

   (c) Researchers have looked at specific strategies and technologies in isolation or within the strict confines of coffee production as it presently stands, with a limited view of innovation.

4. Many current sustainability evaluations methods have problems with practical application. They:
   (a) are designed for more global indices or factor specific;
   (b) do not easily allow for system or situation comparisons; or
   (c) are based on ordinal scales instead of fixed empirical standards.

5. In developing this new methodology, it was necessary to keep the development, weighting and aggregation of indicators as realistically simple as possible, without undermining the end goal of providing the user with a realistic evaluation of how sustainable his/her system was and where changes were needed. Methodology questions relating to selecting, aggregating and weighting of indicators are only controversial among indicator experts. Users just want something they can use.

6. The various parties involved in sustainability evaluation all have specific goals and responsibilities. The CSI model is a management tool primarily focused on the requirements of managers and farmers of industrial systems. To induce a change towards more sustainable production, the stakeholders have to be first aware of the factors that should be considered and then how these factors can be influenced by their decisions and practices. CSI will provide guidance that consults all factors in a more holistic manner that is presently being provided at an operational level.

7. The usefulness of the model in assisting with decision making is largely dependent on the users ability to gather sound information about the various options available at the time of the evaluation. Shifts in government policy, improvements in program efficiency and availability of support will influence the scoring outcome as weights and scores associated with specific options will need to reflect these changes.

8. Care should be taken in the choice of rating scale for the component indicators as extreme conditions would result in values at extreme ends of each scale, disproportionately influencing the output. In general, more research is needed to optimize the accuracy of transforming an objective or subjective condition into an empirical scale that correctly correlates to conditions of the evaluated system.

9. The CSI methodology quantified the relative sustainability of the primary producing systems and can be used to incorporate resource efficiency, and broad socio-economic and institutional factors into the agro-industrial sustainability of developing countries.

8 RECOMMENDATIONS

1. Further study of the application of the "eco-efficiency" factor could be undertaken to determine the possible use of this concept as a complementary tool to present methodologies.

2. The decision assistance function can be expanded by including linkages with mechanist models such as soil erosion prediction models or process optimization software.

3. Other multi-criteria methodologies such as analytical hierarchy programming (AHP) and ordinal ranking procedures, can be used within this evaluation methodology, provided the all sustainability criteria are given equal importance. For example, AHP could be used to assess which indicators should be used within each of the main criteria groups and what weighting based on the inputs from stakeholders.

4. The scaling mechanism used in the composite sustainability indicator (CSI) methodology is predominantly linear. However the use of logarithmic or exponential equations to describe indicators measured value could easily be incorporated into the CSI methodology when/if appropriate.

5. The conundrum of missing or difficult-to-obtain data results in a gap for any sustainability evaluation model. This will only be improved by a dedication to the collection and measurement of data on a case by case basis, or as a result of an overall shift in data requirements at the institutional or industry level. In future, the CSI criteria can be used as a base-point to identify what date is going to be needed to assist in the evaluation of sustainability, and then use this to develop data collection programs within the system and its surrounding sphere of influence.

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APPENDICES

Appendix A
List of Contacts

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2. Alfaro, Carlos – Former Executive Director – ICAFE; General Manager – Cafinter (3 mills)
Cartago, Cartago, Costa Rica

3. Alpízar, José María – Environmental Program – CICAFE (Science Division of ICAFE)

4. Alverez, Juan Carlos – General Manager – Coope El Dos Beneficio, Guanacaste Region

5. Arce, Victor – Assistant Manager – Coope Montes de Oro Beneficio, Western Valley Region, Puntarenas, Costa Rica

6. Aronson, Steve - President - Britt Coffee Company, Central Valley Region.

7. Barzuna, Fernando – General Manager – Volcafe Inc. (6 mills), Central and Western Valley, and Brunca Regions

8. Bejarano, Rafael – General Manager – Integrated Biosystem Demonstration Coffee Plantation in Veracruz, Mexico.

9. Camacho, Randal – Production Manager – Sta. Maria Beneificio, Cafinter, Orosi Valley Region.

10. Campos, Carlos – Organic Farmer and Head of the Associacion del Productores Organico de Turrialba (APOT)
Turrialba, Cartago, Costa Rica

