TOOLS AND CONCEPTS OF JOURNEY TOWARDS A NATURAL CAPITALISM WITH SPECIAL REFERENCE TO ENVIRONMENTAL IMPACT ASSESSMENT, LIFE CYCLE ASSESSMENT AND INDUSTRIAL ECOLOGY

Awang, M. B., Shamsuddin, M. N., Abdullah, R. and Yusoff, M. K.
SEGi University College
9, JalanTeknologi, Taman Sains Selangor,
Kota Damansara PJU5,
47810 Petaling Jaya, Malaysia
E-mail: muhamad@segi.edu.my

ABSTRACT

The evolution of tool applications and approaches for industrial-environmentally related management systems in minimizing their impact on natural environment has facilitated the concept of journey to natural capitalism, notably, on physical flows and the accumulation of substances and materials due to industrial activities. These environmental management tools include risk assessment, resource accounting, cost-benefit analysis, environmental impact statement, and environmental impact assessment. In addition, environmental management system (EMS) series of standards derived from Society of Environmental Toxicology and Chemistry (SETAC) and International Standard of Organization (ISO) Technical Committee 207 initiatives emphasizing on EMS, environmental auditing, life cycle assessment, ecolabeling, environmental performance evaluation, design for environment and climate change. Recent concept on industrial ecology (IE) was introduced and applied respectively into EMS for industrial sustainability. It is based on the integration of human dimension, industrial processes, and environmental concerns that perpetually mimics natural ecosystem processes. This paper describes how these theoretical frameworks of Environmental Impact Assessment (EIA) and Life Cycle Assessment (LCA) tools being developed and applied and subsequently used as central tenet in IE concept in meeting their objectives that indirectly could be further enhanced the journey towards natural capitalism.

1.0 INTRODUCTION

A road map for natural capitalism (Lovins *et al*., 2007) provides numerous examples of companies that leverage the insight in the interest of their own bottom lines and the health of the environment as a whole. It is a startling reconceptualization of how we think about the environment and economic value based on services provided by the earth's ecosystem – amounting to at least 33 trillions of dollars annually (Constanza *et al*., 1997). In dealing with the journey to natural capitalism, there are four major shifts in business practices or business prepositions that are interrelated with each other as highlighted by Lovins *et al*., (2007). These four prepositions encompass: a) reduction in wasteful and destructive flow of environmentally limited resources from depletion to pollution that represent the major business opportunity; b) elimination of waste concept by modeling the close-loop production systems based on nature's design – biologically inspired production model that every output either is returned harmlessly to the ecosystem as a nutrient or becomes an input for manufacturing another product; c) shifting a new perception of value – a move from acquisition of goods as a measure of affluence to one where well-being is measured by the continuous satisfaction of changing expectation for quality, utility, and performance that reward them for implementing the first two innovations of natural capitalism – resource productivity and closed-loop manufacturing; and d) reinvest in natural capital through business activities that restore, sustain, and expand the planet's ecosystems so that they can produce and maintain their vital services and biological resources even more abundantly and sustainably.

The evolution of tool applications and approaches for industrial-environmentally related management systems in minimizing their impact on natural environment has facilitated the concept of journey to natural capitalism, notably, on physical flows and the accumulation of substances and materials due to industrial activities. It covers many categories of environmental problems which include among others are natural resource depletion and environmental pollution. Historically, environmental management tools have significantly emphasized on risk assessment, resource accounting, cost-benefit analysis, environmental impact statement, and EIA. While EMS series of standards derived mainly from SETAC (1991) and International Standard Organization (ISO, 1997, 1998, and 1998a) initiatives that have been developed and evolved over the last 15 years emphasize on EMS, environmental auditing, LCA, ecolabeling, environmental performance evaluation, design for environment, and climate change. The most recent concept being introduced and applied accordingly into EMS for industrial sustainability is IE. It is believed that the approach was reconceptualized in 1990s based on 1940s ideas on the integration of human dimension, industrial processes, and environmental concerns that perpetually mimics natural ecosystem processes. This paper describes how conceptual framework of EIA and LCA management tools being developed and applied accordingly. These tools are very much in line with the concept of IE thinking and the journey to natural capitalism.

1.1 Environmental Impact Assessment and Sustainable Development

Over the last thirty years the world has focused on sustainable development concept – the concept that emphasizes on the needs for making continuous economic growth compatible with social equity and efficient environmental management. Initially it was defined as meeting present needs without jeopardizing the capability of future generations to meet theirs (WECD, 1972). Invariably, the vital questions are to what extent environmental quality can be sacrificed to further progress and to what extent growth can be restricted or modified to protect the environment. In short, it requires to taking into consideration the need to sustain and equitable improvement in quality of life based on appropriate environmental conservation and protection measures to avoid exceeding the environment's recovery and waste absorption capacity (Espinoza and Richards, 2002).

Appropriate environmental conservation and protection measures are very much inline with the concept of environmental impact that was first introduced to address the urban pollution issues and later it was extended to animal, plant and ecosystems. Subsequently it was defined and expressed as the significant alteration of natural and man-made systems and their resources, in different activities that are present in both ecosystems respectively. It is constituted the levels of environmental alterations that cause concern to the different countries and human groups and ultimately translates environmental aspects and protection measures. Essentially the development impacts on the environmental dimension comprise the integration of physical, biological, as well as human dimension or social systems. It covers climate, water, air, soil, noise; fauna, flora and ecosystems; population, culture, socio-economic aspects, heritage-historical values, aesthetics and quality of the landscape. While the terms of environmental systems covers spatial, natural and human variability, and transformation activities refers to mainly the anthropogenic activities such as hunting and gathering, urbanization, fisheries, mining, transportation and energy, agriculture, livestock and forestry.

Figure 1 (*after* Espinoza and Richards, 2002) summarizes the environmental aspects and protection measures. Accordingly, this environmental dimension requires detailed analyses on natural aspects of soil, fauna and flora, and pollution covering air, water, waste and soil and its impacts on ecosystems as well as alteration in landscape and cultural values with special emphasis on human health as the alteration can affect their quality of life. In order to evaluate and assess, to correct human activities and prevent, mitigates or compensate their negative impacts on environmental dimension, a special tool is required. As such an "EIA" was introduced (Figure 2 *after* Espinoza and Richards, 2002). It is a preventive management tool which makes it possible to comply with the environmental policies, and even incorporates early, such as policies into the development and decision making processes.

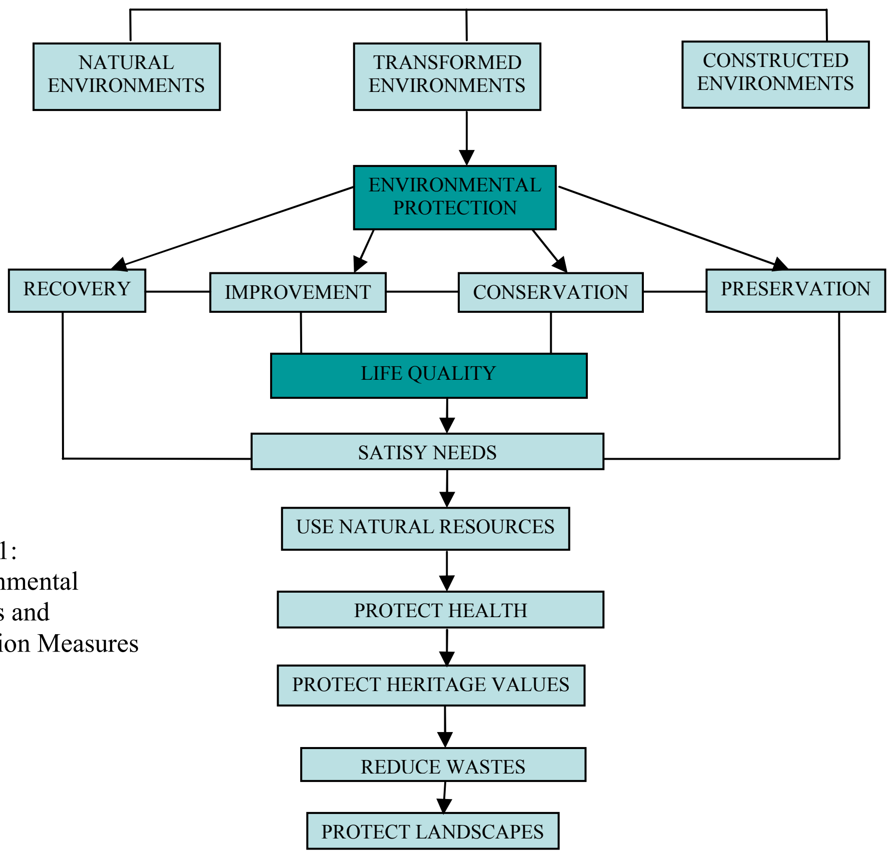


Figure 1: Environmental Aspects and Protection Measures

1.2 Conceptual Framework

The EIA is an innovative process developed as an environmental protection tool by various agencies and endorsed through experiences gained by the developed countries that have incorporated it into their legal systems. It advocates a long-term approach and provides a comprehensive view of human impacts on the environment. Among the important elements that could be derived from the EIA implementation process include motivation to investigate new technological solutions, with greater reflection on the planning and decision making processes leading towards greater creativity and social responsibility in the design and execution of actions and projects. Conceptual framework of the EIA (Espinoza and Richards, 2002) could be summarized as follows:

- Systematic, reproducible, and interdisciplinary evaluation of the potential impact of a proposed action and its alternatives, on the physical, biological, cultural, and socio-economic environment of a geographical area.
- To ensure that significant environmental resources are recognized at the beginning of the decision-making process and are protected through planning and pertinent decisions.
- An early warning process of continuous analysis that protect environmental resources against unjustifiable or unexpected damage.
- Process that transform environmental laws into a uniform set of technical requirements and procedures to analyze human action systematically before their implementation.
- An efficient process calls for significant, premeditated, joint efforts on the part of many entities and actors.
- Helps solve problems during the decision-making process. It provides the bases for more informed decision regarding positive and negative environmental impacts.
- The effectiveness of the EIA depends on the relevance given to the environmental quality at the national, regional, or local levels.
- The adoption of the EIA system can lead to difficult economic decisions and strong political and social commitments. Private and public interest and community consensus for environmental quality form a sound basis for its effective development.

