CHAPTER II

THEORY

Sustainable development requires methods and tools to measure and compare the environmental impacts of human activities for the provision of goods. Environmental impacts include those from emissions into the environment and through the consumption of resources associated with providing products that occur when extracting resources, producing materials, manufacturing the products, during consumption/use, and at the products' end-of-life. These emissions and consumptions contribute to a wide range of impacts, such as climate change, ozone layer depletion, eutrophication, acidification, toxicological stress on human health, ecosystems, source depletion. A clear need, therefore, exists to be proactive and to provide complimentary insights, apart from current regulatory practices, to help reduce such impacts. Practitioners and researchers from many domains come together in life cycle assessment (LCA) to calculate indicators of the aforementioned potential environmental impacts that are linked to products. This chapter introduces criterion of LCA, LCA software tools and introduction to wood-plastic composite.

2.1. LIFE CYCLE ASSESSMENT (LCA)

Nowadays, industrial world, many users (consultants, manufacturers, researchers and institutions actors) assert that Life Cycle Assessment (LCA) is the most successful tool to assess environmental considerations in the product design process. Life cycle assessment is a process to evaluate the environmental burdens by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and material uses and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. LCA considers the entire life cycle of product, process or activity, consist of extracting and processing of raw materials; manufacturing, transportation, distribution, use, re-use, maintenance, recycling and final disposal. All direct and indirect environmental impacts associated with the product, process or activity is included in the assessment as the concept of 'cradle to grave'. The results of LCA can use for comparing goods and services (products) and for identifying opportunities for reducing the impacts attributable to associated wastes, emissions and resource consumption.

LCA has become a widely recognized method in the public and private sector for analyzing and assessing the environmental performance of the product or process. The results of a LCA may be used in various ways such as identify the interactions of a product or service with the environment, quantitatively analyse the environmental loads, provide information to allow prioritisation of environmental improvements and serve as a tool to evaluate the level of achieving target values and meeting regulations as part of company efforts for environmental protection.

2.2 CRITERION OF LIFE CYCLE ASSESSMENT (LCA)

The ISO standards concern both technical aspects as well as the organizational aspects mainly focus upon the design of critical review processes, with special attention to comparative assertions disclosed to the public. They also cover matters such as involvement of stakeholders, formulation of clear goal and question, reporting requirements. The following general standard in the ISO 14040 have produced by ISO:

- International Standard ISO 14040 (1997) on principles and framework.
- International Standard ISO 14041 (1998) on goal and scope definition and inventory analysis.
- International Standard ISO 14042 (2000) on life cycle impact assessment.
- International Standard SO 14043 (2000) on life cycle interpretation.

LCA provides a framework of 4 stages. The four phases of the product life cycle assessment include initiation, inventory analysis, impact assessment, and interpretation and improvement assessment. Show in figure 2.1

