# Lecture 6

## Life Cycle Assessment (LCA)

**STRUCTURE**



## OVERVIEW

In Unit 5, we discussed, among others, how audits help improve the environmental performance of an industry. In Unit 6, we will discuss yet another tool for environmental management, i.e., life cycle assessment (LCA). We will first trace the evolution of LCA and describe the stages of a product life cycle. We will then identify the elements that contribute to the code of good conduct for an LCA. We will also explain the main steps involved in the LCA process, i.e., goal setting, inventory analysis, impact assessment and profile evaluation. We will close the Unit by explaining the application of LCA in private and public sectors.

## LEARNING OBJECTIVES

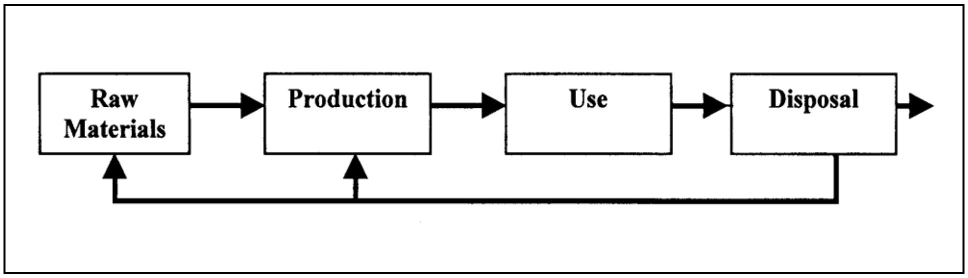
After completing this Unit, you should be able to:

- explain the concept of life cycle assessment (LCA) as an environmental management tool and its potential for identifying all the environmental impacts throughout the entire life cycle of a product;
- describe what a code of good conduct for LCA entails;
- discuss the basic steps involved in an LCA process;
- conduct/co-ordinate an LCA and critically evaluate its outcomes.

## 6.1 Life cycle assessment and its purpose

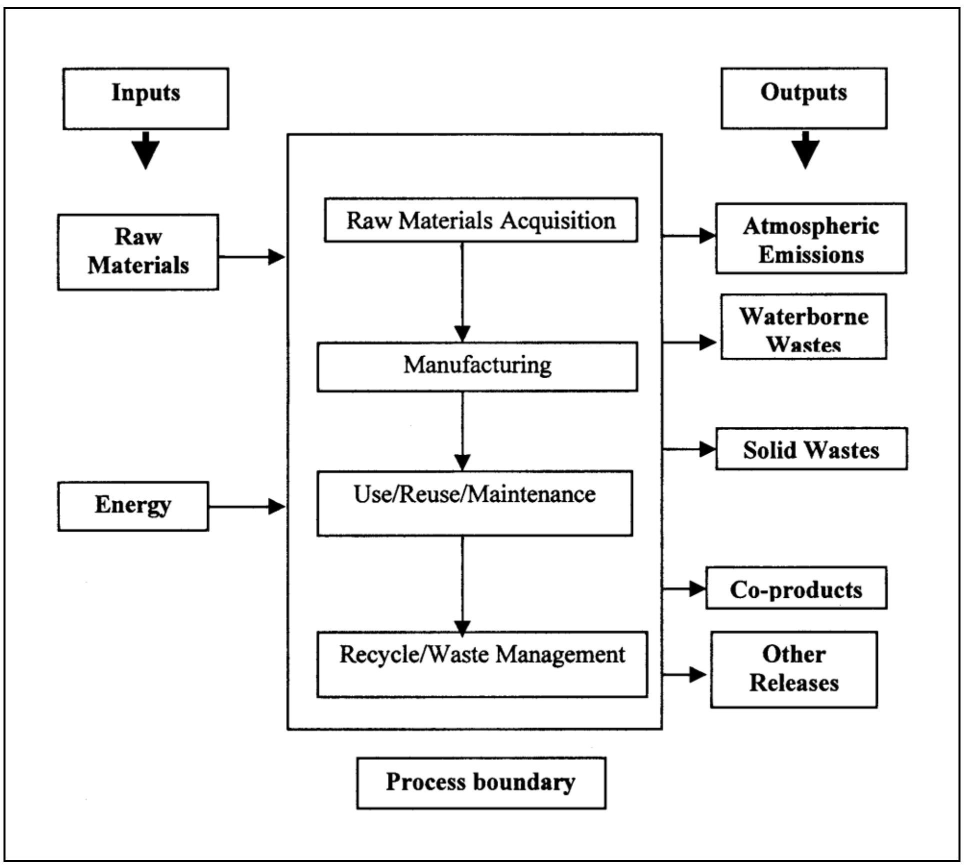
Life cycle assessment (LCA) is a tool to evaluate the environmental effects of a product or process throughout its entire life cycle. An LCA entails examining the product from the extraction of raw materials for the manufacturing process, through the production and use of the item, to its final disposal, and thus encompassing the entire *product system*. A schematic representation of a product life cycle is given in Figure 6.1:

**Figure 6.1**
**Product Life Cycle**




The assessment process includes identifying and quantifying energy and materials used and wastes released to the environment, assessing their environmental impact and evaluating opportunities for improvement as illustrated in Figure 6.2:

**Figure 6.2**
**LCA Process**




The unique feature of this type of assessment is its focus on the entire life cycle, rather than a single manufacturing step or environmental emission. The theory behind this approach is that operations occurring within a facility can also cause impacts outside the facility's gates that need to be considered when evaluating project alternatives.

**Purpose of LCA:**

Government and customers who purchase products from different sectored companies are keen on environmental properties of all the products. EMAS and ISO 14000 are demanding continual improvement in the process of production and in the environmental management system. At this stage there is a need for a tool like LCA that helps organisations meet the demand to improvise process/product.

## 6.2 EVOLUTION OF LIFE CYCLE ASSESSMENT

The principles underlying an LCA were developed in the late 1960s. In the 1970's, the US Environmental protection agency refined the methodology for evaluation of environmental impacts of products and were popularly known as resource and environmental profile analysis (REPA). Initially, it was used mainly on the consumption of energy and other resources. Knowledge of environmentally damaging releases and actions and the estimation of their effects, was too rudimentary at that time to allow a quantitative treatment of the environmental impacts of the product life cycle.

Assessments of product life cycle experienced a renaissance through studies of the environmental loadings and potential impacts of beverage containers (e.g., beer cans, milk containers) performed in various European countries in the early 1980s. These studies involved further elaborations of the principles underlying the assessment of product life cycle and entailed a series of life cycle assessments of materials used in packaging containers (i.e., polyethylene, cardboard, aluminium, etc.). A common feature of the items analysed was their homogenous character and their widespread use in many different contexts.

The late 1980s and early 1990s have seen international attempts to standardise the principles underlying life cycle assessments and to develop codes of good conduct in this field. The list of products that have been subjected to LCA has grown quickly and now includes more complex products such as paints, insulation materials, window frames, refrigerators, hotplates, television sets, etc., as well as the entire service systems or technologies such as electricity production.

As a part of ISO 14000 series of standards ISO in 2000 has come out with the following standards:

- ISO 14040: Environmental Management – LCA – Principles and Framework.
- ISO 14041: Environmental Management – LCA – Inventory Analysis.
- ISO 14042: Environmental Management – LCA – Impact Assessment.
- ISO 14043: Environmental Management – LCA – Interpretation.

Since the last decade or so, LCA is gaining importance as an environmental management tool. It has now emerged as a decision support tool in such areas as business, regulation and policy and to structure technology development in a coherent way. Many potential applications of LCA are envisaged including product improvement and design, environmental management, eco-labelling, green accounting, environmental auditing and reporting, resource management, definition of best available technology (BAT), product policy, strategic industrial planning, strategic environmental policy development, etc. As a general concept, the life cycle approach aims to support the overall goal of sustainability.

**LEARNING ACTIVITY 6.1**

State the basic concept of a life cycle assessment.

**Note**:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

## 6.3 STAGES IN PRODUCT LCA

LCA is split into five stages that include:

1. Planning : Includes Statement of objectives, Definition of the product and its alternatives, Choice of system boundaries, Choice of environmental parameters, Choice of aggregation and evaluation method and Strategy for data collection
2. Screening: Includes preliminary execution of LCA and adjustment of plan
3. Data collection and treatment: Includes measurements, interviews, literature search, theoretical calculations, database search, qualified guessing and also computation of the inventory table