1.3 The Process

The process of the EIA covers objectives and means, respectively. Specifically the objectives deal with the insertion of human activities into the environmental policy that supports sustainable development in order to ensure that:

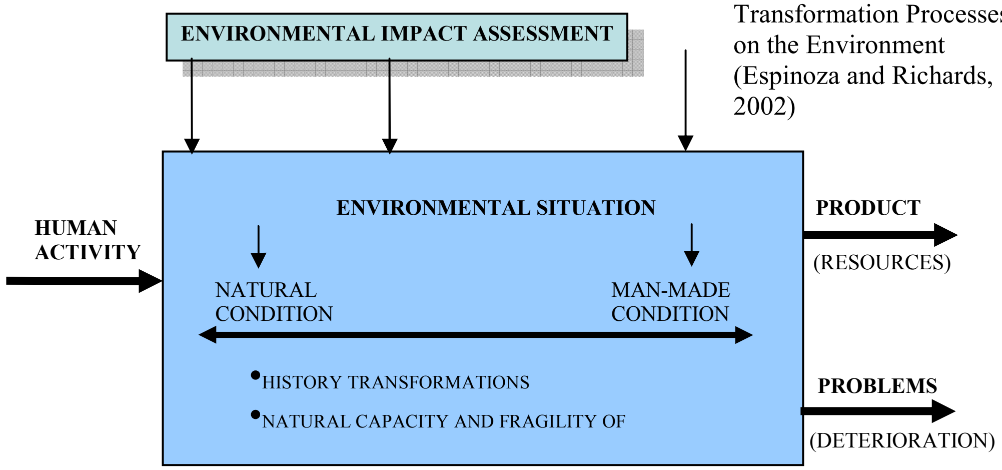
- Actions are environmentally satisfactory.
- Positive and negative consequences are identified at the initial stage of human activities.
- The prevention, mitigation and compensation of negative actions are a key element of environmental management.

While means cover:

- To determine whether the human activities proposed are compatible with the environmental policy and legislation.
- To have a single, informed, and transparent procedure especially designed to review and qualify environmental impacts.
- To conduct preventive studies to identify, forecast, and evaluate negative and positive impacts.

In short, EIA is a preventive management tool applicable to human actions before they are executed. The process involves logical steps and technical requirements through a system where by organization and administration is incorporated using a specific study analysis tool.

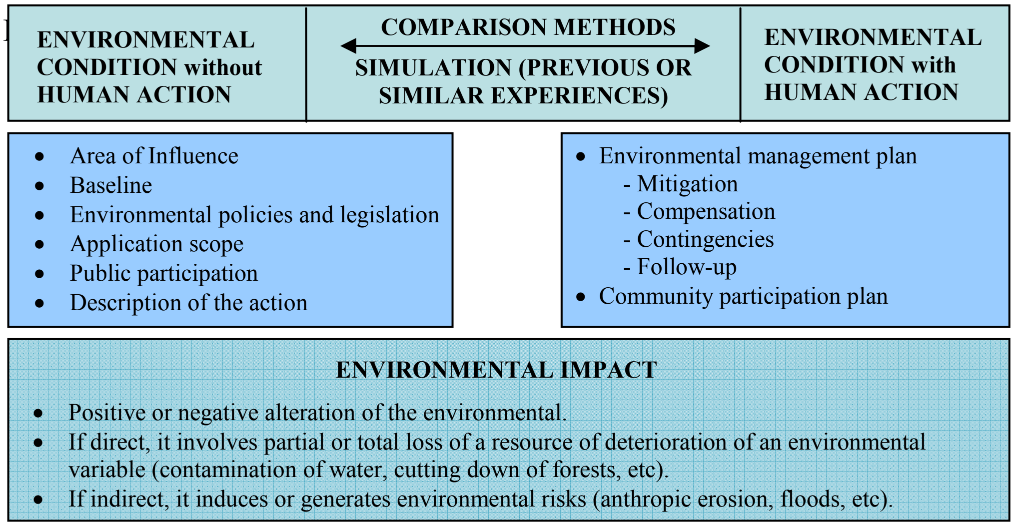
Figure 2: Incidence of Transformation Processes on the Environment (Espinoza and Richards, 2002)



1.4 The Analysis

Figure 3 depicts the analysis of the EIA covering environmental condition before and with human actions utilizing comparative methodologies in determining the potential environmental impacts (either negative or positive alteration of the environment). It considers direct (partial or total loss of a resource or deterioration of an environmental variable such as contamination of water, cutting down of forests, etc.), indirect (induces or generates environmental risks – anthroporic erosion, floods, etc.), cumulative, and synergistic effects, accordingly. Among the parameters need to be determined before human action are area of influence, baseline data and information, environmental policies and legislation, application scope, public participation, and description of the action. In the case environmental conditions with human action, it is specifically emphasized on the environmental plan that cover mitigation, compensation, contingencies, follow-up, and the inclusion of community participation plan.

Figure 3: EIA Analysis Coverage



As the EIA is encouraged to use and adopt different methodologies for different situations in determining the potential of environmental impacts (perhaps introduces a new technology into the environment to solve the environmental deterioration), it is prudent to examine not only the implications of the project, but also the environmental risks of the technology itself. This preventive measure prior to the execution of the project needs to be in place and the following steps should be considered in the assessment:

- Screening – to identify what should be excluded because it is not environmentally relevant.
- Scoping – to define key points to be reviewed in the assessment.
- Use specific methods in each case, such as scenario analysis, preventive environmental standards, and analysis of integrating methodologies.
- Point out the needs for community information and participation.

In addition, the levels of application of instrument such as policies, plans, programs and projects need to be detailed out accordingly. As such at the policy level the environmental significance of major decisions is evaluated, protection measures are taken, and actions and tools are defined for meeting environmental objectives. While at the plan and program level, the environment is considered holistically. It is appraised, classified and the most suitable proposals are selected depending on their potential impact and on political, social, economic and technical conditions. At the project level, details are analyzed for each stage (design, construction, operation, and abandonment) and corrective measures are proposed to eliminate, minimize or compensate any environmental damages.

1.5 Project Cycle and Steps

Espinoza and Richards (2002) summarize (Figures 4 and 5) the planning system for a project cycle linked to the different steps of the EIA, and scheme relating to EIA to an investment proposal with the details of project analysis and procedures, respectively.

Figure 4: Project Cycle and EIA Steps

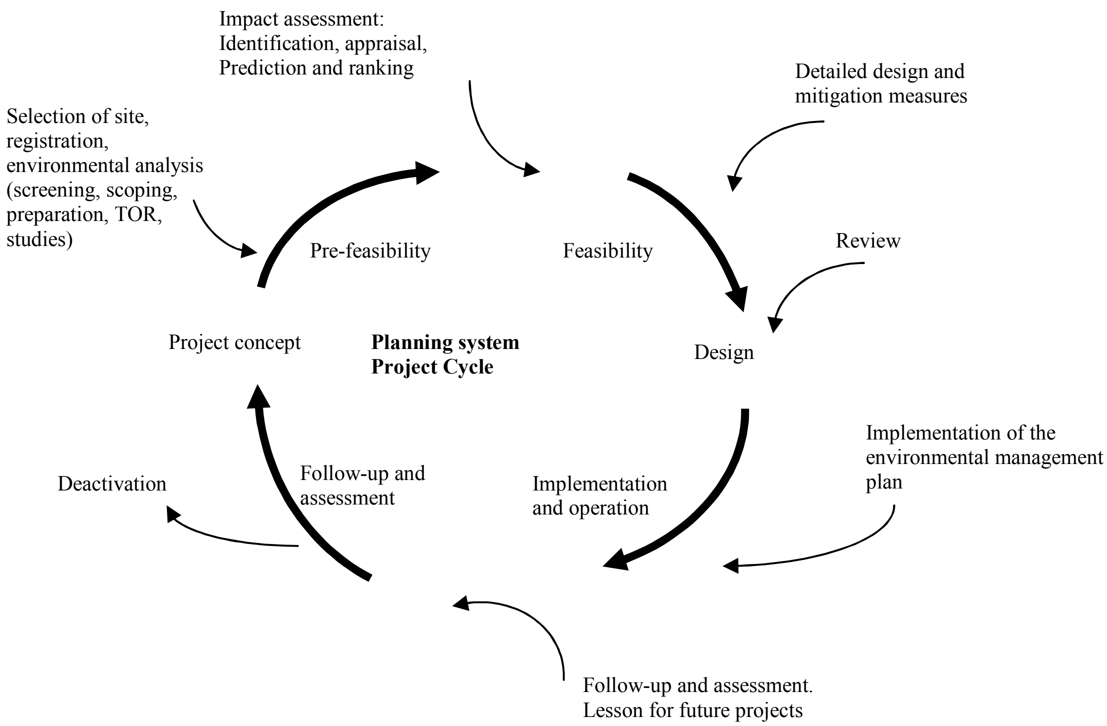
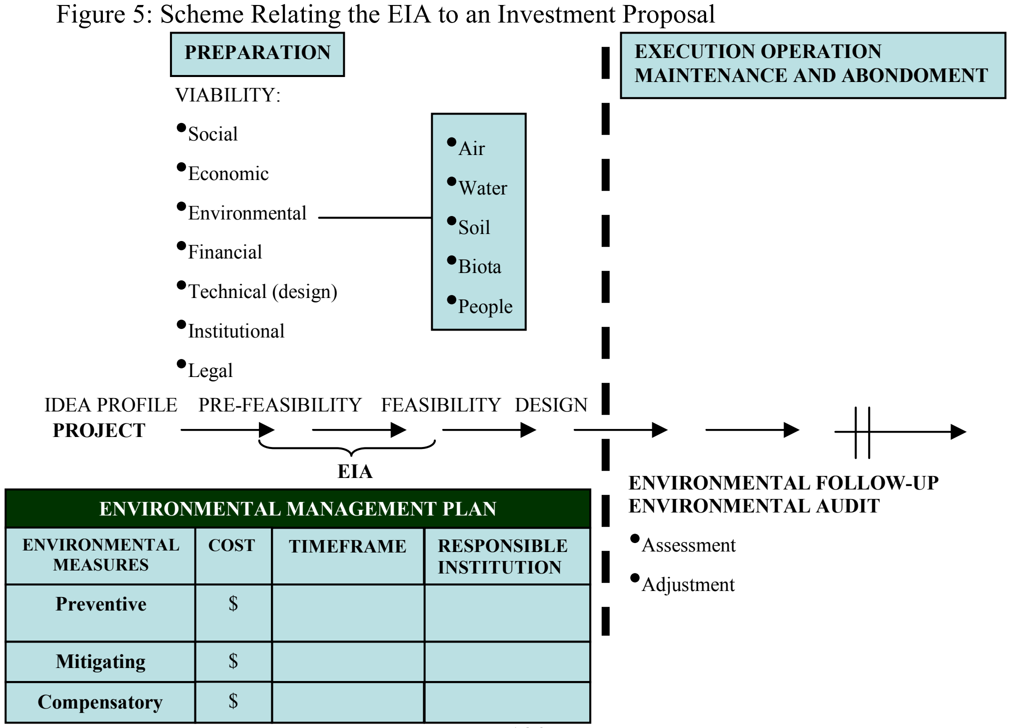