11. Corrales, Bemal – Assistant Manager – Coope Naranjo Beneficio
Naranjo, San Jose, Costa Rica

12. Cutie, Jorge – General Manager – Café del Oro (3 mills), Turrialba Region.

13. Danse, Myrtille - Environmental Consultant – Sustainable Coffee (Suscof) Project – Costa Rican Centre for Technology and Innovation (CEGESTI)
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16. Guardia, Rolando – General Manager – Juan Vinas Sugar Mill
    Juan Vinas, Cartago, Costa Rica

17. Hermenez, Pedro – President – Association of Coffee Producers (Peru) (translation)
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18. Johnson, Linda – Latin American Program Director – Technoserve
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19. Kopper, Roberto – President – National (Costa Rican) Association of Coffee Processors (translation)
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20. Lindle, Ted – Executive Director – Special Coffee Association of America
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21. Marcos, Fernando – Production Manager – Volcafe Inc. (6 mills), Central and Western Valley, and Brunca Regions
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22. Mata, Roberto – General Manager – CoopeDota Beneficio and Cooperative, Sta Maria del Dota, Tarrazu Region, San Jose, Costa Rica

23. Moya , Juan Bautista – Executive Director – ICAFE
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24. Muscler, Reinhold – Professor (Agroforestry), CATIE
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25. Musmanni, Sergio – General Director – Costa Rican National Cleaner Production Centre (UNIDO)
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26. Nunez, Victor – General Manager – Coope Cafira Benefico
Central Valley Region, San Jose, Costa Rica

27. Ortiz, Oscar – General Manager – Juan Vinas Beneficio and Cooperative, Juan Vinas, Cartago, Costa Rica

28. Pauli, Gunter – Executive Director - Zero Emissions Initiative (ZERI)
pauli@zeri.org

29. Perez, Fernada – Director of Environment – Dos Piños Diary
San Jose, Costa Rica

30. Ramirez, Guillermo – Regional Representative (Turrialba Region) – ICAFE 7170 CATIE, Turrialba, Costa Rica

31. Ramirez, Jose - Mill Manager – Volcafe (Diego) Beneficio, Central Valley Region

32. Russillo, Aimee - Business Manager – Rainforest Alliance (Sustainable Coffee Program – Central America)

33. Salazar, Jaime - Quality and Environment Manager – Coope Cerro Azul Beneficio, Guanacaste Region

34. Schram, Albert – Professor (Ecological Economics) – University of San Jose, Costa Rica

35. Suazo, Jimmy - Production Supervisor - Volcafe (Santa Maria) Beneficio, Central Valley Region.

36. Vasquez, Jose – General Manager – Coope Palmares Beneficio, Central Valley Region

37. Vasquez, Rolando – Manager of Milling section (translation) – ICAFE
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38. Veldron, Jaques-Michel – Coffee Producer – Bani coffee region, Dominican Republic

39. White, Greg – Director of Purchasing – Folgers Coffee (Proctor and Gamble)

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40. Zamora, Fabio – General Manager – Cafetalera Aquiares Beneficio and Cooperative Turrialba, Costa Rica
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41. Zamora, Luis – Director – CICAFE (Science Division of ICAFE)

42. Zoffoli, Pier – Enviromental Manager – Ticofrut Beverages (Citrus) Aluhuela, San Jose, Costa Rica

43. Zuniga, William – General Manager – Coope Cerro Azul Beneficio, Guanacaste Region

Appendix B
Coffee Beneficio Survey

Completed By: (name optional) Location:
Date:

1. What is the Approximate Annual Production of Coffee:

2. What is the Total Solid Waste sent to composting facility per season:

3. Which Composting Facility used:

4. Mucilage Removal System (please circle one):

Fermentation *Mechanical Removal* *Combination of Both*

5. If Mechanical Removal is used – what is the total mucilage produced per season:

6. System of treatment (please circle those used):

None *Lagoon* *Anaerobic Digester* *Combination*

Other (please explain) _______________

For Mills with Digesters

7. How old is the digester? _____yrs 8. Who installed the digester? (BTG, for example?)

9. What is the operational efficiency of the digester:

10. How much methane is produced by digester (if known)?

11. What is methane used for (please circle current uses):

Heating waste water *Heat for dryers* *Electricity Generation*

*Other:*___________________

12. If methane is used for electrical generation, approximately how much is generated?

Confidential When Completed

Waste Water Discharge

13. What is the average BOD (DBO) level in effluent:______________

14. What is the average COD (DQO) level in effluent:______________

Wood Use

15. How much wood is used (per season or per fanega)?

Water consumption

16. Since the stricter regulations have been implemented in 1998 how much has the water used per fanega been reduced?

Before modifications	m^3/fanega
Now	m^3/fanega

▪▪

General Comments

17. What area of the mill is in most need for improvement or innovation
Example: energy efficiency of furnaces, operational efficiency of digesters, etc…

18. Is there any new technology that would help the mill be more economically efficient if it were installed?

Please specify the technology and the part of the mill in which it would be installed?

19. What is the most significant operational problem this mill has?

20. Have you ever thought of other ways to use the desecho - either to reduce handling costs, treatment costs, or to generate an economic return from its use? Please explain your ideas.

Thank you.

If it makes you more comfortable, please simply note the location of the mil. The company name can be left blank. Please note that all answers are strictly confidential and will be used for research purposes only.

Appendix C
Industry Survey – Obstacle Assessment

Completed By (name optional): Location:
Date:

1. Type of Organization: Gov Exporter Mill Co-op Farm Research
(please circle one)

2. What is the most significant problem facing the coffee industry today besides the low price of coffee?

3. What has been done in the industry to try to overcome present problems?

4. What are the most significant obstacles to the implementation of environmental innovations within the industry?

5. In your opinion are there new technologies, processes or concepts that would help the industry become more economically efficient?

6. Have you ever thought of other ways to use the desecho - either to reduce handling costs, treatment costs, or to generate an economic return from its use? Please explain your ideas.

Thank you.

If it makes you more comfortable, please simply note the location of the mil. The company name can be left blank. Please note that all answers are strictly confidential and will be used for research purposes only.

Appendix D
Interview Questions for Farmers

It should be noted that this was used as a guideline and was not used as a written survey. The author accompanied ICAFE extension officers in their visits to farmers and helped with some translations. Where knowledge was not available from the farmers themselves, ICAFE offered estimates based on past interaction with that particular farm. Names of farmers were not taken.

Location of Farm
Size
Do you own the farm? Yes No

Do you have another job? Yes No
Does your family help with the farm tasks? Yes No

Do you hire farm workers? How many 1-2, 2-5, +5

What is your average yield in fanegas per hectare?

Do you keep written records about farm production? Yes No
What aspects?

Man-hours of hired workers?
By task?
Man-hours of family?
By task?

If yes to any of above ask for break down of material costs and man-hours by task. If no, try to get approximate breakdown in percentage of total.

Pruning - Shade trees
- Coffee plants

Weeding - Manual weeding
- Herbicides - Application
- Purchase of Materials

Fertilizer - Application
- Purchase of Material

Fungicide/Pesticide - Application
- Purchase of Materials

Cultivation of Seedlings
- Seed Preparation
- Seedling Germination
- Plot preparation (digging holes)
- Planting Seedlings

Farm Upkeep
- Erosion Control
- Application of Soil Conditioners and/or Amendments
- Removal of Leftover Berries (ground and bush)

Agrochemical Use : How many times do you
- Apply Fertilizer
- Apply Herbicides
- Apply Fungicides

How do you decide how much to use?

Decision making criteria?
What issues are important to you when deciding to make changes in the operation of your farm?

Do you produce other crops and/or materials for sale?
Approximately how much relative to your total?

Do you children help in the farm?

Schooling: None Home-school Night classes Regular school

Appendix E
Program Algorithm

[redacted]

Is there any system of monitoring inputs and outputs?

If yes, what is the water usage per tonne of coffee?
- fire wood (cubic meters)?
- kwh/tonne depulping?
- kwh/tonne mucilage removal?
- amount of parchment used in furnaces (percentage of total produced)?
- amount of other fuel?
- amount of BOD (mg/L) in wastewater?
  - COD (mg/L)?

