CHAPTER TWO

2. LITERATURE REVIEW

2.1 Solid Waste

Waste is like a mirror that reflects the various aspects of society. It is important to define waste in a specific manner, as this will reflect the actions involved in managing it, as well as, the range of policies and regulations, and public understanding required (Sarukai, 2000). Human activities generate waste materials. Normally, solid wastes are often discarded because they are considered useless. However, many of these waste materials can be reused and thus, they can become a resource for industrial production or energy generation if managed properly (Tchobanoglous and Kreith, 2002).

In the past, waste was given low priority in government policies and strategies, however, the situation changed in 1990s when the government and people were concerned about generation of waste and they realized that waste could create negative impacts to human life and the environment if poorly managed. There is positive correlation between increasing waste generation and human population (Mahmood and Victor, 2002).The growing population in the world affects the amount of waste being generated. The total global waste generation that was estimated in 2000, was 318 million tonnes and in 2008 it reached 518 million tonnes, and it is expected to reach to 585 million tonnes in 2010 (Agamuthu, et.al, 2009).

Solid waste management is a critical factor in the urban areas of the world, and, it continues to be a major challenge in the developing countries, particularly in the rapidly growing cities ((Latifah, et.al, 2009). In developing countries, increasing waste generation has alarmed authorities regarding issues related to waste disposal. However, nowadays, waste can be used after treatment and is a resource for processing other products.

Solid waste can be defined as: “waste that is other than emission or effluent and is regarded as an inevitable by- product due to human activities, generated at a rate and discarded after use when no longer needed by the generator” (Agamuthu, 2001). When a useful product has been fully utilized it loses its value and thereby becomes waste. In developed countries, wastes are converted into materials that can be reused. These countries give value to waste. In developing countries lack of knowledge or technology causes people not to separate the waste and so it is mixed (McDougall, et.al, 2001). As shown in Figure 2.1, waste can be used if it gets value. Meanwhile, it can be used for other products for example industrial food wastes, which have little value, may be a resource if processed into animal feed (Agamuthu, 2001).

The relationship between waste and value can be shown as below:

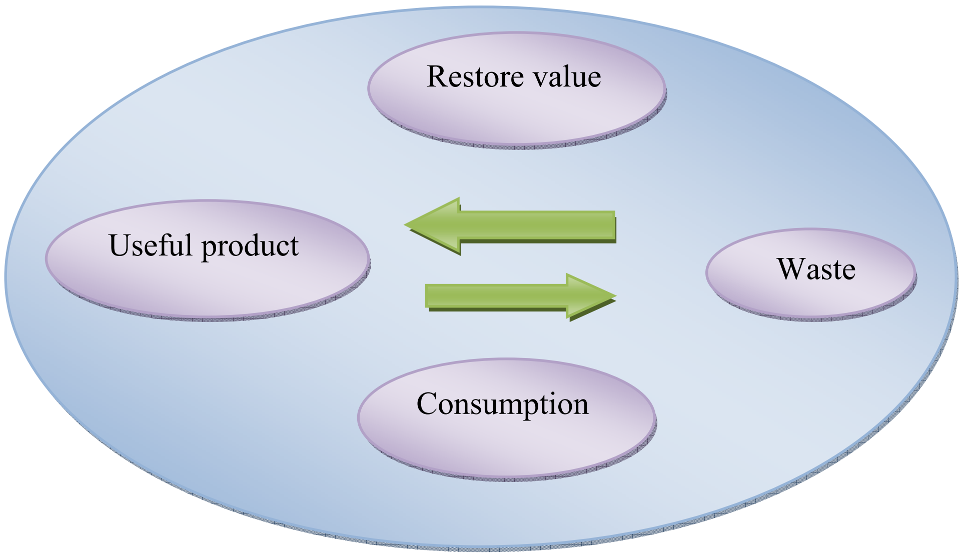

Figure 2.1: Relationship between waste and value

(Source: Agamuthu, 2001)

Human activities inevitably generate waste products (wastewater, air pollutants, solid wastes, etc). The community has a role in transforming natural resources into waste products that could harm the environment. Depletion of natural resources is undesirable. According to McDougall, (2001) classification of waste is as follow:

- Physical state: liquid, solid and gases
- Material type: glass, paper
- Original use: packaging waste and food waste
- Physical properties: combustible, compost and recyclable
- Origin: domestic, commercial, industrial and agricultural
- Safety level: hazardous, radioactive

2.2 Sources of Solid Waste

The main sources of solid wastes are:

- Domestic or residential
- Municipal services
- Commercial
- Institutional
- Industrial
- Agricultural

Agamuthu, (2001) believes that there are four main categories of solid waste as listed below:

- Municipal Solid Waste (MSW): this is mainly household waste, and commercial and industrial waste.
- Hazardous waste: this waste contains hazardous substances that could be harmful to human and environment so the hazard must be removed before waste disposal.
- Agricultural waste: includes both residue and animal waste. Food processing waste which is included in this group and also come under industrial waste.
- Industrial waste: all wastes that come from industrial process, including hazardous waste.

2.3 Solid Waste Management

In the 21st century, both developing, as well as, under developed countries, management of solid waste is a problem because it is not managed properly. One of the important issues is the collection of the solid waste from houses and industries. These wastes are dealt with simply by hauling them to dumps where they are buried or even left to be eaten by animals or burned.

Solid Waste Management can be defined as a process that goes through several stages, beginning with generation of MSW and followed by storage, collection, transfer, transportation, processing and ending with final disposal. Solid Waste Management needs to be carried out in accordance with the principles of economics, consideration of the environment, engineering, feasibility, human health and conservation of the resources and aesthetics (Agamuthu, 2001).

2.3.1 Elements of a Waste Management System

A waste management system includes some or all of the following activities:

- Development and assessment of MSWM activities: this stage needs to be done with the designer of the system, users and stakeholders.
- Setting up special policies.
- Use of characterization of waste: to gear systems to the types of waste generated.
- Recovery of material and physically handling of waste: this includes collection, separation, composting and landfilling.
- Marketing recovered materials: to end-users for industrial, commercial or small-scale manufacturing purposes.
- Organize training programs for MSWM.