Figure 5: Scheme Relating the EIA to an Investment Proposal



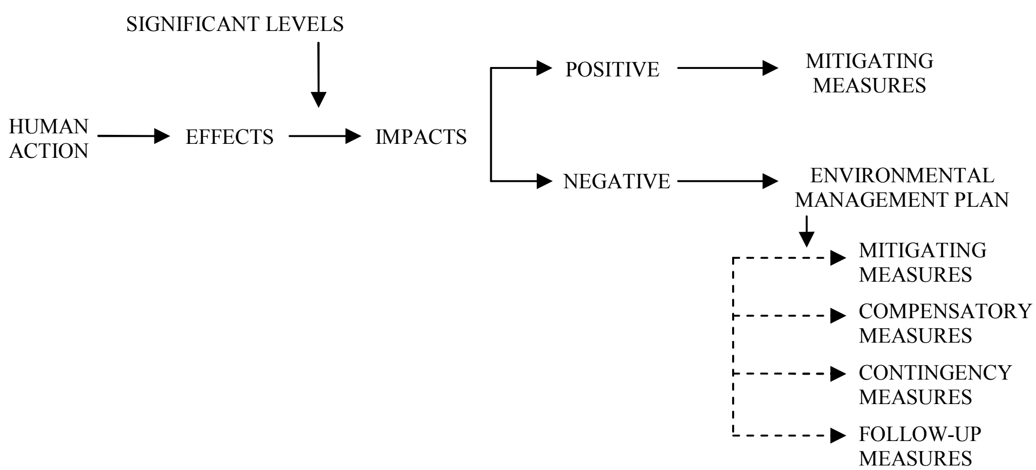
ENVIRONMENTAL MANAGEMENT PLAN			
ENVIRONMENTAL MEASURES	**COST**	**TIMEFRAME**	**RESPONSIBLE INSTITUTION**
Preventive	$		
Mitigating	$		
Compensatory	$		

1.6 Scope and Criteria of EIA

As the objective of the EIA is to prevent situations of deterioration, to establish the most adequate measures for reducing impacts to acceptable levels, and to protect environmental quality, hence, the scope and criteria of the EIA involve a system governing methodologies, criteria, and procedures that are required as pre-requisite in order to evaluate, prevent and correct negative environmental impacts caused by human activities (Figure 6).

More importantly, the general definition of the EIA relates to an early warning process that makes it possible to incorporate environmental policy (*defined as the regulatory principles and basic objectives for environmental protection and their articulation with economic, social, and development policies – it lays the foundations for preparing laws and regulation which are, in turn, the tools for meeting the objectives described in the policies*) in advance. Invariably, the idea is to recognize the environmental variables of concern from the very beginning and to protect them through pertinent decisions by allowing the planned actions into line with environmental policies and regulations established to protect the environment.

Figure 6: Summary of Conceptual Structure of the Environmental Impact Assessment Process



This approach needs to satisfy the following bases:

- Preventive and integrated application of environmental policies.
- Systematic inclusion of the environmental dimension in planning and decision-making.
- Making environmental protection compatible with economic growth.
- Prediction and reduction of negative environmental impacts and enhancing of positive impacts.
- Prevention of negative environmental impacts derived from human activities.
- Application of measures to achieve acceptable environmental levels.
- Extensive and integrated knowledge of environmental impacts.

- Generation of a coherent and reproducible set of data to use in making informed decisions.
- Systematic community participation.
- Motivation to save financial and material resources.
- Contribution to decision-making.

These bases need to be supported by the main mechanisms of the EIA which include:

- a set of requirements, steps, and stages that should be complied with in order for a preventive environmental analysis to be sufficient in itself, according to international standards.
- organization and management of the EIA according to the situation and the capability of those who apply it – EIA system.
- documents that justify the preventive environmental analysis and provide(s) judgment elements to make informed decisions about environmental effects of human activities – EI study.

The EIA also could be used as an early warning system that operates through an on going process of analysis such as

- *to decide* in advance whether an EIA is necessary.
- *to analyze* only the actions that may have a significant environmental impact.
- *to incorporate* beforehand significant impact criteria – (air and water pollution, deterioration of protected natural and ecological resources, undesirable impacts such as landscape deterioration, generation of noise, and others, discharges of toxic or hazardous substances or waste generation, cumulative adverse effects, negative socio-cultural impacts, significant public controversy).
- *to clearly define* the scope of the EIA and consider – (widespread participation, determine of key points, elimination of insignificant points, allocation of requirements for study preparation and qualification, identification of he purpose of the action and the alternative actions) designed to protect the environment against unjustifiable or unexpected damage.

As a prediction tool, the EIA is useful only if it can influence the planning and future development of each human action; thus, its application should begin in the earliest possible phase of the decision making process as the EIA attributes will:

- integrate by different components of the environment and various disciplines
- provide a context for the pertinent elements of the environment
- target the significant impacts
- flexible enough to adjust to the individual case
- predict consequences after implementing an action
- incorporate community participation
- report possible impacts
- support the environmental protection and improvement policy
- complement an integrated development of actions, together with political, economic and social decisions
- lead to the abandonment of the environmentally unacceptable actions, mitigate the negative impacts until acceptable levels are reached and adjust change in time

- support decision-making

Another important feature of the EIA is that through the exercise, it will make it possible to compare the existing situation with the situation that would results from a specific plan action. The comparison will serve to identify the positive impacts and the environmental benefits of the project under evaluation, as well as those negative impacts that will need to be managed if deterioration is to be prevented.

The environmental impact study which sets forth the argument to decide on the best possible location for an activity based on their background analysis, if there are alternatives from the environmental perspective. The study also will record the EIA process at different stages – analysis, prognosis, and measures taken to make an action compatible with environmental protection.

1.7 Limitations

Among the limitations found in environmental impact studies are:

- It is not always possible to emphasize the interdisciplinary character, although this is essential
- They used predictive methods based on scientific information that is always not available
- They used abstract concepts which cannot always compete with sciences that incorporate quantifiable data
- They need data that are all at the same level and exchangeable on compatible scales
- Since they have a varied methodological framework, it is necessary to know the land or place affected in order to define its use
- They use fragility and quality analysis of the affected land for which there are often no baseline data available.
- They require detail ed information that is not always available or is not compatible with the study requirements
- They have to improve the methods of appraisal for analyzing environmental impacts in the same as the economic and social impacts
- Some environmental components are difficult to address, such as quality analysis, fragility of the land and landscape value, among others

1.8 Functional Stages of the EIA System

An EIA system requires some basic components in order to meet the goals of the environmental protection efficiently, with the main objective is to facilitate and unify the procedures to provide a clear environmental certification under equal conditions. These components are characterized by:

- Establishment of substantive national environmental policy that sets environmental protection priorities
- Definition of legal requirements for EIA process
- Creation of regulations and requirements to implement the law systematically, strictly and pragmatically

- Establishment of an administrative procedure for preparation, coordination, orientation and qualification of studies that analyze environmental impacts
- Identification and clarification of organizational functions and responsibilities with the current legislation
- Coordination of drafting and reviewing of reports and of the decision-makings process among environmental agents, private agents, consultant and the general public
- Ongoing evaluation of the success of the program and those responsible for it
- Encouragement of community participation at all stages

Essentially, theoretical framework of the EIA could be expressed in four stages as summarized in Figures 7 and 8 based on the different requirements of the stakeholders. These stages are as follows;

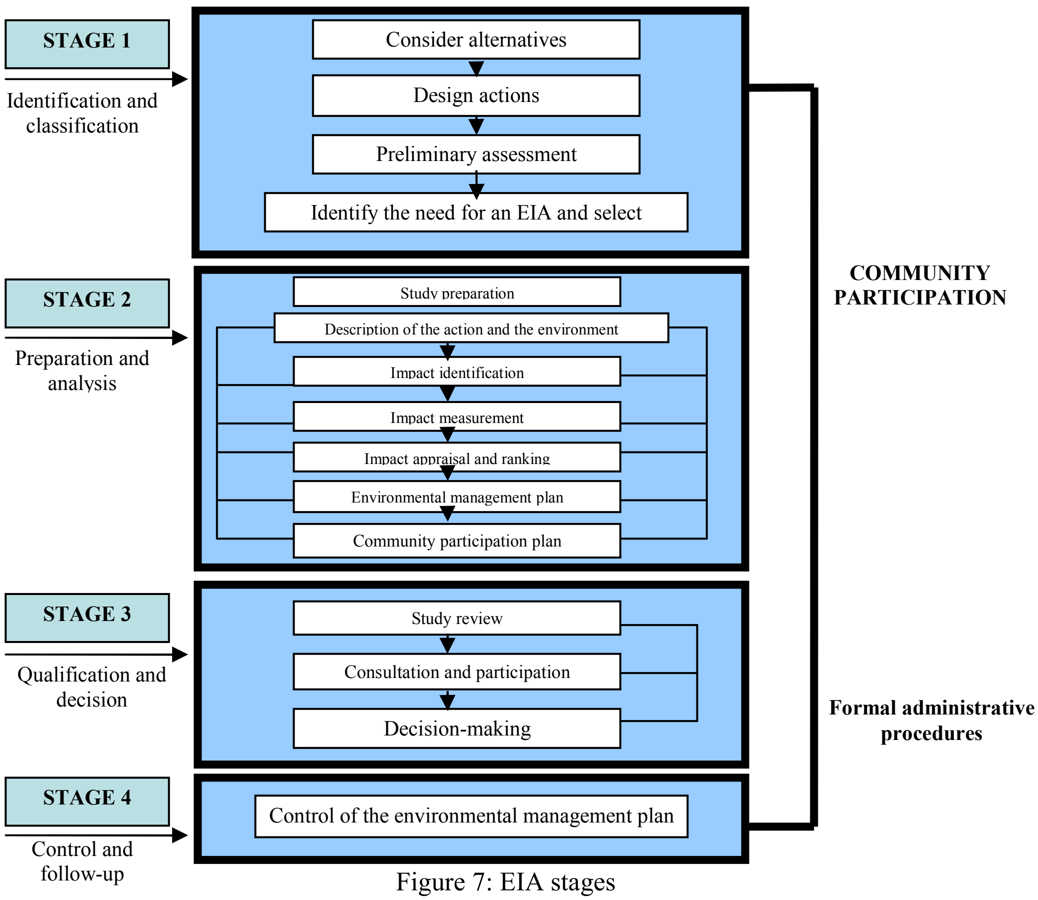


Figure 7: EIA stages

i) **identification and classification** - it defines the need for an EIA and types of environmental category required with a preliminary evaluation based on project description, description of the area of influence, and possible mitigating measures. The key aspect is to identify accurately the level of study required and its coverage that ensures the adverse environmental impacts will be prevented and minimized

ii) **preparation and analysis** covering description of the environment, prognosis and analysis of the environmental impacts, and environmental management plan– it corresponds to valid application of the study scope for a specific project. The significant impacts, identified in the preliminary evaluation, are reviewed and their mitigating and compensatory measures are established for the subsequent review and definition of mitigating, monitoring, and control requirements. In addition, the environmental management is prepared, the follow-up and control task is proposed, and community participation is coordinated