Inputs are linked to other equations that are used to calculate resource use and by-product production

What is the average annual capacity of the mill (fanegas)?

What is the maximum daily capacity?

What is the average daily capacity? — Input

Does the depulping system operate in parallel or series?
- If series, how many lines?
- If parallel - how many receiving hoppers?
  - how many 1st grade depulpers?

Present use of waste heat?

Type of wastewater treatment system? (AL, AEL, AED, other)

Any revenue generated/saved through use of by-products?

Are there any environmental concerns or complaints that need immediate attention?
- What to they involve? (wastewater, pulp, air quality, firewood, other) — Input

How much space/land is available for upgrades and/or technology installations?
A=none, B=<0.5 hectare, C=0.5-1 hectare, D=>1 hectare

What is the beneficio's linkage with coffee farmers? (Regional, Local, Coop)

Is there an in-house OHS or environmental training program for workers?
- If yes, how many hours per quarter are spent training?

Percentage of workers the are from the local community?

Number of workers with specific educational backgrounds or skill sets:
- Unskilled labour (in a technical sense)
- Some vocational training
- Completed technical training
- University educated (business or technical)

Minimum age permited to work in mill?

Injury rate last five years? (if available) — Input

Average Rainfall during harvest season — Input

The user is then asked if this is a decision making scenario or an evaluation. In the case of a decision making scenario the material, energy and economic values are calculated using the input conditions of the process and the theoretical output conditions given the different system options presented. If Then statements are imbedded that use the amount of land available, the beneficio linkage (R,L,C), the presence of system monitoring and annual rain fall to output the suggested options for consideration within the model.

Table E.1. Consumption values used to calculate efficiency of resource and energy use

Resource	Ideal (practical) consumption per tonne
Wood (m3)	0.2
Water (m3)	4.0
Electricity (kwh)	110
Agrochemicals (per ha)	
Herbicides (L)	1
Pesticides (kg)	10
Fertilizers (kg)	100

Based on the inputs into the "Systems Considerations" table the percent consumption as compared to the ideal can be calculated. The scores then input into the table as simple excel equation outputs. The Return on Resource calculation relies on the user's understanding of the options available for the use of by-products as value added products. It was not "operationalized" into the system and was calculated using material balance calculations from the theoretical integrated biosystem (Figure 6. 14) based on what was applicable for the system being evaluated.

The user is given the option of accepting the default weights or is prompted to input their own. If one of the criteria is less than 0.15 a message is produced asking the user to increase the weighting.

		System1	System2	System3	System4	System 5	System 6	System 7	System 8
Indicators	Weights	Indicator Values							
Eco-Efficiency									
Material Intensity									
Energy Intensity									
Return on Resouce									

Previous page
Next page

Cultivation
Economic Calculations

	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8
Material Input								
Soil Amendments								
Fertilizer								
Organic								
Inorganic								
Pesticides								
Fungicides								
Herbicides								
Pesticides								
Nematicides								
Seedlings								
Alternative Crops								
Labour Costs								
Fertilizer Application								
Pesticide Application								
Harvesting								
Planting Shade trees[1]								
Maintaining Shade Tree[2]								
Pruning Shade Trees								
Pruning Coffee Coffee								
Planting Seedlings								
Planting Crops								
Weeding								
Erosion Control								
Soil Conditioning								
Harvesting Crops								
Fixed Costs								
Repair and maintenance								
Taxes								
Loan interests								
Revenue								
CoffeeYield								
Multiplier (based on niche)								
Crops								
Timber								
Firewood (Prunings)								
Present Value of System								

1 - only for systems being converted to polyculture
2 - only for first three years after planting

Net Present Value Calculations

Number of years into the future?								
Interest rate								
Coffee Yield distribution function								
Coffee pricing distribution function								
Crop Yield distribution function								

System 1	NPV (	0	) =
System 2	NPV (	0	) =
System 3	NPV (	0	) =
System 4	NPV (	0	) =

Distribution Functions used within the programming are as follows:

- *Yield Reduction (%) 0-6 years* – Triangle distribution (-5, -2, 0) (max, most likely, min)
- *Yield Reduction (%) 6 + years* – Triangle distribution (-15, -10, 0)
- *Pricing* - Discrete probability distribution based on last 30 years of pricing data
- *Crop yields* – Uniform distribution from 10 to 30 % of coffee revenue (at average coffee pricing)
- *Interest rate* for NPV calculation (adjusted for inflation) – 10%
- Monte Carlo simulation was run with 1000 iterations of randomly chosen values from within distribution functions
- Sensitivity data, percentage of iterations greater than zero, and regression coefficients are calculated automatically by @ Risk software and is used in economic criteria scoring.