- Create awareness to the public.
- Recognize financial mechanisms.
- Obtain prices for services.
- Supervise the public sector.
- Incorporate private sector business.

Theses important elements of waste management were often regarded only from an engineering and technical view point. It is essential to realize that these elements are embedded in the local institutional, socio cultural and economic context, which is further influenced by national politics, policies and legislation as well as national global and economic factors. Physical handling of solid waste and recyclables (storage, collection, transport, treatment and soon) is just on Solid Waste Management (SWM) activity, is alone cannot fulfill the requirement for sustainable and integrated solutions. Other activities are equally important. Making policy, as well as setting and enforcing standards and regulations, evaluation data on waste generation and characterization for purposes of planning and adapting system elements, ensuring that workers and stockholders get training, carrying out public information and awareness and education programs for improve the public knowledge on waste separation and storage. More and more, involving private companies SWM is seen as an easy way out. However, an important factor in the success of private sector participation is the ability of the client –usually a municipal administration to write and enforce an effective contracts and it is clear that without proper supervision and monitoring it cannot be successful. To provide economic services delivery, sustainable and integrated SWM considers, a) decentralized or bundled services as needed to optimize such economies, b) comprehensive cost analysis and planning for continues rationalization of routing, crew size and technologies and selection of systems and equipments according to local condition and preventive maintenance of vehicles and facilities (Agamuthu, 2001).

Essentially, the final option for waste management is disposal in landfills. Indeed, all the management options have an important role to play, to minimize the amount of waste. The techniques applied for waste processing depend on the materials in the waste, the policy and management system used and the availability of local or regional opportunities for marketing. The treatment method can be used to reduce the amount of residue from waste which is sent for disposal and to achieve one or more of the following targets:

- Reducing the impact of waste on the environment.
- Reducing transportation cost.
- Separating material and recovering energy or materials.
- Reducing the volume of waste that is sent to landfills for disposal.
- Minimizing overall costs.
- Reducing the risks on the environment and public health, and
- Conserving the natural resources.

These methods can be used in waste management to reduce the impacts of waste on environment, human health, management cost, etc. (Baud, et. al, 2004).

2.4 Solid Waste Management in Malaysia

A growing population and a high standard of living have resulted in increased waste generation in Kuala Lumpur (KL), the capital city of Malaysia. It is expected to double in the next twenty years. Today, the biggest environmental problem Malaysia faced is waste. The cause of the increased amount of waste generation is an increasing population, urbanization and industrialization process. In 2009, total waste generation in Malaysia was 30,000 tonne per year (Agamuthu, et. al, 2009). In this country, industrialization has brought economic prosperity, but caused pollution and degradation of the environment. Planning and management of solid wastes in Malaysia is under the responsibility of Local Government. In 1991 Kuala Lumpur spent about RM 25.2 million for managing solid waste. However, in 1997 the Environmental Protection Society Malaysia (EPSM) called for an official policy for recovery of solid waste (Mohamed, et al, 2009). The policy defined how waste was to be separated and placed in separate containers and that organic waste was to be used for composting or energy generation. In addition, an increase in the generation of municipal waste from 5.6 million tonnes in 1997 to 8.0 million tonnes in 2000, showed that Malaysia was in need of an urgent management plan for solid waste disposal (Agamuthu, et. al, 2009). Today Malaysia generates about 1.7 kg per day per person of solid waste, especially in major cities. The total MSW generation in Kuala Lumpur in 2008 was 3,564 tonnes per day (Mohamed, et.al, 2009).

2.5 Paper Production / Consumption

The word paper is derived from the Greek term for ancient Egyptian writing material called Papyrus, which was formed from the beaten strips of papyrus plant. The immediate predecessor to modern paper is believed to have originated from China in approximately the 2^{nd} Century BC, although there is some evidence for it being used before this date. Paper is made from plant fibers called cellulose, which are found in wood. Cellulose must be converted into pulp before being used to manufacture paper.

To begin the papermaking process, recovered fiber is shredded and mixed with water to make pulp. The pulp is washed, refined, cleaned and then turned to slush in a beater. Color dyes, coatings and other additives are mixed in, and the pulp slush is pumped onto a large moving screen. As the pulp travels down the screen, water is drained away and recycled. Nowadays, due to rapid economic development and population growth, the demand for paper has also increased in the world. Europe and North America are the major centers for production and consumption of paper products such as: tissue, printing paper, writing paper, linerboard, corrugating medium, carton board and newsprint. In recent years the predominance of paper production in North America has been eroded by the rapid growth in paper production and demand in other regions of the world, particularly in Asia. From 1997 to 2007 production of paper in Asia increased by 76 percent and Asia's share of world paper production rose from 29 percent to 38 percent. Paper production in Latin America grew by 40 percent between 1997 and 2007

(Honnold, 2009).The total production of paper in the world increased by 4.2 percent from 2005 to 2006 (Magnaghi, 2006) (Table 2.1).

Table 2.1: Comparison between production of paper and board in 2005 and 2006 in different regions:

Country	**2005 (million tonnes)**	**2006 (million tonnes)**
Asia	129	140
Europe	109	113
North America	102	102
Latin America	17	18
Australia	3	3
Africa	4	4
Total	364	380

(Source: Magnaghi, 2006)

As shown in Table 2.2, the highest consumer of paper in 2006 was Asia, while the second highest was Europe, followed by North America, Latin America, Africa and Australia. The total consumption of paper in year 2006 was 197 million tonnes and the total collection of paper in the same year was 196 million tonnes (Magnaghi, 2006).