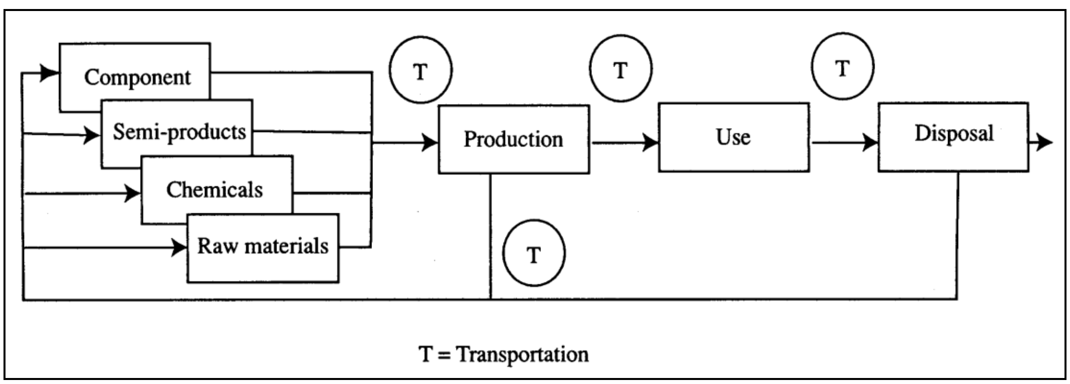
4. Evaluation: Includes classification of inventory table into impact categories, aggregation within category, normalisation and weighting of different categories
5. Improvement assessment: Includes sensitivity analysis and improvement priority and feasibility assessment

It is generally recognized that the first stage is extremely important. The result of the LCA is heavily dependent on the decisions taken in this phase.

The screening LCA is a useful step to check the goal-definition phase. After screening it is much easier to plan the rest of the project.

Figure 6.3 gives a diagrammatic representation of the stages in the life cycle of a product:

**Figure 6.3**
**Product Life Cycle Stages**




Note that Figure 6.3 complements Figures 6.1 and 6.2. As depicted in these figures, each stage of the life cycle receives materials and energy as inputs and produces:

- outputs of material or products to subsequent life cycle stages;
- emissions to the environment.

There are a number of issues associated with the life cycle stages, and we will touch upon some of these, next.

***Extraction of raw materials***

This stage in the life cycle includes the extraction of all materials involved in the entire life cycle of the product. Typical examples of activities included in this stage are forest logging and crop harvesting, fishing and mining of ores and minerals. The inventory for the extraction of raw materials should include raw materials for the production of the machinery (i.e., capital equipment) involved in manufacturing the product and other stages of the product life cycle. Raw materials used in the production of electricity and energy used in the different life stages of the product should also be considered. Collecting data for the raw materials extraction stage may prove to be a complex task. It may also lead into iterative processes such as assessing the inputs and outputs related to extraction of the raw materials that is used in the production of end products. Often, the most serious environmental problems of the product life cycle associated with this first stage. It is a common error to leave out parts of the raw materials stage from the LCA. Essentially, the decision of what to include or exclude in the LCA should be based on a sensitivity analysis.

***Manufacture of a product***

The manufacturing stage encompasses all the processes involved in the conversion of raw materials into the products considered in the LCA. Apart from the manufacturing processes at the plant where the product is made, this stage takes into account production of ancillary materials, chemicals and specific or general components at other plants, no matter where they are.

***Transportation***

As is indicated in Figure 6.3, transportation is really not a single life stage in itself. Rather, it is an integral part of all stages of the life cycle. Transportation could be characterised as conveyance of materials or energy between different operations at various locations. Included in this stage, apart from the transport process itself, is the production of packaging materials for the transportation of the product. The transport stage would possibly also include an appropriate share of the environmental loadings and consumptions associated with the construction and maintenance of the transport system, whether this is road, rail, water or air transportation.

***Use of product***

The use-stage of the product occurs when it is put in service and operated over its useful life. This begins after the distribution of the product and ends when the product is used up or discarded to the waste management system. Included in the use-stage are releases and resource consumptions created by the use or maintenance of the product.

***Waste management***

Wastes are generated in each phase of the life cycle, and they need to be properly managed to protect the environment. The management of wastes may involve alternative processes such as the following:

(i) **Reuse:** This means the use of the product or parts thereof in new units of the same product or in different products.

(ii) **Recycling:** This means the use of materials in the product for manufacture of the same or other products.

(iii) **Incineration:** This refers to the combustion of the product, generating heat that may be used for electricity production or heating.

(iv) **Composting:** This refers to the microbial degradation of biological materials yielding compost for improvement of agricultural soils.

(v) **Waste water treatment:** This refers to the organic matter degradation and nutrients removal from sewage water, creating sludge that is deposited on agricultural land.

(vi) **Land filling:** This means the deposition of the product in landfills.