Economic Calculations (Processing)

Year	1	2	3	4	5	6	7	8	9	10
Pr (AP)										
Pr (EC)		Some are fixed, others will be input with a probability distribution function								
Pr (LC)										
C&I										
S										
NPV (Interest rate, 5 years)		Average								
NPV (Interest rate, 10 years)		Average								
Risk (probability that NPV is > 0 as per Monte Carlo Simulation - 1000 iterations NPV (5) NPV (10)										

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Similar to the cultivation calculations, static economic values are input where appropriate and those values with variability or probability distribution functions associated with their value are input as an equation. The Monte Carlo simulation will then calculate the NPV (5) and NPV (10) and output the average for each as well as the risk (percentage >zero) based on the input distributions. The conditions of these numbers provide the basis for logic equations that input the economic criteria scores into the system scoring table via imbedded excel commands.

Each criteria table is on a page of its own. The user inputs the scores for each using the scoring guide found in section 6.5.2. Similar to the Eco-Efficiency criteria the user can accept the default weights or change them. At the bottom of each table the user is given the option to move to the next page or to go back to the page before and re-enter data.

Socio-Environmental Criteria		*System 1*	..	..	..	..	..
Compliance	0.2						
Training requirements	0.1						
Stakeholder attitudes towards environmental issues	0.4						
Alignment with national sustainability policies	0.1						
Availability of reliable data	0.2						

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Environmental Criteria		*System 1*	..	..	..	..	..
Level of System Monitoring	0.2						
Resource Consumption	0.1						
Impacts of Wastes	0.2						
Response	0.1						
Soil Health	0.2						
System Resilience	0.1						
Biodiversity levels	0.1						

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Socio-economic Criteria		*System 1*	..	..	..	..	..
Level of community stability	*0.25*						
Level of bargaining power held by industry stakeholders	*0.2*						
Access to credit	*0.3*						
Pay rate compared to living costs	*0.25*						

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Social Criteria		*System 1*	..	..	..	..	..
Availability of industry support of worker's well-being	0.25						
Injury rate amongst workers	0.25						
Balance of work and leisure	0.25						
Child Labour	0.25						

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Institutional Criteria		*System 1*	..	..	..	..	..
Level of institutional support	0.2						
Demonstrable case studies/examples	0.2						
Availability of appropriate technology transfer expertise	0.2						
Efficiency of communication networks	0.2						
Ease of market access for resulting product	0.2						