Table 2.2: Total Paper Consumption in 2006 (collection + import - export) for the different regions (in million tonnes):

Region	Collection	Imports	Exports	Consumption
Asia	70	28.7	5	92.7
North America	51.8	2	16.9	37.3
Latin America	8.9	1.9	0.29	10.5
Europe	61.7	12.3	19.6	54.4
Australia	1.7	0.0074	1.1	0.55
Africa	1.7	0.23	0.07	1.9
Total	196.0	45.7	44.1	197.4

(Source: Magnaghi, 2006)

The total production capacity of all Malaysian paper mills is 1.3 million tonnes per year but the amount consumed is still more than the production capacity (Mohammad, 2009). As shown in Table 2.3, the total collection of paper in 2006 in Malaysia was 1.2 million tonne and the total consumption in the same year was 1.4 million tonne. This means recycling in this country is in the infant stage. An efficient policy and the necessary strategies are not in place / lacking (Magnaghi, 2006).

Table 2.3: Total Collection of paper in 2005 and 2006 and total Consumption in 2006 in Malaysia (million tonnes)

Country	**Consumption 2006**	**Collection 2005**	**Collection 2006**
Malaysia	1.4	1.18	1. 2

(Source: Magnaghi, 2006)

Asia, North America and Europe consume over 90% of paper and paperboard (Figure 2.2).

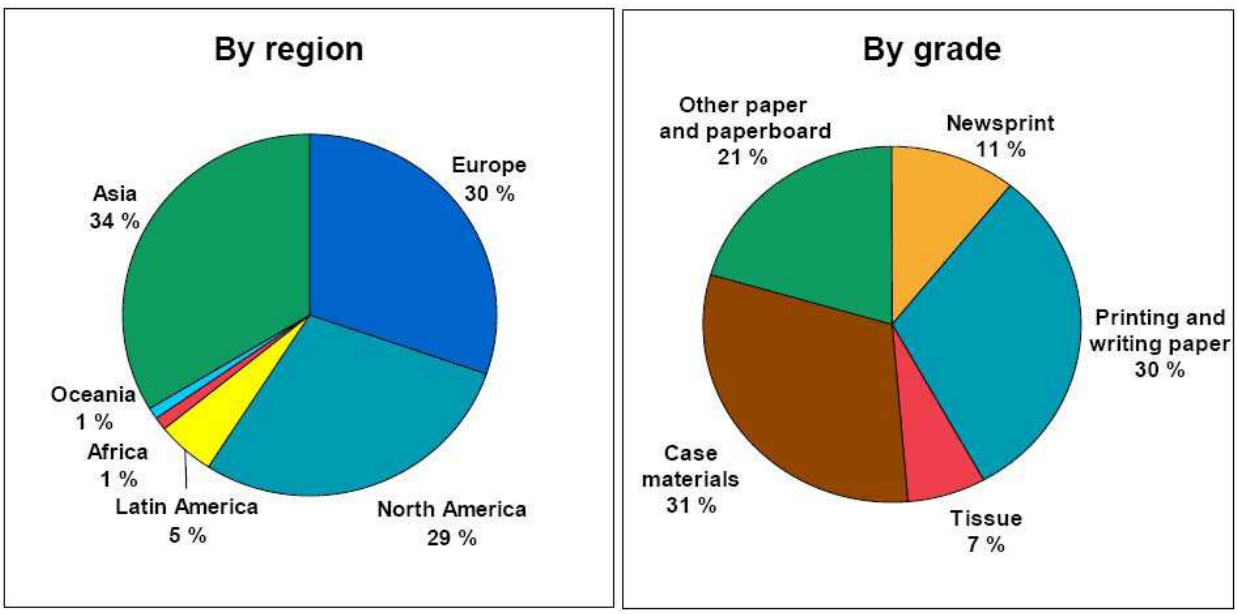

Figure 2.2: Pulp and paper production in the world by regions and by grade (2004), total 360 million tonnes

(Source: Forsstorm, et. al, 2006)

World paper and paperboard demand is expected to grow by about 2.1 % till year 2020 and the growth will be fastest in Eastern Europe, Asia (except Japan) and Latin America. There are two kinds of paper production: one way is to use wood as raw material and the other is to use non-virgin material like kanaf, bagasse (Honnold, 2009 and Forsstorm, et. al, 2006).

Primary categories for paper waste include:

- Office paper (copier paper, computer printout, stationery, tablet paper)
- Printing and writing grade paper (mail, magazines, directories, books).

2.6 Waste Minimization

Potential for actual pollution is the basis for the current environmental concerns over waste management. Historically, the environment has been considered as a sink for all waste produced by human activity. All the materials that are used by humans have been released to the environment through air, soil or water. Consequently, when the emissions are at a low level, natural biological and geochemical processes are able to deal with these emissions without affecting the environmental conditions.

However, a growing population and an increase in human activity could cause greater pollution and increase the emissions to the environment. The natural process cannot prevent changes to the environment if there is a sharp increase in the level of emissions. At this level, the natural processes may break down completely and become harmful to both human beings and the ecosystem.

Consequently, due to growing knowledge and understanding of society, nowadays, the public are concerned about the environment, which is no longer considered as an external sink for wastes, but as part of a global system that needs careful and efficient management. Waste minimization and /or pollution prevention is one of the best options in waste management (McDougall, et.al, 2001).

2.6.1 Waste Minimization Concept

Pollution prevention can be defined as the stages taken to reduce or remove any hazardous materials from waste. Waste minimization, waste diversion, reuse and recycling are the options that can reduce pollution. In industrial sector, cleaner technology can also reduce pollution.

The United States Environment Protection Agency (USEPA) defines pollution prevention as: "The use of materials, processes or practices that reduce or eliminate the creation of pollution or waste at source. It includes practices that reduce the use of hazardous materials, energy, water or other resources and practices that protect natural resources through conservation or more efficient use". The first option in waste management hierarchy is waste minimization; the next options are Reuse, Recycling or Recovery (3R) and the final option is disposal in landfill. Implementation of pollution prevention in production technologies and strategies can reduce the waste via the waste streams (Agamuthu, 2001).

The best management techniques that can be applied for solid waste are: minimizing waste, preventing waste and avoiding waste generation. A good way to successfully reduce waste volumes would be to be knowledgeable about the composition of waste.