Each form of waste treatment mentioned above may be considered a processing of waste associated with a certain consumption of resources. This results in various releases into the environment, and the possible generation of energy or materials that will be an input to the manufacturing process of this product or of other products.

Before you read any further, it is a good idea to look at the Course **Municipal Solid Waste Management** in which we discussed the different waste management processes in detail.

As implied, the LCA of products is an important environmental management tool. However, as with every tool, difficulties do arise with LCA too. In Section 6.3, we will discuss the problems and the questions that have to be taken into consideration, while analysing the life cycle of a product.

## 6.4 A CODE OF GOOD CONDUCT FOR LCA

As mentioned earlier, LCA emerged during the last decade as a tool to provide an objective assessment of the total environmental impact associated with a product through its entire life cycle. In several countries, LCA is considered the primary tool by which environmental impacts of products should be regulated by government authorities. However, problems do exist. Let us look at some of the major LCA limitations below, as revealed in various studies:

(i) **Data quality:** In a manufacturer-sponsored study to compare a product with its alternatives, the consultants performing the LCA were able to get a very detailed and current data from the manufacturer for the processes involved in the production of that product. However, they had to depend on secondary data from the literature or earlier studies with regard to the production processes concerning the alternative products. Obviously, comparative studies on the basis of the secondary data tend to lack credibility.

(ii) **Life cycle boundaries:** A Dutch study excluded the production of several raw materials, including crude oil, for the polycarbonate production. The German study did not include emissions from the energy production associated with the life cycle of the milk containers. Most studies did not consider the working environment.

(iii) **Country-specific technology types:** An example is the LCA conducted on the production of electricity used in the product life cycle. In a Swedish study, the electricity production was based on nuclear power and hydroelectricity, while a Swiss study, based on a US energy scenario since 1972, used coal as the energy source. This should explain the difference in the emissions found in the two studies. In addition, as the waste processing systems contribute to the nature and level of emissions, it is important to examine these systems as well. For example, if the waste is incinerated and the combustion energy is used for electricity production, the Dutch study may tend to favour carton containers over recyclable polycarbonate bottles.

(iv) **Evaluation stage priorities:** In the cases where alternatives do not have particular advantage over one another, the priorities in the evaluation stage become decisive for the outcome. A recommendation of the Danish study (referred to at (ii) above) was based on an evaluation stage choice between reduced consumption of raw materials and water, but on the releases of dichloromethane into the working environment (for polycarbonate bottles), and higher energy consumption and loading of bio-accumulating and possibly carcinogenic chlorinated compounds in the waste from production (for the milk cartons).

Considering the versatility and many diverse possible applications of the LCA tool, it may be difficult to obtain reproducible and consistent results through standardisation, without losing the necessary flexibility for adaptation to particular cases being studied. Given this scenario, it is important that we include the following factors in a code of good conduct for LCA:

(v) **Definition:** This involves finding answers to such questions as: Is the purpose of the study explicitly defined? Is it meant for internal company use or for public use? If the study is intended for public use, has it been peer reviewed? Is it clearly stated for whom the study is performed and by whom it is sponsored? Is the definition of the functional unit appropriate?, etc.

(vi) **Delimitation of system under study:** This involves finding answers to such questions as: Is there an explicit and clear delimitation of the system under study? Is the life cycle described in detail, stage by stage? Are the life cycle description and process tree plausible? Do they describe the real world system in a realistic way? Does the study include the extraction of raw materials? Does the study include the production of electricity? What production scenario is used? Is it appropriate? Does the study include the manufacture of real capital for all life cycle stages? If the study has precluded capital, is this omission substantiated? Do you find the omission reasonable? Is the disposal stage covered by the study?, etc.

(vii) **Inventory:** This involves finding answers to such questions as: Does the inventory cover all processes of the process tree? Is there a reference to the source of every piece of data in the inventory? Is the data quality appropriate, i.e., primary and recent data for all the important processes of the life cycle? Do the data describe a relevant technological level of the processes? Is the use of data of lower quality or omission of processes from the inventory based on sensitivity analyses? Is the quality of the data used for the compared alternatives similar? Are data on impacts to the working environment present in the inventory? Is it acceptable that they be left out in the considered study?, etc.

(viii) **Impact assessment:** This involves finding answers to such questions as: Has any impact assessment been performed? Does it consider all the important environmental effect types? Does it consider resource and working environment issues?, etc.

(ix) **Evaluation:** This involves finding answers to such questions as: Are the subjective steps of the evaluation separated from the objective ones? If not, is the evaluation transparent? Are the priorities clear? Are the conclusions of the assessment clear? Are the assumptions underlying the weighting explained, and do you agree with them?, etc.