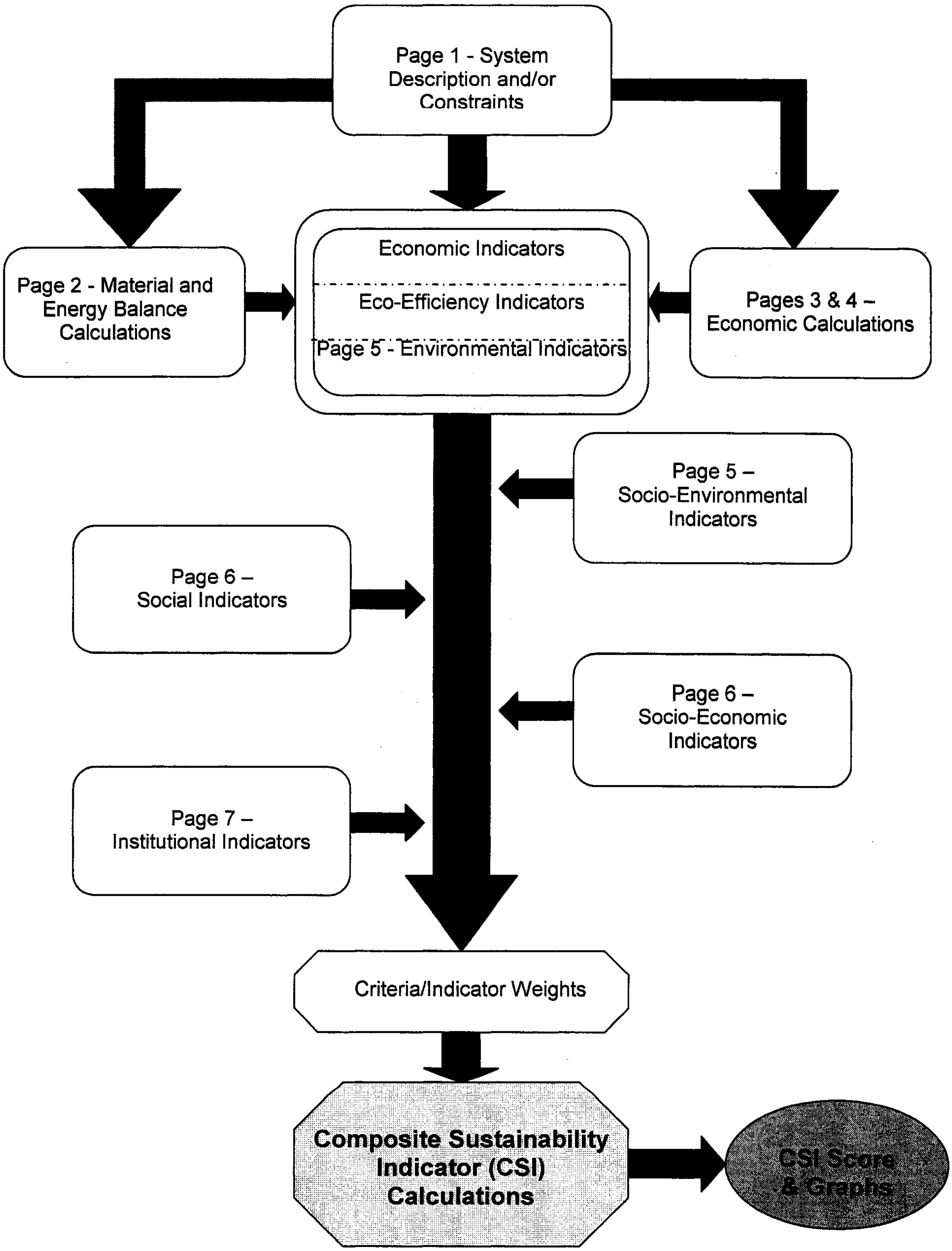
Calculate
Go Back

The "Calculate" hyperlink assumes the user is happy with the input data and wishes to proceed to the output table. As in previous pages, the "Go Back" hyperlink, takes the user to the previous table.

Indicators	Weights	System 1	System 2	System 3	System 4	System 5	System 6
Social	0.14						
Socio-economic	0.14						
Economic	0.15						
Eco-efficiency	0.14						
Environmental	0.15						
Socio-environmental	0.14						
Institutional	0.14						
Total Score							

Go to Statistical Graphs
Go to Output Graphs
Change Input Data

The "Go to Statistical Graphs" hyperlink takes the user to the @Risk output graphs and data. This assumes that the user understands the meaning of the various parameters such as regression coefficients, median, mode, and other standard statistical nomenclature. The "Go to Output Graphs" are merely the graphical representation of output table. The values are also output to another table where the user can manipulate the weighting of the major criteria to see what the change in outcome is. The "Change Input Data" hyperlink takes the user back to the "Systems Consideration" page.


Page 1 - System Description and/or Constraints
Page 2 - Material and Energy Balance Calculations
Economic Indicators
Eco-Efficiency Indicators
Page 5 - Environmental Indicators
Pages 3 & 4 – Economic Calculations
Page 5 – Socio-Environmental Indicators
Page 6 – Social Indicators
Page 6 – Socio-Economic Indicators
Page 7 – Institutional Indicators
Criteria/Indicator Weights
Composite Sustainability Indicator (CSI) Calculations
CSI Score & Graphs