As shown in Figure 2.3, Waste Management hierarchy is made up of several elements and there are as many options for it. The best option is waste minimization and the last is land disposal.

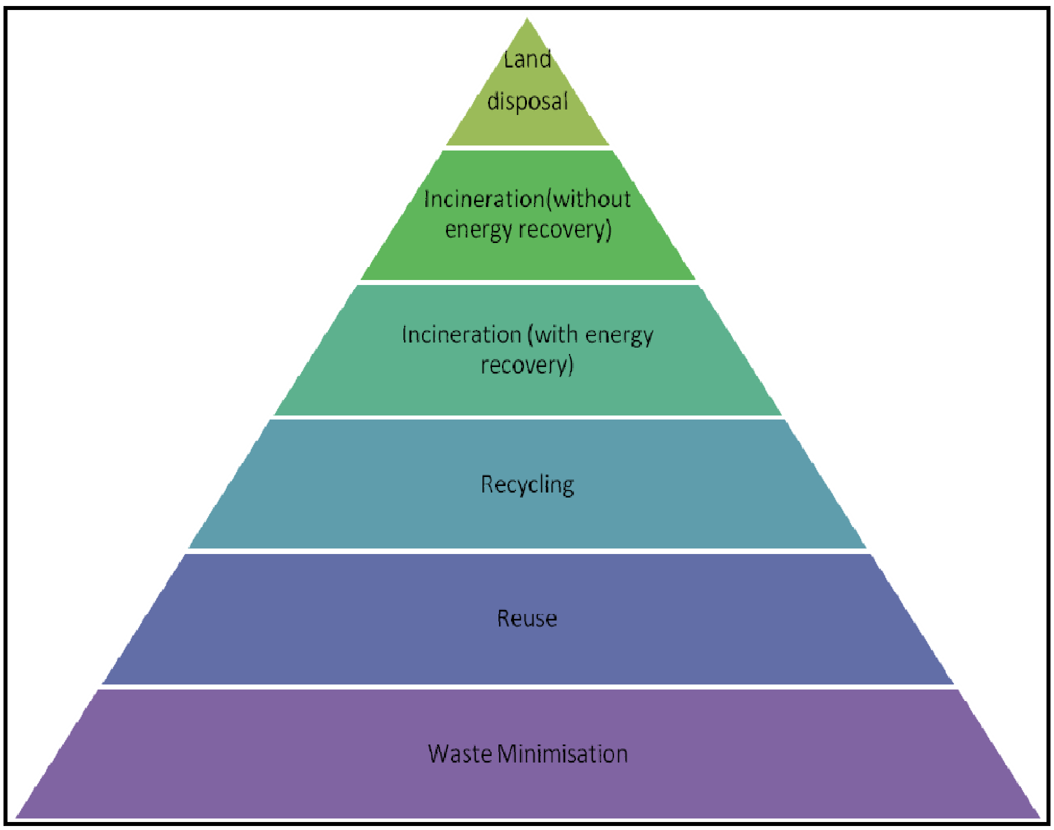

Figure 2.3: Waste Management hierarchy (Source: Baghchi, 2004)

It may not always provide an optimum choice between cost and environmental impacts. The current consensus is to use Integrated Solid Waste Management (ISWM). Planners have flexibility to choose from different elements of waste management options. These will result in minimization of energy, reduction of environmental impacts and reduction of space for the landfills which will be affordable by the community (Baghchi, 2004). Agamuthu, (2001) states that the waste management hierarchy can be listed as follows:

- Avoid the creation of waste or minimize the amount of waste generation.
- Reduce the hazardous substances or negative impacts from the waste.
- Reuse and recover materials from the waste stream.
- Recycle, reuse and /or recover materials as inputs for new products/processes and composting.
- Use incineration for recovery of energy.
- Reduce the volume of waste for disposal.
- Dispose of waste in an environmentally sound manner.

The three elements in waste minimization are:

- Source prevention and /or source reduction of waste.
- Improve the quality of the waste (e.g.by reducing hazardous materials from the waste).
- Use (3R) reusing/recycling and recovery to minimize waste.

Waste exchange is another option to reducing waste disposal; the waste product from one process becomes the raw material for a second process (McDougall, et.al, 1995).

Agamuthu,(2001) reasons that the basic initiatives required for waste minimization are as follows:

- Separate waste at source.
- Monitor inventory to scrutinize hazardous material purchases.
- Use other materials.
- Modify the process.
- Change or modify the design of the product.
- Exchange the waste.
- Implement the different options available for recycling waste.

The first step in waste minimization is an evaluation of existing processes or unit operations in order to identify problem areas in term of fugitive and process waste production (UNEP, 1994). Another step is to develop and implement a waste minimization program which includes facility assessment, evaluation, selection of techniques, program implementation and monitoring (Hunt and Schecter, 1990).

This procedure is suitable for all types and sizes of industries and is flexible to be altered to meet local needs. Obtainment of top management commitment, setting of realistic goals and timescales which are consistent with the policies adopted by top management at the beginning of the project are the key elements to a successful waste minimization program. Then, technical and economic feasibility are selected for implementation (Hunt and Schecter, 1990; Petek and Glavic, 1996). There are several barriers to waste minimization, such as organizational, communication, economic, waste generation and regulatory barriers (Wong, 2006). The biggest problem for implementation of waste minimization in an industry is organization barriers (Goldner, 1991). The reluctance to change and being afraid of so called ‘ Cleaner Production’ is hindering Malaysian Small and Medium Industries (SMI’s) to step into waste minimization practice (Biro and Perundingan,2003). Although the implementation of the waste minimization project may require some additional investment in the initial state, it can provide long-term benefits in various aspects as demonstrated in Figure 2.4 (Clark, 1995).