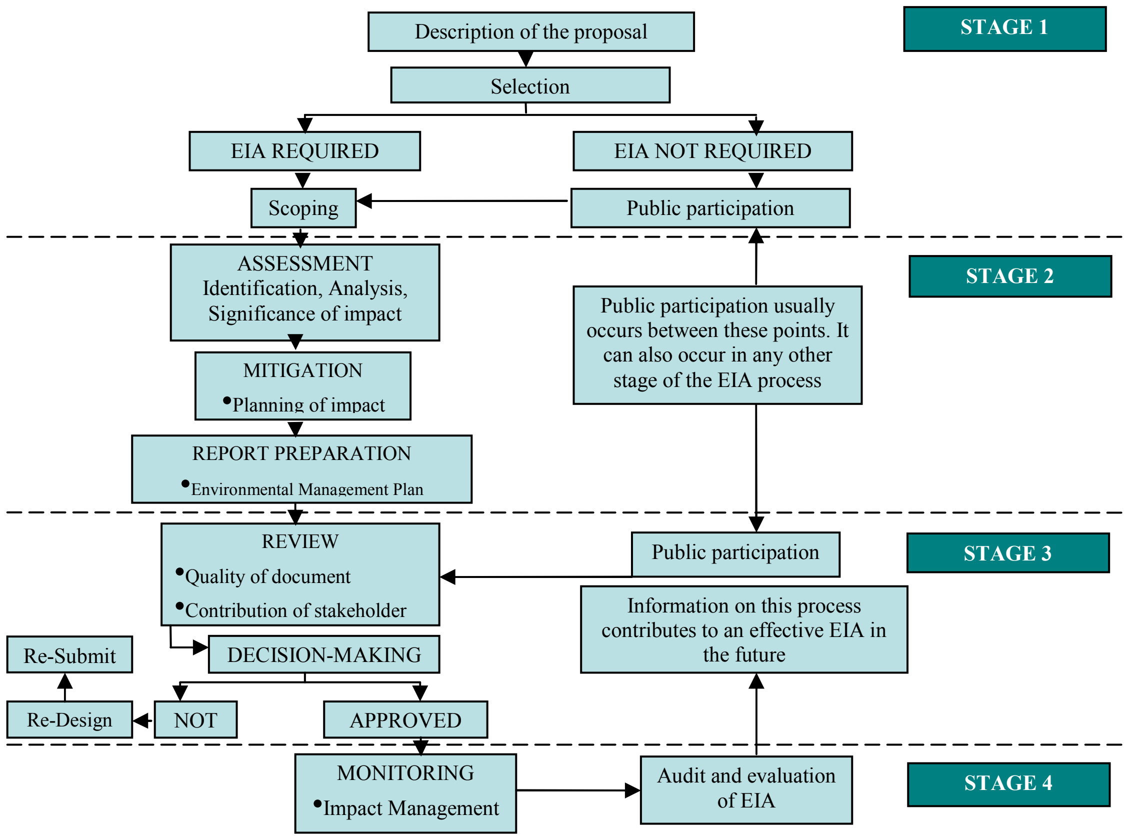
iii) **qualification and decision** – it correspond to the formal review of environmental impact studies by the authority to confirm the adaptation and relevance of the measures proposed in the management of significant negative impacts derived from specific action. The review focuses on whether it effectively complies with the formal and administrative aspects, the minimum technical quality requirements, and the environmental sustainability of the project for the purpose of either approved, rejected, or modifications of the studies are requested

iv) **follow-up and control** – verification of the environmental management plan for the post-project implementation period is being duly executed, and also the conformity of the environmental protection criteria governing the EIA process is strictly followed, and the area of influence and current environmental legislation are recognized accordingly. This final stage will ensure that the action and all related activities, mitigating measures, and control and follow-up mechanism protect the environment satisfactorily. Among the follow-up actions commonly used are:

a. monitoring of water, air and soil quality, and waste generation
b. flora and fauna samplings used as bioindicators
c. reports on the environmental situation of the project and evolution of the plan for compliance with protection measure
d. report on the evolution of socio-cultural aspects
e. complementary environmental studies, if appropriate.

In short, the EIA means, ultimately, that a permanent relation is maintained with the human activity to be undertaken, from the design phase to the abandonment whereby compliance with environmental protection measures should be monitored permanently. As such the ultimate objective of the EIA is to prevent situations of deterioration, to establish the most adequate measures for reducing human impacts to acceptable levels, and to protect environmental quality be attained sustainably.

Figure 8: Flow Chart of EIA Procedures in the International Development Bank (IDB) and Its Relation to the Stages of the General Scheme of an EIA System



In short, the EIA means, ultimately, that a permanent relation is maintained with the human activity to be undertaken, from the design phase to the abandonment whereby compliance with environmental protection measures should be monitored permanently. As such the ultimate objective of the EIA is to prevent situations of deterioration, to establish the most adequate measures for reducing human impacts to acceptable levels and to protect environmental quality be attained sustainably.

2.0 LIFE CYCLE ASSESSMENT

2.1 Concept and Definition

As the society has become more concerned about the issues of natural resource depletion and environmental degradation due to industrial pollution, many businesses have responded to this awareness by providing services and products using greener processes. Consequently, the environmental performance of products and processes has become a key issue to many companies. This has led to industrial environmental strategies shifted from traditional "end-of-pipe" solution to pollution prevention strategies. They focus on cleaner technology and moving beyond compliance using pollution prevention strategies and

EMSs in order to improve their environmental performance and compete sustainably. This approach entails through a concept that considers the entire "life cycle" of a product (Currant, 1996) produced through industrial systems. It begins with the extraction of the raw materials from the earth to create or manufacture the product, use, and ends at the point when all materials of the products are disposed and returned to earth. An LCA evaluates all stages of product's life that enables to estimate the cumulative environmental impacts resulting from all stages in the product life cycle including raw material extraction, material transportation, ultimate product disposal, etc. Essentially, by including the impacts through out the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product and process selection (Curran 2006).

2.2 Life Cycle Stages

Figure 9 illustrates the possible life cycle stages that can be considered in an LCA and typical inputs/outputs measured (USEPA 1993). ISO (1997) defines LCA as a technique to assess the environmental aspects and potential impacts associated with a product, process or services by compiling an inventory of relevant energy and materials and environmental releases; evaluating the potential environmental impacts associated with identified inputs and releases; and interpreting the results to help decision-makers make a more informed decision. Earlier, SETAC (1991) defines LCA as an objective process to evaluate the environmental burdens associated with a products, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact of those energy and material uses and releases in the environment, and to evaluate and implement opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation, and distribution; use/reuse/maintenance; recycling; and final disposal as shown in Figure 10 as an example for a treatment project and could be generalized as illustrated in Figure 11.

Figure 9: Life Cycle Stages (Source: EPA, 1993)