**LEARNING ACTIVITY 6.2**

Which of the materials described in Case 6.2 would you consider to be the least harmful to the external environment and the working environment?

**Note**:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

## 6.5 PROCEDURE FOR LCA

Four steps are involved in carrying out an LCA, and these are:

(i) Definition of scope, goals, and delimitation of the life cycle.

(ii) Preparation of an inventory.

(iii) Assessment of impact of environmental loadings in terms of environmental profiles.

(iv) Evaluation of environmental profiles according to the defined goals.

In Subsections 6.5.1 to 6.5.4 we will discuss these steps in detail.

### 6.5.1 Defining the goal and scope

The goal of an LCA study must unambiguously state the intended application, including the reasons for carrying out the study and the intended audience. The statement of goal must also indicate the intended use of the results and users of the results. The practitioner, who has to reach the goal, needs to understand the detailed purpose of the study in order to make proper decisions throughout the study. Examples of goals of life cycle assessments are:

- To compare two or more different products fulfilling the same function with the purpose of using the information in marketing of the products or regulating the use of the products.
- To identify improvement possibilities in further development of existing products or in innovation and design of new products.
- To identify areas, steps, etc., in the life cycle of a product to meet the eco-labelling criteria.

Transparency is essential for all kinds of LCA studies. The target group of the LCA study is also important to have in mind the choice of reporting method. The goal can be redefined as a result of the findings throughout the study.

While the goal definition determines the level of sophistication of the study and the requirements to reporting, the definition of the scope of an LCA sets the borders of the assessment, i.e., what may be included in the system and what detailed assessment methods are to be used.

In defining the scope of an LCA study, the following elements must be considered and clearly described:

- The functions of the system, or in the case of comparative studies, systems.
- The functional unit.
- The system to be studied.
- The system boundaries.
- The allocation procedures.
- The types of impact and the methodology of impact assessment and subsequent interpretation to be used.
- Data requirements.
- Assumptions.
- Limitations.
- The initial data quality requirements.
- The type of critical review, if any.
- The type and format of the report required for the study.

The scope should be sufficiently well defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal. LCA is an iterative technique.

Therefore, the scope of the study may need to be modified while the study is being conducted as additional information is collected.

Let us now describe some of the elements mentioned above to define the scope of an LCA.

### *Functional unit*

Definition of the functional unit or performance characteristics is the foundation of an LCA because the functional unit sets the scale for comparison of two or more products including improvement to one product (system). All data collected in the inventory phase will be related to the functional unit. When comparing different products fulfilling the same function, definition of the functional unit is of particular importance. The three aspects that have to be taken into account when defining a functional unit are the efficiency of the product, the durability of the product and the performance quality standard (Lindfors et al., 1995c).

When performing an assessment of more complicated systems, e.g., multi-functional systems, special attention has to be paid to by-products. Waste treatment systems are an example of processes with different outputs (e.g., energy, a fertiliser). When comparing different systems, inclusion of the produced amount of energy and fertiliser is an example of handling of different by-products in the definition of the functional unit.

### *System boundaries*

The system boundaries define the processes/operation (e.g., manufacturing, transport and waste management processes) and the inputs and outputs to be taken into account in the LCA. The input can be the overall input to a production as well as input to a single process, and the same is true for the output. The definition of system boundaries is a quite subjective operation and includes geographical boundaries, life cycle boundaries (i.e., limitations in the life cycle) and boundaries between the technosphere and biosphere. Due to the subjectivity of definition of system boundaries, transparency of the defining process and the assumptions are extremely important. Note that wastewater treatment is an example of a process that often is omitted when defining the system boundaries.

***Data quality***

The quality of the data used in the life cycle inventory is naturally reflected in the quality of the final LCA. The data quality can be described and assessed in different ways. It is important that the data quality is described and assessed in systematic ways that allows others to understand and control the actual data quality. Further descriptions, which define the nature of the data collected from specific sites and that from published sources and indicate whether the data should be measured, calculated or estimated, should also be considered for maintaining data quality.

In all studies, however, the following additional data quality indicators are to be taken into consideration at a certain level of detail, depending on goal and scope definition:

- **Precision:** That is, the measure of variability of the data values for each category expressed (e.g., variance).
- **Completeness:** That is, the percentage of locations reporting primary data from the potential number in existence for each data category in a unit process.
- **Representativeness:** This means the qualitative assessment of the degree to which the data set reflects the true population of interest (i.e., geographic, time period and technology coverage).