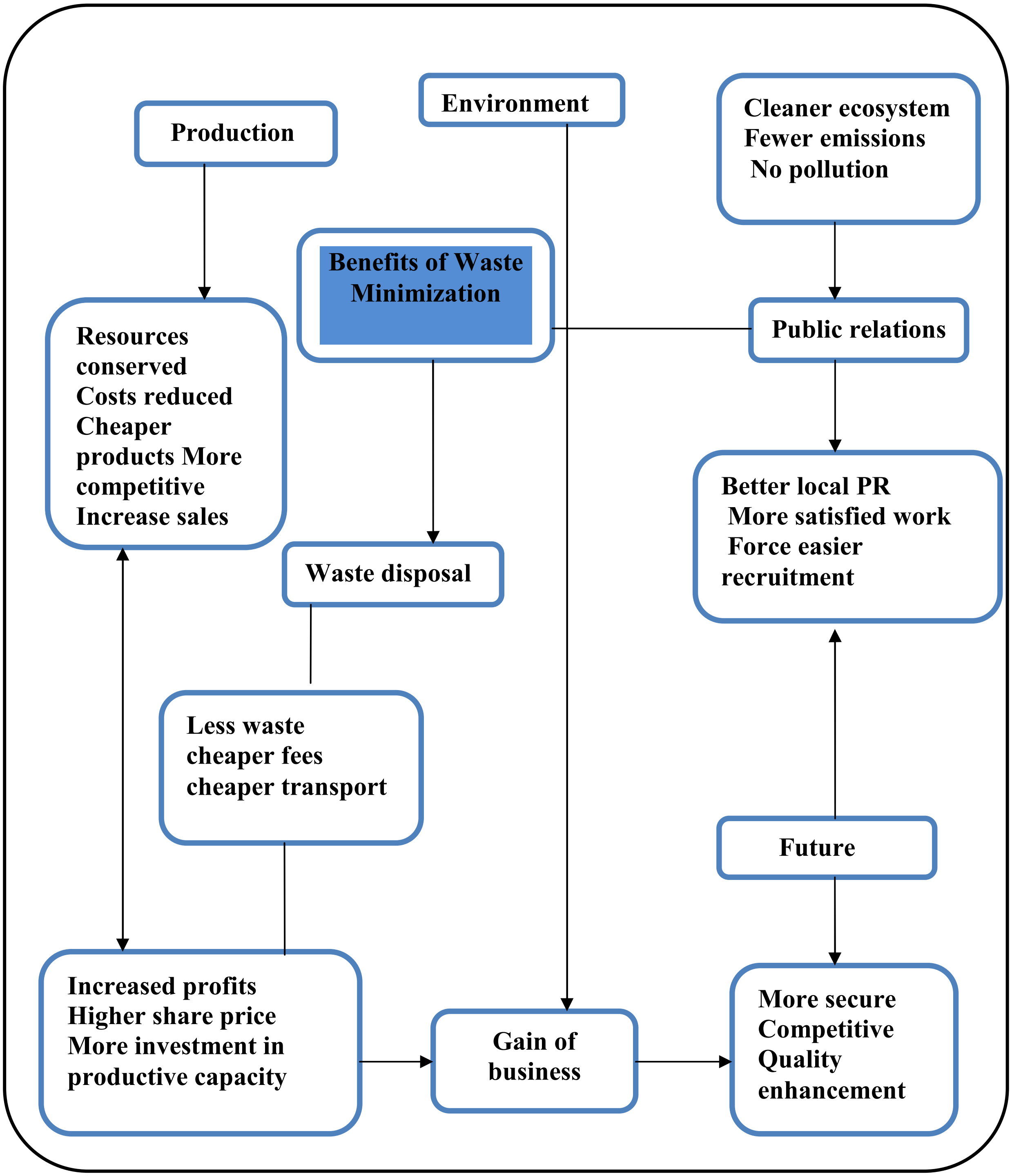

Figure 2.4: Various benefits accrued from implementation of Waste Minimization Program Source: (Clark, 1995)

Waste minimization usually benefits the waste producer: costs for both the purchase of goods and for waste treatment and disposal is reduced and the liabilities associated with the disposal of hazardous waste are less ended. The most important benefit of implementation waste minimization would be lower waste disposal costs, higher production and reduced impact on the environment (Agamuthu, 2001).

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2.6.2 Benefits of Waste Minimization

As shown in Figure 2.4, the most important benefits of waste minimization would be less expenditure for waste disposal, high production, minimum impacts on the environment, better public relations and resources business climate (Clark, 1995).

The effects of waste minimization which can be translated into benefits are as follows:

- Waste represents loss of raw materials or energy that the producer has paid for (e.g. the producer bears the costs of handling, managing and disposing waste).
- In some cases waste could be harmful to environment indirectly and/or directly.
- Waste treatment and disposal options increase (Noorzalina and Salim, 2002).

2.6.3 Waste Minimization in Malaysia

In Malaysia, the use of cleaner production or waste minimization is still at an infant stage even though industries are generally aware of the benefits accrued from the incorporation of waste minimization practices in the manufacturing process. The

Federation of Malaysia Manufacture (FMM) has expressed an interest in developing waste minimization information programs for its members. Modifying the tax law for the industries that implement cleaner production and /or waste minimization technology is another suggestion (Agamuthu, 2001).

2.7 Clean Technology

Cleaner production is a concept similar to waste minimization. The United Nations Environment Program (UNEP) defines clean production as: "The continuous application of an integrated preventive environmental strategy to processes and products to reduce the risks to human and the environment". Most countries focus their attention on end-of-pipe treatment, which emphasizes pollution control rather than pollution prevention.

There are several options associated with technological solutions to pollution problems. These options are as follows:

- **Environmental Technology:**

This technology is suitable for point sources and can be used to eliminate pollutants from the soil, water and air.

- **Eco-Technology:**

This method uses the ecosystem to solve problems caused by pollution. The techniques used are such as the creation of artificial ecosystems and recovery of deteriorated ecosystems.

- **Cleaner Technology:**

This can be done by changing production methods to reduce pollution (Noorzalina and Salim, 2002). Cleaner technology for a production process can be included in all activities such as: removal of hazardous substances or toxic materials, reduction of waste and emission at source and using materials and energy in the best ways to generate less waste. However, for products, the policies and strategies stress on reducing the impacts from the products and services arising from their design, usage and final disposal (Agamuthu, 2001).