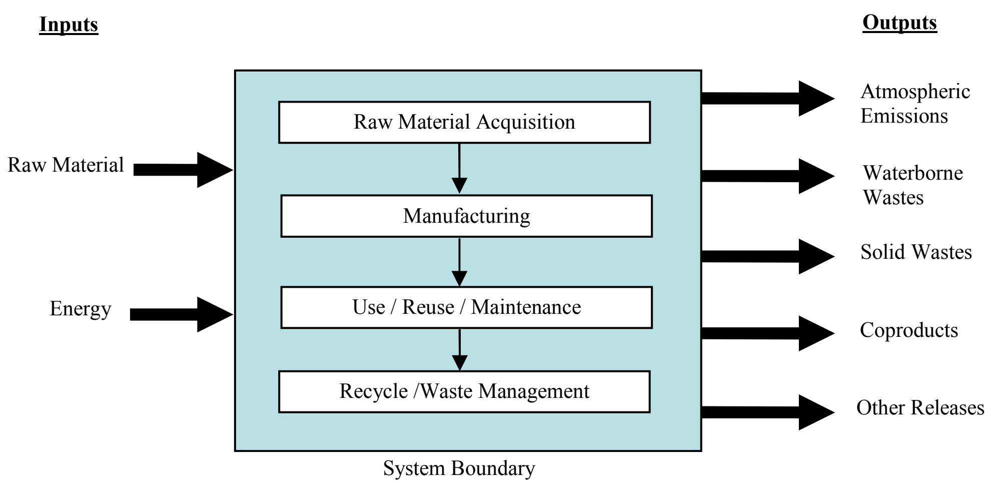


Figure 10: An Example Life Cycle Stages for a Treatment Project

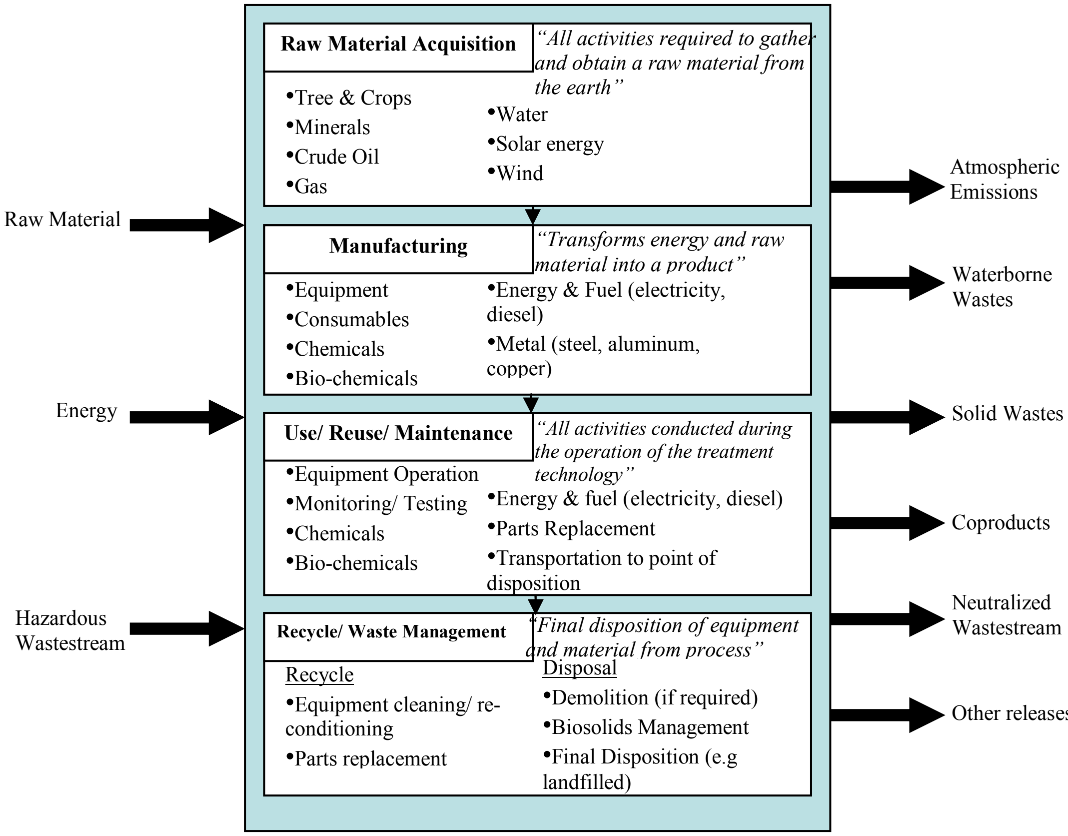
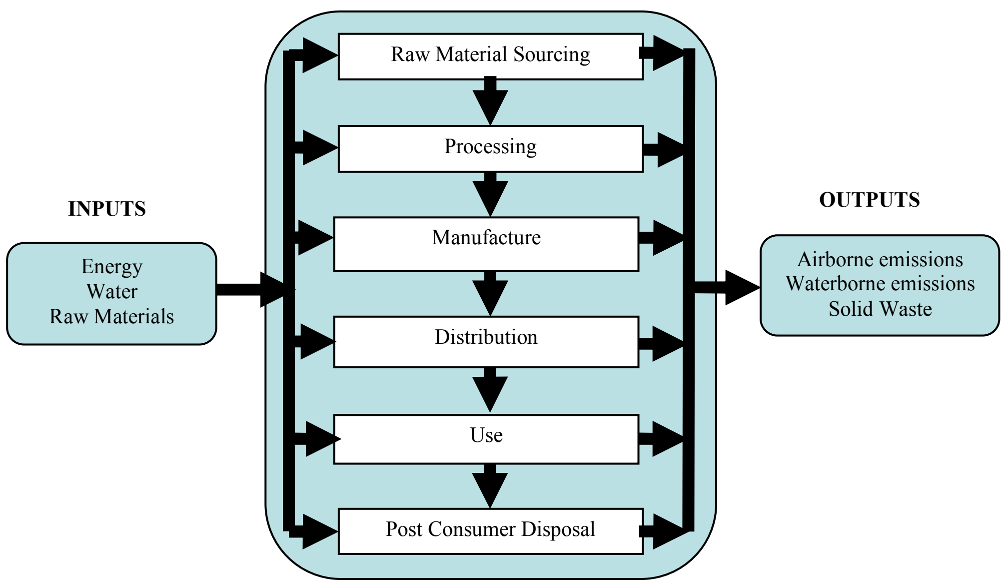


Figure 11: The Stages of a Product's Life Cycle



2.3 Life Cycle Phases

The process of LCA is a systematic, phased approach and consists of four components, namely; a) goal definition and scope, b) inventory analysis, c) impact assessment, and d) interpretation as illustrated in Figure 12.

- *Goal definition and scoping* – define and describe the product, the process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment. The goal definition component states the reason for performing a specific study, define the options that will be compared and the intended use of the results. This fundamental stage of LCA involves identifying the system boundaries (technical, geographical and time) and the procedures for handling the data. Rules and assumptions need to be transparent and fully documented, as every stage will involve the needs for choices and value judgment.

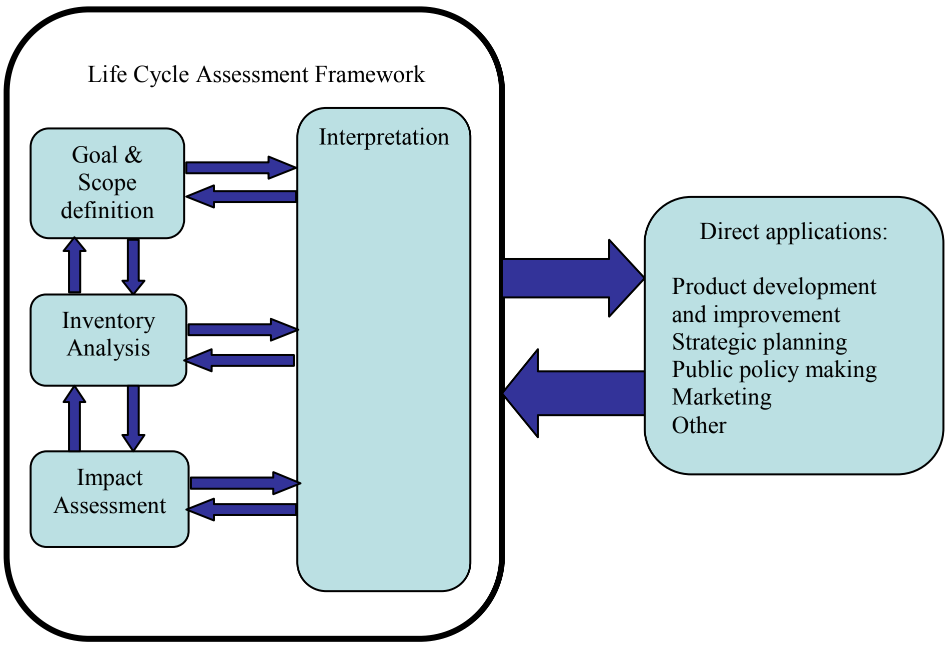
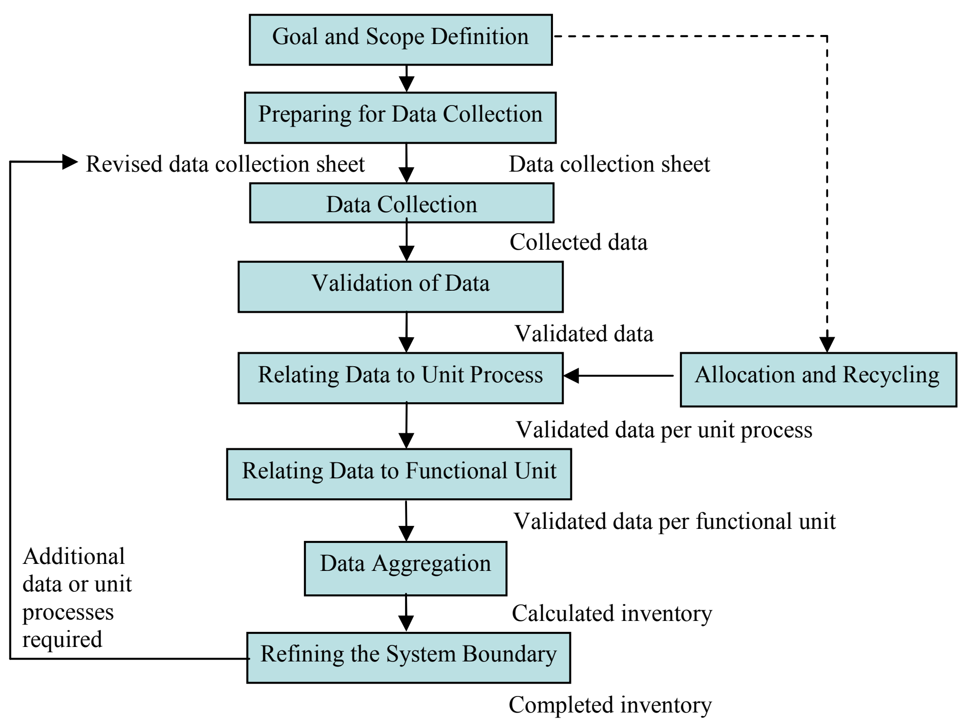


Figure 12: Phase of an LCA. Source: ISO 14040 (1997)

In defining the scope of the study basically it outlines the parameters within which the study will be carried out should be compatible with the goal. It requires descriptions on; the functions of the product systems, the functional units, the product systems to be studied, the product system boundaries, allocation procedures, the type of indicators and the methodology of the Life Cycle Impact Assessment and subsequent Life Cycle Interpretation to be used, data requirements, assumptions, limitations, the initial data quality requirements, the type of critical review and the type and format of the report required for the study.

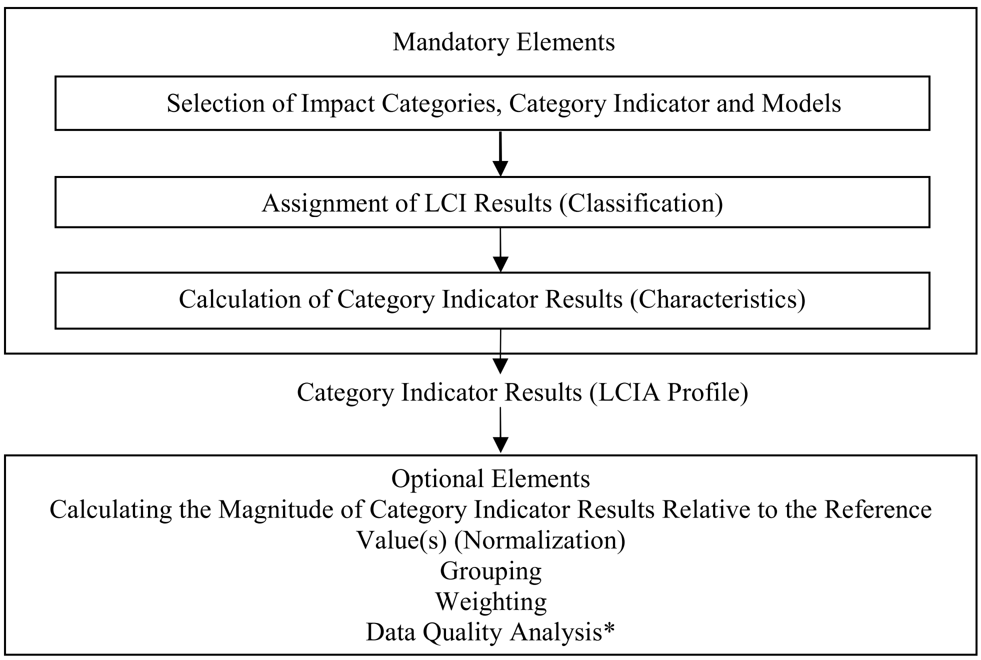
- *Inventory analysis* – identify and quantify energy, water and materials usage and environmental releases identified in the inventory analysis. It accounts for all the material and energy inputs and outputs over the whole life cycle of the product or service. Figure 13 illustrates the operational steps involve in the LCI. The procedure entails describing the Life Cycle as a series of steps, and then calculating the inputs and outputs for each of these steps. This amount to constructing a materials and energy balance for each step in the Life Cycle. The analysis of all inputs and outputs for each stage in the Life Cycle can then be combined to give the overall Life Cycle Inventory (LCI). Essentially, an LCI provides enormous knowledge about and insight into the operation of a given system, which can provide the basis for applying and integrating other environmental information and assessment tools into a system for the purpose of comparison.