- **Reproducibility:** This means the qualitative assessment of the extent to which formation about the methodology and data values allows an independent practitioner to reproduce the results reported in the study.
- **Consistency:** This means the qualitative assessment of how uniformly the study methodology is applied to the various components of the analysis.

***Critical review process***

The purpose of the critical review process is to ensure the quality of the life cycle assessment. The review can be either internal or external. This may also involve the interested parties as defined within the goal and scoping definition. The critical review process ensures that:

- the methods used to carry out the LCA are consistent with the international standard and are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study;
- the study report is transparent and consistent.

### 6.5.2 Analysing the inventory

Inventory analysis is the second phase in an LCA, consisting of issues such as data collection, refining system boundaries, calculation, verification of data, relating data to the specific system and allocation.

We will describe each of these issues, next.

### Data collection

The inventory analysis includes collection and treatment of data to be used in preparation of a material consumption, waste and emission profile for the phases in each life cycle. The data can be both site-specific (e.g., from specific companies, specific areas and specific countries) and general sources (e.g., trade organisations, public surveys, etc.) The data have to be collected from all single processes in the life cycle. The quantitative data are important in comparisons of processes or materials, but often the quantitative data are missing or the quality is poor (too old or not technically representative, etc.). However, a more descriptive qualitative data can be used for environmental aspects or single steps in the life cycle that cannot be quantified. This can be used when the goal and scope definitions allow a non-quantitative description of the conditions.

Data collection is often the most work intensive part of a life cycle assessment, especially if site-specific data are required for all the single processes in the life cycle. In many cases, average data from the literature (often previous investigations of the same or similar products or materials) or data from trade organisations are used. The average data can be used in the conception or simplified LCA to get a first impression of the potential inputs and outputs from producing specific materials. When doing a detailed LCA, site-specific data is preferred. Note that since average data are often some years old, they may not represent the latest in technological development.

### Refining system boundaries

The system boundaries are defined as part of the scope definition procedure. After the initial data collection, the system boundaries can be refined, i.e., as a result of decisions of exclusion of life stages or sub-systems, exclusion of material flows or inclusion of new unit processes shown to be significant, according to the sensitivity analysis. The results of this refining process and the sensitivity analysis are to be documented. This analysis serves to limit the subsequent data handling to those inputs and output data, which are determined to be significant to the goal of the LCA study.

***Calculation procedures***

No formal demand exists for calculation in life cycle assessment except the described demands for allocation procedures. Due to the amount of data, it is recommended, as a minimum, to develop a spreadsheet for the specific purpose. The appropriate programme can be chosen, depending on the kind and amount of data to be handled.

***Validation of data***

The validation of data has to be conducted during the data collection process in order to improve the overall data quality. Systematic data validation may point out the areas where data quality must be improved or data must be found in the similar processes. During the process of data collection, a permanent and iterative check on data validity should be conducted. Validation may involve establishing mass balances, energy balances and/or comparative analyses of emission factors. Obvious anomalies in the data appearing from such validations will result in alternative data values complying with the data quality requirements.

For each data category and for each reporting location where missing data are identified, the treatment of the missing data should result in an acceptable reported data value, a *zero* data value if justified and a calculated value, based on the reported value from unit processes employing similar technology.

### *Relating data*

The fundamental input and output data are often delivered from industry in arbitrary units, e.g., energy consumption as MJ/machine/week emissions to the sewage system as mg metals/liter wastewater. The specific machine or wastewater stream is rarely connected to the production of the considered product alone but often to a number of similar products or perhaps to the whole production activity.

For each unit process, an appropriate reference flow has to be determined (e.g., one kilogram of material, one mega joule for energy, etc.). The quantitative input and output data of the unit process shall be calculated in relation to this reference flow. Based on the refined flow chart and systems boundary, unit processes are interconnected to allow calculations of the complete system. The calculation should result in all system input and output data being referenced to the functional unit. Care should be taken when aggregating the inputs and the outputs in the product system. The level of aggregation should be sufficient to satisfy the goal of the study.

### *Allocation and recycling*

When performing a life cycle assessment of a complex system, it may not be possible to handle all the impacts and outputs inside the system boundaries. This problem can be solved through either of the following ways:

- expanding the system boundaries to include all the inputs and outputs;
- allocating the relevant environmental impacts to the studied system.