2.7.1 Benefits of Cleaner Technology

The application of cleaner technology has several benefits as follows:

- Reduces of hazardous or toxic substances from waste and also the quantity of materials and energy wastage.
- Reduces waste at the source rather than at end-of-pipe.
- Reduces waste disposal /discharge/emission to the environment.
- Improves productivity.
- Creates better public image.
- Reduces risks when the generation, transportation, storage and treatment or disposal of hazardous waste is minimized.

Consequently, there are several benefits in implementing of cleaner technology. They are: reduced emission to the environment, less waste generated, saving money by reduced energy and resources which are used during the production process (Vincenzo et.al, 2009).

2.7.2 Cleaner Technology in Malaysia

Cleaner Technology (CT) has been implemented in Malaysia since 1990's. The use of cleaner production or waste minimization is still at an infant stage. Even though, industries have knowledge and awareness of the benefits from incorporating waste minimization practices in the manufacturing process, there is no solid waste management policy in Malaysia (Agamuthu, 2001 and Agamuthu et.al, 2004). Cleaner Technology (CT) or Cleaner Production (CP) has been introduced into the Malaysian Small and Medium Enterprises (SME) - sector primarily by foreign donor supported by project interventions.

The establishment of the Environmental and Energy Technology Center at SIRIM was founded by a grant from the Danish Cooperation for Environment and Development (DANCED) Ministry of Environment and Energy. Small and Medium –scale Industrials (SMI) were targeted within three sectors: Textile, food and electroplating industries (Wangel, et.al, 2004).

The implementation of CP is still limited to certain quarters of the industry, particularly owned by multi-national companies. Small and Medium Scale Industries (SMI) are still ,in general, reluctant to adopt CP, mainly due to perceived additional cost in adapting a new 'Cleaner Technology'. There are several reports from industries which have successfully applied CT/ CP programme especially in waste minimization (Biro Inovasi and Perundingan, 2003).

2.8 Recycling

In the 1990s, 3R (Reuse/Recovery and Recycle) programs became a challenge. The public accepted the recycling program because their awareness of the environment increased and they also understood what environmental quality meant. For Americans solid waste management, source reduction and recycling became the most popularly accepted methods. The rate of recycling of Municipal Solid Waste (MSW) in the United States in 2000 was about 22 percent, not including composting. MSW generation increased from 205 million to more than 230 million tonnes per year during 1990 to 2000.

The materials that can be recycled include newspaper, cardboard, mixed paper etc. Nowadays, in developed countries people are very sensitive about their environment so they usually participate in the recycling program. Many citizens started recycling by separating the waste at their homes and taking it to recycling center (Tchobangolous and Kreith, 2002).

2.8.1 Benefits of Recycling

According to Babu, (2006) the benefits from recycling can be classified as follow:

- Conserving natural resources.
- Saving energy in production and transport.
- Reducing pollution.
- Reducing the cost incurred in monitoring, treatment and disposal procedures.
- Reducing the requirement of waste disposal facilities like landfills and incineration.
- Reducing the cost of products and raw materials.

Recycling is the process of turning one products useful part into a new product; this is done to conserve on the consumption of resources, energy, cost and space used in landfills. It is estimated that to make one tonne of paper using recycled fiber saves 17 trees,3.3 cubic meter (m^3) of landfill space, 360 L of water, 100 L of gasoline, 27.21 kg of air pollutants and 10401 kilowatts of electricity (Malaysian Newsprint Industries,2007 and WasteCap,2008). Recycling paper uses 60% less energy than manufacturing paper from virgin timber (WasteCap, 2008).

2.8.2 Recycling in Malaysia

In Malaysia, unfortunately the three most important elements in the Integrated Solid Waste Management (ISWM) hierarchy (reduction at source, recycling the waste and waste transformation) are not officially and legally included in the waste management practice. Nowadays, a few NGOs do carry out recycling activities. One of the major problems is the separation of waste at source. Other problems are the lack of organization for the reduction of waste at source and insufficient recycling programs. Only 1 to 2 percent of the garbage is recycled when the target should be 25 to 30 percent. Now, the rate of recycling in Malaysia is 5 percent (Agamuthu, 2001; Agamuthu, 2009). However, it was estimated in the 9th Malaysian plan that from the future waste, about 45 percent will be made up of food waste or organic waste, 24 percent plastic, 7 percent paper and 6 percent iron and glass with the balance made up of other materials (Latifah, et.al, 2009).

At present, most of the MSW in Malaysia is sent to landfills as there is limited recycling. According to the Ministry of Housing and Local Government at the moment there isn't a specific law on 3R (Reuse, Reduce and Recycle) programs. However, in December 2000 Malaysia launched a National Recycling Program. As a result, Malaysia stands to benefit in various ways. Landfills can be reduced, expenditure on waste disposal can also be reduced, open burning can be reduced or eliminated, natural resources can be conserved, energy can be saved, greenhouse gas emissions be reduced, floods be minimized and the overall image of waste management be improved by effective waste paper recycling (Malaysian Newsprint Industries, 2007). As shown in Table 2.4, rate of waste recycling in Malaysia in 2002 was 5 percent and it increased to 7 percent in 2005 and the National Goal for waste recycling is expected to reach 22 percent in 2020.

However, the official rate of recycling is still 5 percent. This means Malaysia needs more time and efficiency in waste management to achieve the National Goal.