Figure 13: Procedures for Life Cycle Inventory Analysis. Source: ISO 14041 (1998)



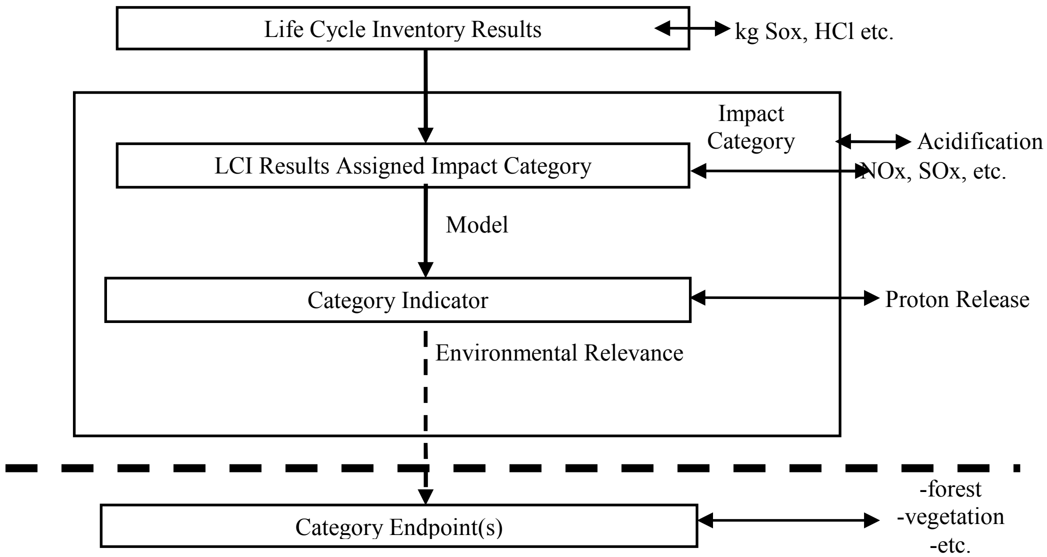
- *Impact assessment* – assess the potential human and ecological effects of energy, water, and material usage and the environmental release identified in the inventory analysis. It provides a system–wide perspective f environmental and resource issues for product or service systems. The Life Cycle Impact Assessment (LCIA) assigns LCI results to specific, selected impact categories – an impact category is used to group certain LCI results that are associated with a particular environmental issues. For each impact category, appropriate indicators are selected and a characterization model is used to calculate indicator results. The collection of indicator results normally - the LCIA profile - will provide an environmental context for the emissions and resource use associated with the product or service system. The LCIA is also composed of several mandatory elements that convert LCI results to indicator results. There are also optional elements for normalization, grouping or weighting of the indicator results and data quality analysis techniques (Figure 14) that cover both mandatory and optional elements of LCIA. While Figure 15 shows a schematic diagram that outlines the procedure for converting LCI results to category indicator results, as each indicator should be assessed for environmental relevance.

Figure 14: The General Framework that Includes Both Mandatory and Optional Elements of LCIA



*Mandatory in Comparative Assertion

Figure 15: Example of LCI Results Converted Into Category Indicator Results



Interpretation – evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or services with a clear understanding of the uncertainty and the assumption used to generate the results. Figure 16 summarizes relationships of the three elements in the Life Cycle Interpretation to other phases of the LCA:

- identify the significant issues based on the LCI and LCIA phases of the LCA
- evaluate the significant issues based upon completeness, sensitivity and consistency checks; and draw conclusions, make recommendations and report the significant issues.

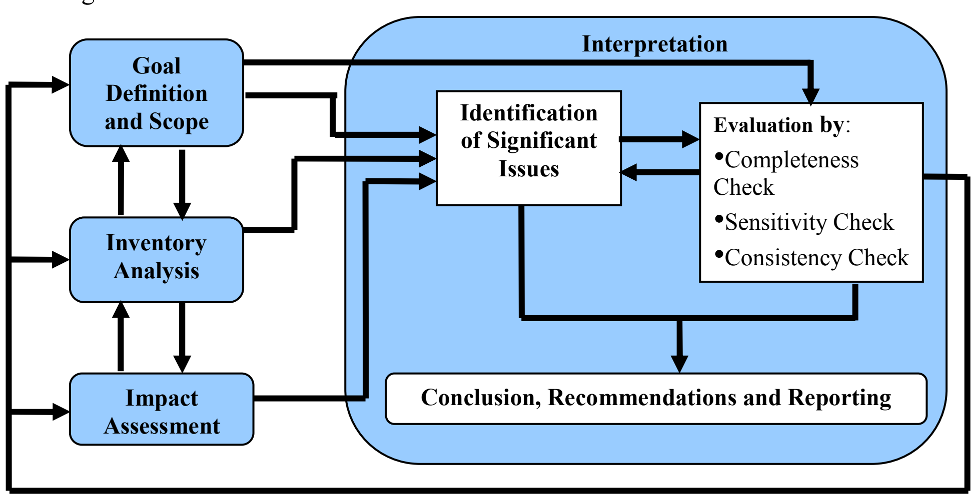
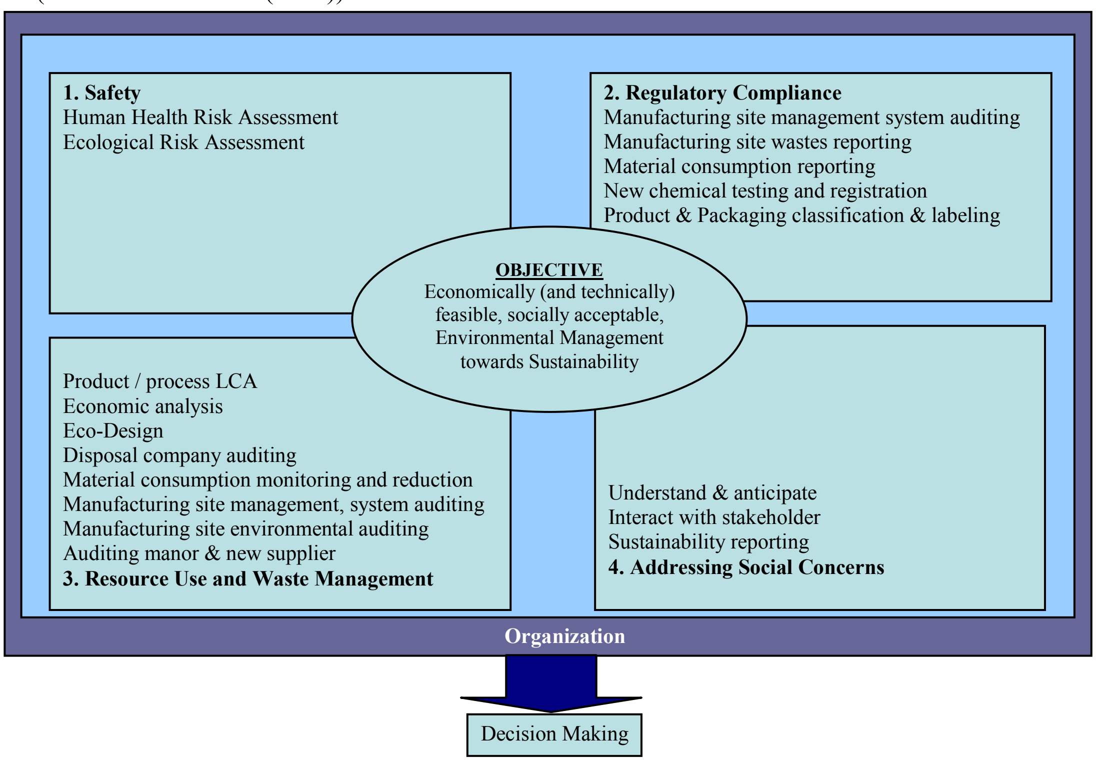


Figure 16: Relationship of Interpretation Steps with other Phases of LCA (Source: ISO, 1998b)

Essentially, interpretation is a systematic technique to identify, qualify, check, and evaluate information from the results of the LCI analysis and /or LCIA of a product system, and present them in order to meet the requirement of the application as described in the goal and scope of the study. It is closely linked to the iterative nature of the process of scope definition, inventory analysis, and impact assessment. Interpretation also involves a review of all the stages in the LCA process and a check that all assumptions are consistent by performing sensitivity analysis.

Figure 17 outlines the position of LCA within an environmental management framework. Invariably, the inter-organizational environmental management includes life cycle management, network environmental management, environmental stakeholder management or regional environmental management that addresses the central issues such as materials and energy flows across the firm, organizational, regional and national boundaries and borders are applying the concept accordingly.

Figure 17: The Position of LCA within an Environmental Management Framework
(Source: White *et al*. (1995))



3.0 INDUSTRIAL ECOLOGY

3.1 Introduction

Industrial systems are growing rapidly as subsystems of the parent ecosystem and are creating a "full world", because of the linear "throughput" flow model of matter and energy (Daly, 1996). Consequently, the global ecosystem is dominating by human-manufactured capital and becoming scarce in natural capital and the life supporting ecosystem services. Approximately 80% of the world's energy production relies on non-renewable - emission intensive fossil fuel (Williams, 1994). In addition, the industrial society produces vast amount of wastes harmful to the ecosystems. Consequently, an earlier proposal on "Strategies for Manufacturing" by Frosch and Gallopoulus (1989) has been reevaluated and recognized by many scholars and industrialists. The suggestion was made that, perhaps, the industrial systems could use the natural ecosystem model to improve their environmental performance and change toward the vision of an "industrial ecosystem" which would mimic the way materials and energy flow in nature. Similarly, sustainable management rules has been used extensively in theory of ecological economics (Daly, 1990) emphasizing on; *harvest rate of renewable resources should not exceed regeneration rates, waste emissions should not exceed the relevant assimilative capacities of ecosystems, and non-renewable resources should be exploited in a quasi-sustainable manner by limiting their rate of depletion to the rate of renewable substitutes*.

3.2 Concept and Definition

Although there is no accepted standard definition that fully captures the ethos of IE and satisfies all researchers (Baldwin *et al*., 2004), however, there are many underlying themes common to most definitions. The definition provided by Frosch and Gallopoulus (1989) as … *"in such a system the consumption of energy and materials is optimized, waste generation is minimized and the effluent of one process…. serve as the raw material for another process. The industrial ecosystems would function as an analogue of biological ecosystems"*…indicating that the systems perspective is required and emphasized on energy and materials as the focus and that both should be optimized. They also suggest that a closed looping material is required, as waste is used as resources for another process - the biological analogy is a useful way in which to understand the industrial systems.