When avoiding allocation by expanding the system boundaries, there is a risk of making the system too complex. The data collection, impact assessment and interpretation can then become too expensive and unrealistic in terms of time and money. Allocation may be a better alternative, if an appropriate method can be found for solving the actual problem. Allocation can be necessary when dealing with:

- *multi-output black box* processes, i.e., when more than one product is produced and some of those product flows are crossing the system boundaries;
- multi-input processes, such as waste treatment, where a strict quantitative causality between inputs and emissions seldom exists;
- open-loop recycling, where a waste material leaving the system boundaries is used as a raw material by another system, outside the boundaries of the studied system.

On the basis of the principles presented above, the following descending order of allocation procedures is generally recommended:

- Wherever possible, allocation should be avoided or minimised. This may be achieved by subdividing the unit process into two or more sub-processes, some of which can be excluded from the system under study. Transport and materials handling are examples of processes, which can sometimes be partitioned in this way.
- Where allocation cannot be avoided, the system inputs and outputs should be partitioned among their different products or functions in such a way as to reflect the underlying physical relationship among them. That is to say, they must reflect the

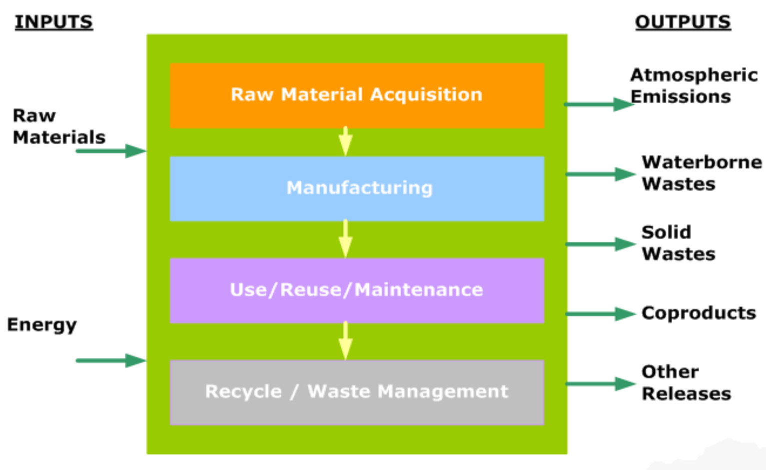
way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.

- Where physical relationship cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in such a way as to reflect economic relationships between them. For example, burdens might be allocated between co-products in proportion to the economic value of the products.

For inventory analysis, the life cycle stages in general is given in figure 6.4

**Figure 6.4**

**Stages in Life Cycle assessment**




### 6.5.3 Assessing environmental impact

Impact assessment involves category definition, classification, characterisation and valuation/weighting. Let us now discuss each of these elements.

***Category definition***

The life cycle assessment involves, as a first element, the definition of the impact categories to be considered (ISO, 1997c). This is a follow-up of the decisions made in the goal and scoping phase. Based on the type of information collected in the inventory phase, however, the boundaries defined in the goal and scoping may be redefined.

The impact categories are selected in order to describe the impacts caused by the products or product systems considered. The issues that need to be considered when selecting impact categories include the following:

- **Completeness**: This means that all environmental problems of relevance should be covered by the list.
- **Practicality**: This means that the list should not contain too many categories.
- **Independence**: This means that double counting should be avoided by choosing mutually independent impact categories.
- **Relation to the characterisation step**: This means that the chosen impact categories should be related to available characterisation methods (Lindfors et. al., 1995).

The impact categories considered are abiotic resources, biotic resources, land use, global warming, stratospheric ozone depletion, ecotoxicological impacts, human toxicological impacts, photochemical oxidant formation, acidification, eutrophication and work environment.

### *Classification*

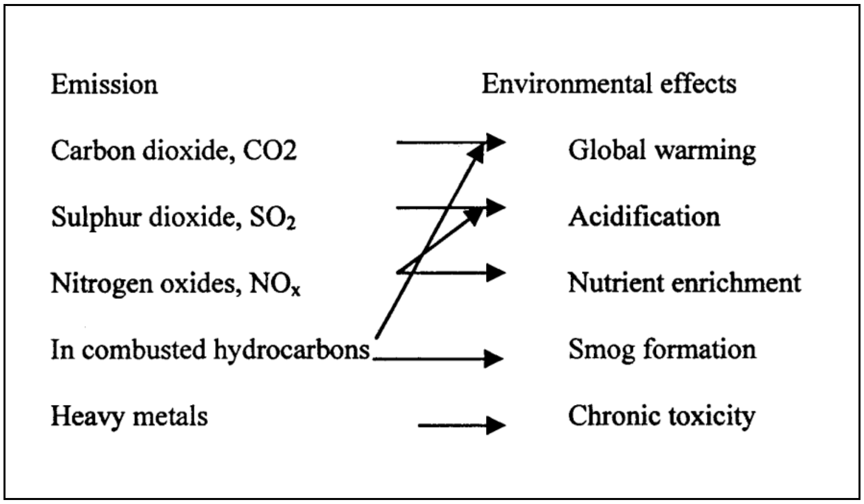
The life cycle impact assessment includes, as a second element, classification of the inventory input and output data (ISO, 1997c).