Table 2.4: Priority Issues in National Waste Management

Treatment	**Malaysia**	**National Goal**		
Year	**2002**	**2001**	**2005**	**2020**
Recycling	5.0	3.0	7.0	22.0
Composting	0.0	0.0	4.0	8.0
Incineration	0.0	0.0	11.9	16.8
Inert Landfill	0.0	0.0	9.2	9.1
Sanitary landfill	95.0	97.0	67.9	44.1
Total	100.0	100.0	100.0	100.0

(Source: Agamuthu, 2009)

2.9 Life Cycle Assessment (LCA)

Achieving sustainable development requires tools and methods. These instruments can improve quality and analyse all the environmental impacts that are inherent in the products and services. Each product has a life which starts with the design of the product and is followed by resources extraction, manufacturing, production, use/consumption and the final stage is end-of –life activities (collecting, reuse, recycling and waste disposal). The whole process and the related activities produce environmental impacts and this is due to the consumption of resources, which results in emissions to the environment (Rabitzer, et.al, 2004). Industries and businesses evaluate their activities to understand the effect of their activities on the environment. Some companies try to use several methods, policy and strategies to reduce their impacts on the environment. However, society is concerned about the strategies that can be used to reduce the environmental impacts such as resource depletion and environmental degradation. The companies use strategies, tools and environmental management systems, for this purpose. One of these tools is Life Cycle Assessment (LCA). LCA has its roots in the 1960s, when the scientists concerned about the rapid depletion of fossil fuels and non- renewable resources, developed LCA as an approach to understand the impacts of energy consumption (Bathish, 2006).

2.9.1 Definition of LCA

LCA is defined as a methodology for quantifying all inputs and outputs from products or activity systems. As shown in Figure 2.5, a full life cycle can begin with extraction of raw materials and then proceed through production and use. However, it will end with waste treatment, like a journey from cradle to grave. The Life Cycle Inventory stands for the accounting of resources and energy that are used as inputs and, waste generation and emission as outputs, in all of the stages (Vigon and Jensen, 1995).

LCA enables the estimation of the environmental impacts at all stages of the product, ranging from extraction, transportation of materials, production, disposal, etc (Sumiani, 2009).

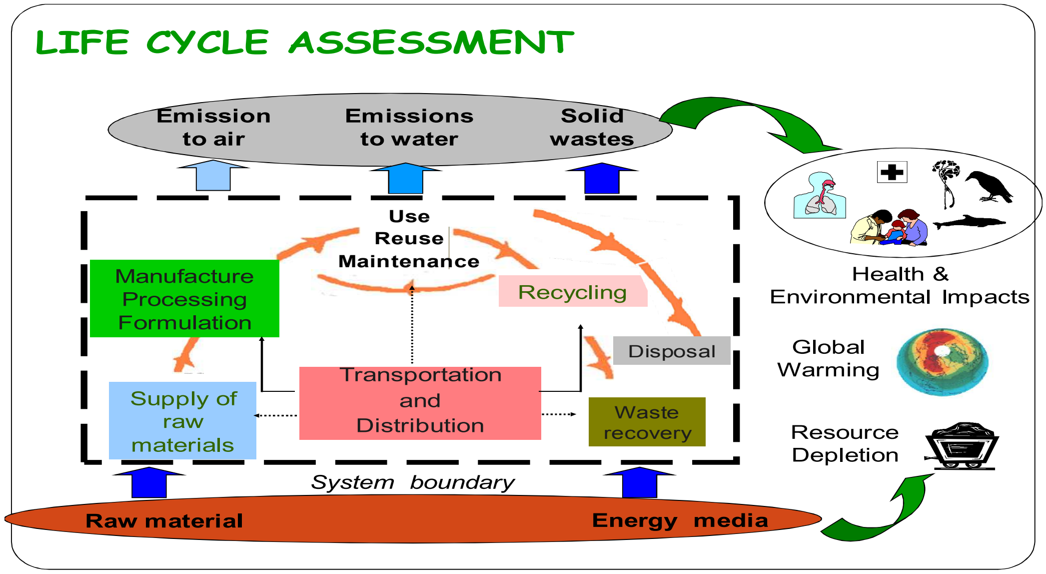

Figure 2.5: A Full Life Cycle Assessment Process , (Source: Sumiani, 2009)

LCA is a "cradle –to- grave" assessment for industrial systems. It means that to create a product, raw materials which are needed can be gathered from the earth. When the product has been fully utilized its remains will be returned to the earth.

LCA includes the inputs, outputs and potential environmental impacts of the product system through its life cycle. All the stages in the LCA are evaluated (Figure 2.6). Thus, LCA is a tool for the analysis of the environmental impacts of the products at all stages in their life cycle from the extraction of resources, through the production of materials, product parts and the product itself and the use of the product up to the management of it after it is discarded either by reuse, recycling or final disposal (Guinee, 2002).

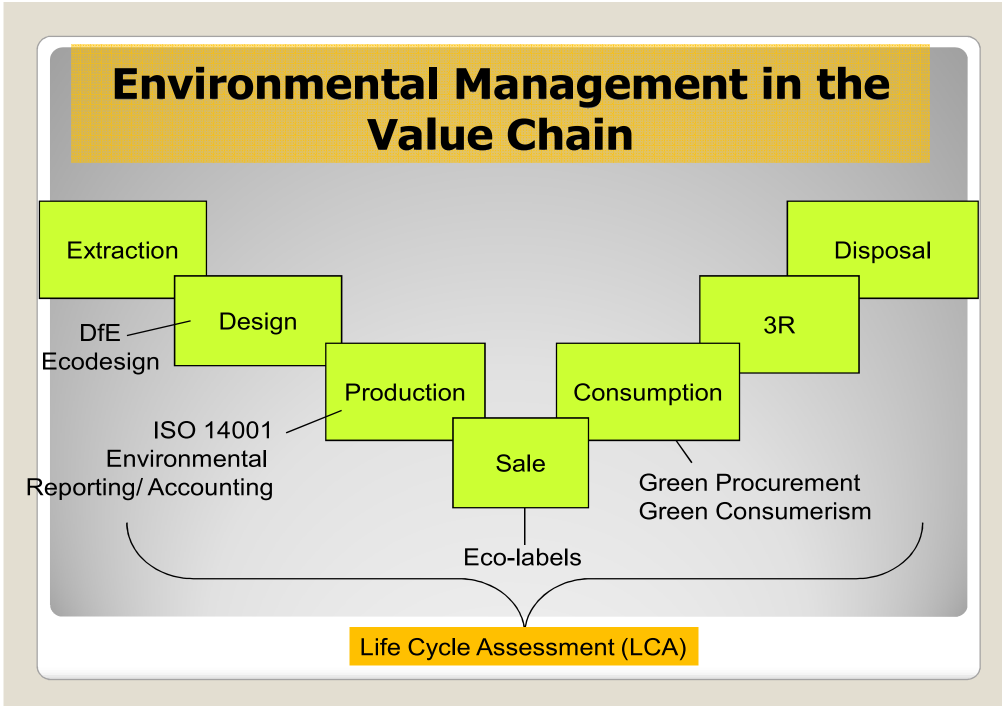

Figure 2.6: Life Cycle Assessment (Environment Management in the Value Chain)