Subsequently, Frosch and Uenohara (1994) describe IE as *"an integrated systems approach to managing the environmental effects of using energy, materials, and capitals in industrial ecosystems. To optimize resource use (and to minimize waste flows back to the environment), managers need a better understanding of the metabolism (use and transformation) of materials and energy in industrial ecosystems, better information about potential waste sources and uses, and improved mechanisms (markets, incentives, and regulatory structures) that encourage systems optimization of materials and energy use*". Implying that reducing the environmental impacts and optimization of the resource use are the main goals, though the sustainable development was not mentioned explicitly. In addition, the idea of top-down pressure in the form of markets, incentives, and regulatory structures was also introduced.

On a similar note, Graedel (1996) offers IE's definition as "*the study of the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a system view in which one seeks to optimize the total material cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal*". He emphasizes on the importance of the integration of industrial and natural systems, optimization of resource use and evolutionary process. It includes the use of tools associated with IE, the notion of carrying capacity, and the cradle to grave perspective that is the backbone of the life cycle analysis (LCA). Earlier, a more comprehensive definition provided by Allenby (1994) as "*the means by which a state of sustainable development is approached and maintained. It consist of a system view of human economic activity and its interrelationship with fundamental biological, chemical, and physical systems with the goal of establishing and maintaining the human species at level that can be sustained indefinitely – given continued economic, cultural and technological evolution evolve accordingly*". The definition highlights that a system perspective is needed to fully understand industrial ecosystems concept. Notably, if optimization is the only objective, the industrial structure would soon become rigid, uncompetitive and inevitably non-sustainable, as the system requires both, an evolutionary nature (an integration of industrial) and natural activities are systematically in place.

3.3 Theoretical Framework

The dominant natural science and engineering side of IE has developed a theory for understanding and analysis of the flows of matter and energy within and between the human industrial system and the natural ecosystem. The emphasis on the utilization and understanding of the natural ecosystem metaphor in industrial ecosystems became the main attraction to the scholars in developing the theory. The industrial ecosystems would be able to move toward sustainable development by using the model of solar energy-based materials recycling and energy cascading natural systems. Subsequently, the industrial and other societal actors would develop cooperative material recycling and energy cascading networks (Korhonen, 2004). Currently, more practical IE tools and metrics include material flow analysis, substance flow analysis for individual substances or a limited group of substances, and environmental LCA for the material and energy flows associated to the life cycle of a product 'from cradle to grave" (Van Berkel *et al*., 1997) being developed and utilized.

The incorporation of the inter-organizational environmental management that complements the more traditional intra-organizational corporate environmental management approach and tools into IE practice enhances the versatility of the IE theoretical framework. The importance of the inter-organizational environmental management is highly applicable in managing the eco-industrial-park, or industrial symbiosis studies - as one of the application areas of the IE (Korhonen, 2004). Korhonen also maintains that this theoretical framework is very much based on the assumption that "*the current knowledge from natural sciences, environmental sciences, thermodynamics, conservation laws, primary production through photosynthesis, the biogeochemical cycles and biology and ecology is enough to know that the world is not ecologically sustainable, and also enough to determine the overall* *direction toward ecological sustainability and away from the unsustainable direction"*. Furthermore, the aspect of IE encompasses natural science and decision science covering either prescriptive or descriptive sciences approach that in reality require a clear distinction between the two in minimizing the weaknesses of the concept. As pointed out by Andrews (2003) among the weaknesses of the concept of IE is "*a predominant focus on the big picture answers "what" questions about the environmental problems, but not "how" questions about their origins –or solutions*".

Arguably, there is practical, instrumental and technical stage of IE that should be coupled with a more normative and metaphoric stage, covering physical recycling infrastructures, recovery systems, recycling technologies, techniques and instruments (these are only the practical and instrumental preconditions of industrial ecosystems) as well as the cultural and the social preconditions of industrial ecosystems. Without a culture of cooperation and trust between the industrial ecosystem participants the linkages between the waste producer and a firm that would use the waste as a raw-material or fuel do not happen, or if they do, will not last long (Korhonen, 2000; Gibbs, 2003). Indeed all values, preferences, interests, decisions and type of behaviour are affected by the "culture" that differed geographically depending on the varied and nature of the society, and their professions.

Basically, IE could be divided into two main components, namely, the physical flow of matter and energy, and the structural and organizational characteristics and properties of IE. The former stresses on the flow between and within the industrial systems and ecosystems aiming to contribute to the efforts of controlling and reducing the impacts that the use of the flows generates on the ecosystems (Jelinski *et al*., 1992, Graedel and Allenby, 2003, Graedel, 1996). The latter, identifying whether there are connections and links between the system components, and what kind of connections and links, and how are these organized. In this connection, Spring (2001) argues on the adoption or the insights from biology and ecology in IE is inappropriate. Henceforth, he proposed "eco-mimicry" (learning from natural ecosystem model when designing our industrial system – use as prescriptive) and "ecology as constraint" (provide us limits and boundary conditions – telling us what we should not do) approach could be utilized natural ecosystem model in industrial system. As such the limit to nature's capacity to produce services, the source and the sink functions essentials for human society, the resources flows into economic activities and the ability of nature to assimilate wastes and emissions, the output flows from societal and economic activities are accounted for.

In short the industrial actors and policy makers must listen to in order to reduce the ecological footprint to a sustainable level. Obviously the approach requires and only achievable through maintaining the level of favorable or successful outcome of planning and management, as well as the level of concrete and practical actions and measures as stipulated in sustainability theory (Robert *et al*., 2002) and its hierarchal levels. The physical flows of matter and energy is possible to prescribe the vision and the overall goal for industrial ecosystems by using the description of the ecosystem as a model (Korhonen, 2004). However, the prescription of suggestions for practical and concrete actions and measures derived from the description of ecosystems is not possible or rather difficult to achieve fully, as actions and measures depend on the specific situation and on the particular context in which they are applied. Taking into consideration that in the case of structural and organizational characteristics and properties of ecosystems and industrial systems, the prescription for industrial ecosystems based on the description of how ecosystems are operated is rather difficult. Undoubtedly, the difficulties of assigning a monetary value for nature are immense (Constanza *et al*., 1998), despite the fact that many ecological economics and environmental economics monetary valuation methods exist. The complete value of nature cannot be measured through quantitative monetary valuation methods, as the monetary value is finite, and the value of nature is infinite. Moreover, environmental policy prescriptions using monetary values can result in incomplete information regarding the natural ecosystem.

3.4. Applications

Although the interpretation of the material and energy flow model of nature when used in industrial ecosystem seems to be a difficult, however, case study of Kalundborg as depicted in Figure 18, Ehrenfeld and Gertler, (1997) and also Brand and de Bruijn, (1999) considered as among the most successful model. The model appeared to be the most often-cited (over 100 papers and book chapters highlighting the characteristics of the case study). It serves as a successful case of the implementation of the material and energy flow theory of industrial ecosystem or "industrial symbiosis". The impetus to develop these recycling structures was purely economic – both to reduce the costs increasingly associated with waste disposal and as an extra income-producing service for other companies located nearby (Desrochers, 2002). It is developed spontaneously without any extra pressure. The relationships and symbioses that developed were due to economic factors. Additional revenue could be gained, as accepting waste could be charged as a service. The recycling network also helped avoid the costs and taxes that associated with waste disposal. According to Korhonen (2003), Kalundborg utilizes non-renewable fossil resources and adopting the ecosystem principle of gradual change – *the development of the system should respect reproduction cycles of the nature*. Conceptually, roundput and gradual change mean that industrial ecosystems do not use non-renewable, or if they do, only at the rate that substitutes (in renewable) are found, and the ecosystem emission binding capacity is preserved, and utilization of the renewable are very much less than their reproduction capacities.

A similar approach of industrial ecosystem (inspired by Kalundborg) was adopted for Styria, Austria, where they begin their analysis with a large basic goods company, traced the waste streams of this company and other associated companies, as well as forms of recycling cooperation, until the geographic company was reached. What is interesting in a number of cases is that the waste material from some companies was a higher quality than the previous virgin materials. Unlike Kalundborg and Styria, industrial ecosystem relating to metal-manufacturing industry in the American state of Massachusetts focused more restricted to copper/copper alloy and lead. It represents a substantial fraction of industrial consumption that unlikely to be substituted in the near future, and involved in one of the oldest industrial systems.

In short, IE is a modern approach to thinking about economy-environment interactions that requires familiarities with industrial activities, environmental processes, and societal interactions, a combination of specialties that is rare (Graedel and Allenby, 2003). It evolves to present concepts, approaches and tools to study the physical flows of matter and energy within and between industrial systems and natural ecosystems (Figure 19). It is a new of looking at the interaction between human and natural systems, representing a significant augmentation, rather than replacement of existing approaches to environmental issues, reflecting the reality of the world within which human and environmental systems operate involving technology and evolution of human culture and economic systems.