Classification is a qualitative step based on a scientific analysis of the relevant environmental processes. The classification has to assign the inventory input and output data to potential environmental impacts, i.e., impact categories. Some outputs contribute to more than one impact category, and therefore, they have to be mentioned twice. The resulting double counting is acceptable if the effects are independent of each other. However, double counting of different effects in the same effect chain (e.g., stratospheric ozone depletion and human toxicological effects, such as skin cancer) is not allowed.

The impact categories can be placed on a scale dividing the categories into four different space groups: global impacts, continental impacts, regional impacts and local impacts. The grouping is not mutually exclusive (e.g., environmental toxicity can be global, continental, regional as well as local.) The impact categories are often related directly to *exposure* (e.g., global exposure leads to continental impacts). Some of the impact categories are strongly correlated with continental, regional or local conditions. Certain lakes in Scandinavia can be mentioned as examples of localities that are more predisposed to acidification than lakes in other parts of Europe. The *time* aspect is also important when considering certain impact categories (e.g., global warming and stratospheric ozone depletion with time horizons of 20 to 500 years).

Now, let us consider an example of classification. In the manufacture of refrigerators, many of the activities relating to the production process involve the combustion of fossil fuels (e.g., coal, oil and natural gas) for electricity or heat generation, and combustion causes various emissions that may be classified as given in Figure 6.5:

**Figure 6.5**
**Classification of Emissions**




### *Characterisation*

The life cycle impact assessment includes, as a third element, the characterisation of the inventory data (ISO, 1997 c).

Characterisation is mainly a quantitative step, based on scientific analyses of the relevant environmental processes. It has to assign the relative contribution of each input and output to the selected impact categories. The potential contribution of each input and output to the environmental impacts has to be estimated. For some of the environmental impact categories, there is consensus about equivalency factors to be used in the estimation of the total impact (e.g., global warming potentials, ozone depletion potentials etc.) while for some others there may not be any consensus (e.g., biotic resources, land uses, etc.).

### *Valuation/weighting*

Characterisation results in a quantitative statement on different impact categories (e.g., global warming, stratospheric ozone depletion and ecotoxicological effects.) Comparison of these categories is not immediately possible. Therefore, the life cycle assessment includes, as a fourth element, a valuation/weighting of the impact categories against each other.

Weighting aims to rank, weight, or if possible, aggregate the results of different life cycle impact assessment categories in order to arrive at the relative importance of these different results. The weighting process is not technical, scientific or objective, as these various life cycle impact assessment results are not directly comparable (e.g., indicators for greenhouse gases or resource depletion.) However, applying scientifically based analytical techniques may assist in weighting. The purpose of weighting the following aspects:

- To express the relative preference of an organisation or group of stakeholders based on policies, goals or aims and personal or group opinions or beliefs common to the group.
- To ensure that process is visible, documentable and reportable.
- To establish the relative importance of the results is based on the state of knowledge about these issues.

Different institutions based on different principles have developed weighting approaches including the following:

- **Proxy approach:** In this approach, one or a combination of several quantitative measures is stated to be indicative of the total environmental impact. Energy consumption, material displacement and space consumption are examples of using this approach.
- **Technology abatement approach:** The possibility of reducing environmental burdens by using different technological abatement methods can be used to set a value

on the specific environmental burden. This approach can be applied to inventory data as well as impact scores.

- **Monetarisation:** This approach is based on the premise that utilitarianism (values are measured by the aggregation of human preferences), willingness to pay/accept is an adequate measure of preferences and the values of environmental quality can be substituted by other commodities. This approach can be applied to inventory data as well as impact scores.
- **Authorised goals or standards:** Environmental standards and quality targets as well as political reduction targets can be used to calculate critical volumes for emissions to air, water, soil or work environment. National or local authorities within a company can formulate the targets or standards.