(Source: Sumiani, 2009)

The Society of Environmental Toxicology and Chemistry (SETAC) was the first international body to act as an umbrella organization for the development of LCA. SETAC's aims are development in specific areas of research and application of the results in the field of environmental management (SETAC, 2008). Product life cycles have played an important role in the field of LCA, which has been used to evaluate the environmental performances of products (Alan, 2005).

2.9.2 LCA Methodology

Mattsson, (2003) indicated that LCA is a tool for evaluating the environmental impacts associated with a product/process or activity during its life cycle. Also, LCA is suitable for several purposes in that it could provide knowledge of a product and its related environmental impacts. Mattson, (2003) believes that LCA also makes it possible to isolate which stages in the life cycle of a process or product make the most significant contribution to its environmental impact. Other reasons for undertaking an LCA study could be to assess improvement or alternatives or compare products, processes or services.

Life Cycle Assessment (LCA) is a phase-approach methodology. LCA can maintain consistency by using the ISO 14040 series of standards. According to the ISO 14040 standard, LCA is a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. A product system is a collection of materially or energetically connected unit process, which performs one or more defined function (ISO, 14040, 1997).

Environmental assessment tools such as the Life Cycle Assessment (LCA) as described under group 5 of the standards, aims is to identify opportunities for environmental improvements (Anderson, 1998). There are four standards which describe LCA, as follows (Chong, 2004):

- “ISO 14040:1997- Life Cycle Assessment – Principles and Framework”

- “ISO 14041:1999- Life Cycle Assessment –Life Cycle Inventory”

- ISO 14042:2000 –Life Cycle Assessment –Life Cycle Impact Assessment”

- ISO 14043:2000- Life Cycle Assessment –Interpretation”.

According to the ISO 14040 guidelines for the LCA methodological framework ,a Life Cycle Assessment shall include a goal and scope definition ,inventory analysis ,impact assessment and interpretation of results (Murphy,2004)(Figure 2.7).

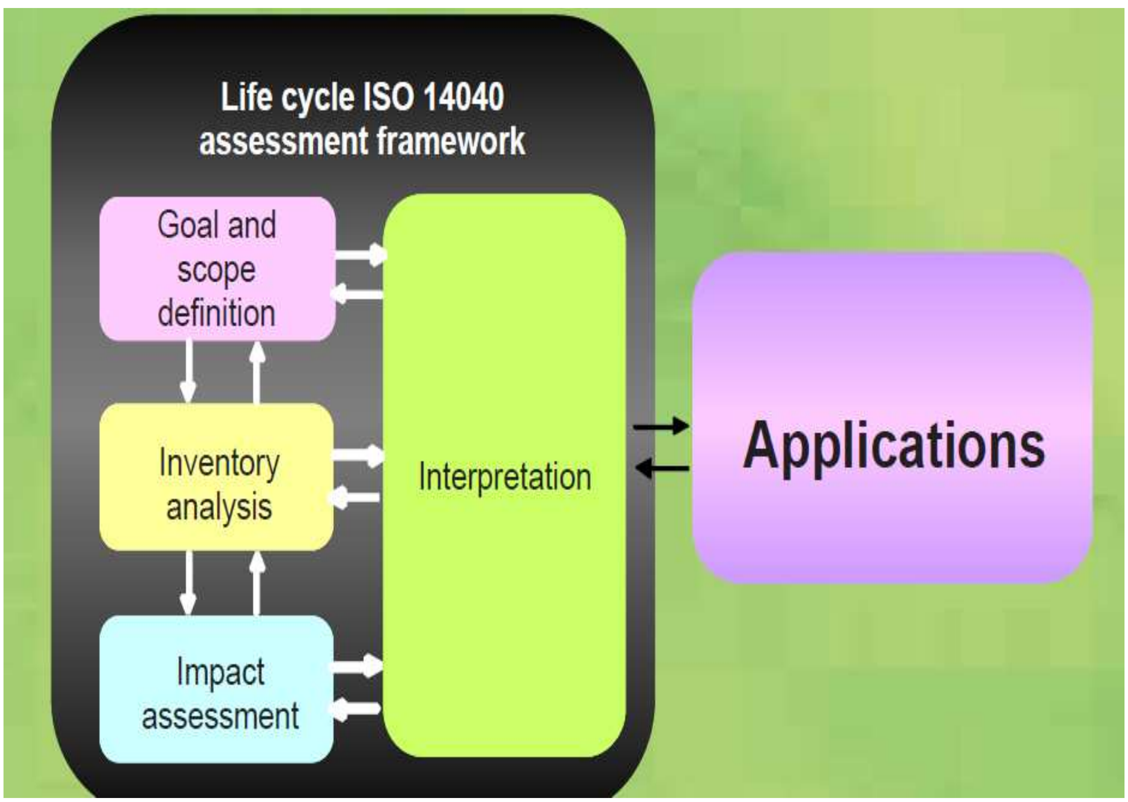

Figure 2.7: Framework of Life Cycle Assessment under ISO 14040

(Source: Murphy, 2004)

As shown in Figure 2.7, the Life Cycle Assessment study includes four phases:

- Goal and Scope Definition
- Inventory Analysis
- Impact Assessment
- Interpretation

The double arrows in Figure 2.7 illustrate that LCA is an interactive process , where changes in various choices at diffrent phases occur continuously, as the LCA practitioner gradually becomes wiser and more focused (Sumiani,2009).