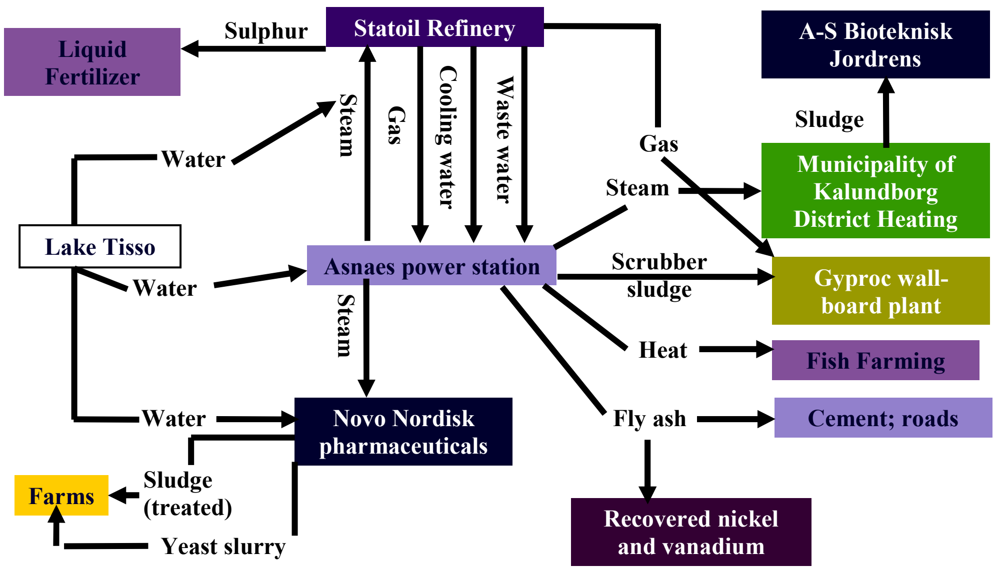


Figure 18: Flow of Resources in the Eco-industrial System at Kalundborg, Denmark

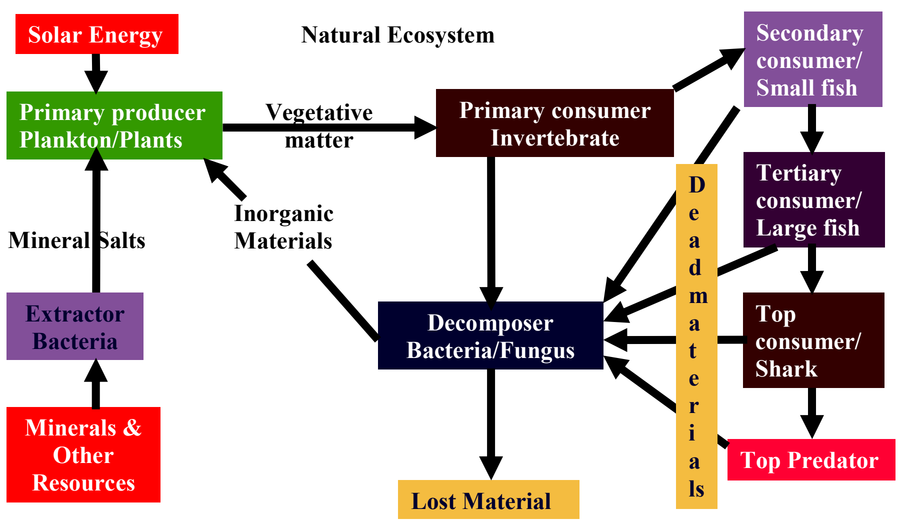


Figure 19: Biological Food Chain in Natural Ecosystem

4.0 EIA and LCA in the Context of Industrial Ecology

As mentioned earlier, the EIA is an innovative process developed as an environmental protection tool by various agencies and endorsed through experiences gained by the developed countries that have incorporated it into their legal systems. It advocates a long-term approach and provides a comprehensive view of human impacts on the environment. Among the important elements that could be derived from the EIA implementation process include motivation to investigate new technological solutions, with greater reflection on the planning and decision making processes leading towards greater creativity and social responsibility in the design and execution of actions and projects.

On the other hand, the LCA is the primary scientific methodology that underlies the concept of life cycle management. A central tenet of IE is that of LCA as the essence of LCA is the examination, identification and evaluation of the relevant environmental implications of a material, process, product, or system across its life span from the creation to disposal or, preferably, to recreation in the same or another useful form. Life cycle management is the cooperative effort by persons at different stages of the life cycle of a product to redesign product systems to reduce their overall environmental impacts. It is the shift of normal industrial management practice away from linear mechanistic thinking and toward holistic systems thinking. It is an expansion of perspective from cradle-to-gate, to cradle-to-grave, and eventually, cradle to cradle. As mentioned earlier, IE refers to a concept of envisioning industrial system as analogous to natural systems. Fundamentally, the application of LCA is analogous to what in ecological science is called autecology – the study of a single species (or specific product system) in relation to its environment. What will develop from it is an industrial counterpart to synecology - the study of how manufacturing processes fit together into a viable community, wherein almost nothing is wasted. All processes will be resources as their by-products provide the primary material for a subsequent process in a continuous regenerative loop. IE is the science of multiscale planetary stewardship, involving the practice of intelligent oversight of the planet as it undergoes natural and anthropogenically driven variability (Graedel and Allenby, 2003). Although the notion of the IE was first proposed during the 1950s, however, it wasn't until the 1990s that academics and industrialists began to take it seriously as an organizing concept with which to model the transitions necessary for industry to become sustainable (Erkman, 1997).

In summary, since the introduction of IE concept, there have been new ways of approaching technology-environment interactions, among others, industrial metabolism, input-output models, intensity/efficiency methods, pollution prevention, LCA, design for the environment and dematerialization. It is becoming increasingly interdisciplinary and evermore broadly relevant. These include the relevance of biological ecology, indicators and metrics, the service sectors, industrial symbiosis, system analysis, and scenario development. In essence, the IE is the combination of technology with society, and that combination has many facets and many implications. It requires to understand, and needs to appreciate corporate and societal interactions, and to understand something of the interactions of industrial activities and the environment (Graedel and Allenby, 2003).

REFERENCES

Allenby, B. R. (1994) Integrating Environment and Technology: Design for Environment, In: Allenby, B. R. and Richards, D (eds.): *The Greening of industrial Ecosystems*. National Academy Press. Washington DC.

Andrew, C. (2003) B*ridging the Descriptive-prescriptive Devide in Industrial Ecology in Hukkinen* (ed.) Technology, Society, Environment, Helsinki University of Technology. Espoo, Otamedeia, Oy, Findland, 13-18pp.

Baldwin, J.S., Ridgway, K., Winder, B. and Murray, R. (2004) Modelling Industrial Ecosystems and the 'Problems' of Evolution. *Progress in Industrial Ecology. An International Journal.* **1(1/2/3)**. 2004. 39-60pp.

Brand, E. and de Bruijin, T. (1999) Shared Responsibility at the Regional Level: The Building of Sustainable Industrial Estates. *Journal of European Environment*. **9**: 221-231pp.

Constanza, R., d'Arge, R., DeGroot, R. S., Faber, S., Grasso, M. and Hannon, B. (1997) The Value of the World Ecosystem Services and Natural Capital. *Nature* 387: 253-260pp

Constanza, R., d'Arge, R., DeGroot, R. S., Faber, S., Grasso, M. and Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P. and van den Belt, M. (1998) The Value of the World Ecosystem Services and Natural Capital. *Ecological Economics*. **26**: 3-16pp.

Curran, M. A. (ed) 1996. *Environmental Life Cycle Assessment*. McGraw-Hill.

Curran, M. A. (2006) *Life Cycle Assessment: Principles and Practice*. EPA/600/R-/060 USEPA, Cincinnati, Ohio. 80pp.

Daly, H. (1990) Toward Some Operational Principles of Sustainable Development. *Ecological Economics*. **2**: 1-6pp.

Daly, H. (1996) *Beyond Growth: The Economics of Sustainable Development*. Beacon Press. Boston.

Desrochers, P. (2002) Regional Development and Inter-industry Recycling Lingkages: Some Historical Perspectives. *Entrepreneurship and Regional Development*, **14**, pp.49-65.

Ehrenfeld, J. and Gertler, N. (1997) The Evolution of Interdependence at Kalunborg. Industrial Ecology. **1(1)**: 67-80pp.

Environmental Protection Agency. 2003. *Tools for the Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI): User's Guide and System Documentation.* EPA 600/R-02/052 National Risk Management Research Laboratory. Cincinnati, Ohio, USA.

Environmental Protection Agency. 1993. *Life Cycle Assessment: Inventory Guidelines and Principles*. EPA 600/R-92/245. Office of Research and Development. Cincinnati, Ohio, USA.

Erkman, S. (1997) Industrial Ecology: A Historical Perspective. *Journal of Cleaner Production*. **5(1-2)**: 1-10pp

Espinoza, G. and Richards, B. (2002) *Fundamental of Environmental Impact Assessment*. Inter-American Development Bank-IDB and Inter-American Association of Sanitary and Environmental Engineering – AIDIS. 15-37pp.

Frosch, R. A. and Uenohara, M. (1994) '*Chairman's Overview'*. In: Richardson, D. J. and Fullerton, A. B. (eds). Industrial Ecology US-Japan Perspective. National Academy of Engineering. Washington DC.

Frosch, D. and Gallopoulos, N. (1989) Strategies for Manufacturing. *Scientific American*, **261(3)**, Sept. 1989, 94-102pp.

Gibbs, D. C. (2003) Trust and Networking in Inter-firm Relations: The Case of Eco-industrial Development. *Local Economy*. **18(3)**: 222-236pp.

Gibson, W. (1997) A Practical View of Life Cycle Assessment. In: Tibor, T. and Felman, I. (eds.) *Implementing ISO 14000*. Irwin Professional Publishing, Chicago. 445-460pp.

Graedel, T. E. (1996) On the Concept of Industrial Ecology. *Ann. Rev. Energy Env.* **21**: 69-98pp.

Graedel, T.E. and Allenby, B.R. (2003) *Industrial Ecology*. 2nd Ed. Prentice Hall, Upper Saddle River, NJ. 363pp.

International Standards Organization, 1997. *Environmental Management - Life Cycle Assessment – Principles and Framework ISO 14040.*

International Standards Organization, 1998. *Life Cycle Assessment – Impact Assessment ISO 14042.*

International Standards Organization, 1998a. *Life Cycle Assessment – Life Cycle Interpretation ISO 14043.*

Jelinski, L. M., Graedel, T. E., Laudise, R. A., McCall, D. W. and Patel, C. K. N. (1992) Industrial Ecology; Concepts and Approaches. Proceedings of National Academy of Sciences. **89**: February, 1992, 793-797pp.

Korhonen, J. (2000) *Industrial Ecosystem – Using the Material and Energy Flow Model of An Ecosystem in An Industrial System*. Ph.D. Thesis. Jyvaskyla Studies in Business and Economics 5. University of Jyvaskyla, Finland.

Korhonen, J. (2003) On the Ethics of Corporate Responsibility – Considering the Paradigm of Industrial Metabolism. *Journal of Business Ethics*. **48(4)**. 301-315pp.

Korhonen, J. (2004) Theory of Industrial Ecology. *Progress in Industrial Ecology. An International Journal.* **1(1/2/3)**. 2004. pp.61-88.

Korhonen, J. and Strachen, P.A. (2004) Towards Progress in Industrial Ecology. *Progress in Industrial Ecology. An International Journal.* **1(1/2/3)**. 2004. pp.1-23.

Lovins, A. B., Lovins, L. H. and Hawken, P. (2007) A Road Map for Natural Capitalism. *Harvard Business Review* – July/August 2007. 172-183pp.

Robert, K. H., Schmidt-Bleek, B. Aloise de Larderel, J., Basile, G., Jansen, J. L., Kuehr, R., Price Thomas, P., Suzuki, M., Hawken, P. and Wackernagel, M. (2002) Strategic Sustainable Development – Selection, Design, and Synergies of Applied Tools. *Journals of Cleaner Production*. **10**: 197-214pp.

Templet, P.H. (2004) Diversity and Other Emergent Properties of Industrial Economics. *Progress in Industrial Ecology. An International Journal.* **1(1/2/3)**. 2004. 24-38pp.

Van Berkel, R., William, E. and Lafleur, M. (1997) Development of An Industrial Ecology Tool Box for the Introduction of Industrial Ecology in Enterprises -1, *Journal of Cleaner Production*, **5(1-2)**, 11-26pp.

White, P., De Smet, B., Owens, J. And Hindle, P. (1995) Environmental Management in An International Consumer Goods Company. *Resource Conservation and Recycling*. **14**: 171-184pp.

William, R., Socolow, R., Andrew, C., Berkhout, F. and Thomas, V. (eds,) (1994) Roles for Biomass Energy in Sustainable Development: *Industrial Ecology and Global Change*. Cambridge University Press, Cambridge, UK. 199-228pp.