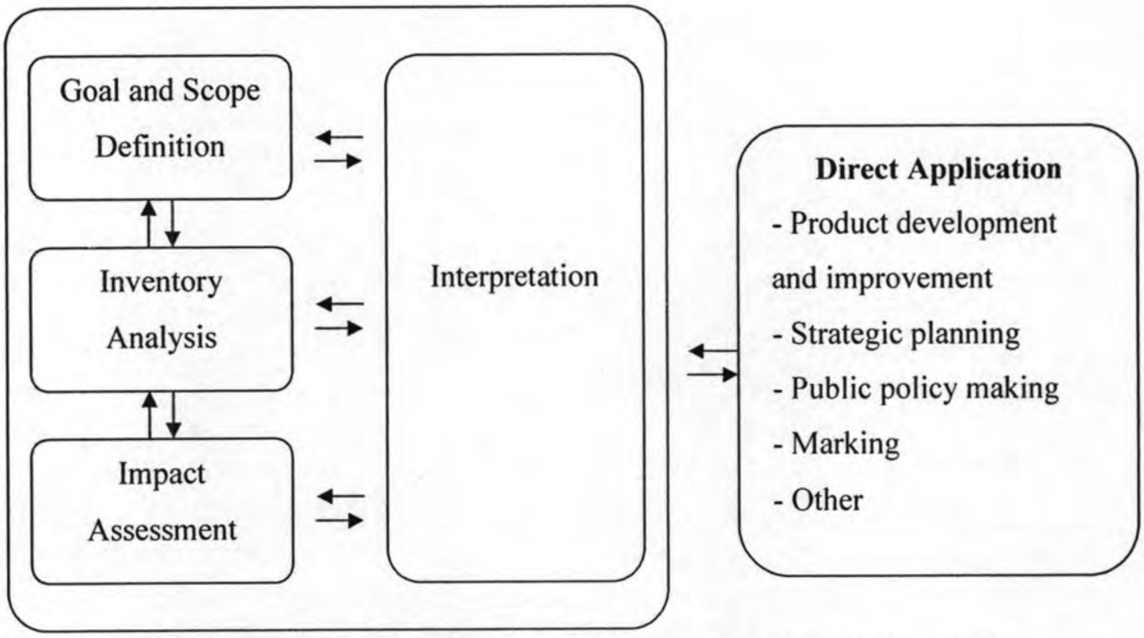

Figure 2.1 Phases and applications of an LCA (based on ISO 14040, 1997).

In the goal and scope definition, the purpose of study and its scope are defined in relation to how the results to be used. The functional unit is established in this step, with the necessary data and information needed for the inventory and impact assessment also identified. The selection of functional unit is straightforward for processes (usually in unit of mass) but more debatable for products where product effectiveness rather than mass or volume becomes of key importance. For example, '1 kg of WPC' used as the functional unit of Wood-Plastic Composites.

The next component of LCA is inventory analysis, which quantifies the inputs (using mass and energy balance) and output (products and its releases) for all processing steps included in the system boundary. The life cycle of each of products considered is defined by assembling the processes which constitute the different phases of the life cycle. These phase consist of industrial processes such as the production of materials or components, consumer processes and post-consumer processes. The collection of combined processes with their mutual relationship is called a process tree. The inventory also comprises the collection of the processes data. Process data consist of economic data (use and production of material, products and services) and of environmental data (extractions of resources and emissions of substances). The result of the inventory is a list of the loading onto the environmental in term of extraction and emissions caused by a functional unit of the product analyzed.

The impact assessment component of LCA is defined as a quantitative and qualitative process to identify, characterize and assess the potential impacts of the environmental intervention identified in the inventory analysis. According to the 'Code of Practice', impact assessment consists of three distinct steps: Classification, Characterization, and Valuation

The improvement assessment is in interpretation is the only component which does not yield a description of the interactions between life cycle and environment; it gives information on the opportunities to decrease the environmental burdens associated with a function unit of product. Improvement assessment involves looking at how the results of LCA can be used, not only in terms of how the adverse environmental impact of the system can be reduced, but also how the results should be interpreted in corporate with other considerations.

2.2.1 Goal and scope definition

The first phase in an LCA is goal and scope definition which containing of goal, scope, functional unit, and data quality. The definition of the goal and scope is the critical parts of an LCA due to the strong influence on the result of the LCA.

2.2.1.1 Defining the goal

The definition of the purpose of the life cycle assessment is an important part of the goal definition. The goal of an LCA study shall unambiguously state the intended application, including the reasons for carrying out the study and the intended audience, the goal definition also has to define the intended use of the results and users of the result. 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.

2.2.1.2 Defining the scope

The definition of the scope of the life cycle assessment sets the borders of the assessment. 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. Since 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. Summarizes the single points mentioned in the ISO standard are product group, system boundaries, and data quality goal.

2.2.1.3 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. 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. Comparisons between systems shall be done on the basis of the same function, measured by the same functional unit in the form of equivalent reference flows.

2.2.1.4 System boundaries

It is necessary for LCA to define boundaries around the system and also clear that by leaving outside the system boundary, the result can be distorted. The system boundaries define the input and output to be taken into account in the LCA.

2.2.1.5 Data quality

Type of data is important to determine in advance since data quality issues are completeness, consistency, and reproducibility. Data quality requirements contain following points: time period, geography, technology and allocation.

2.2.2 Inventory analysis

Inventory analysis comprises the material and energy flow analysis of the studies system within defined system boundaries. This includes an analysis of environmental interventions which is a change in environmental directly caused by human activity during the entire product life cycle. Environmental interventions are measurable physical parameters.

The inventory analysis based on the functional unit of the product defined in the goal definition and the selected products with provide this function. The functional unit is realized a through product, and the product is associates with past and future processes. Hence, the first action in an inventory analysis is to draw up an overview of the processes which the life cycle is implemented in each of the products systems under investigation, which is know as a process tree. Next the process data have to be collected and entered. The aggregation of this data throughout the process tree into inventory table will ultimately provide a list of all interventions in the environment which are associated with the product system.

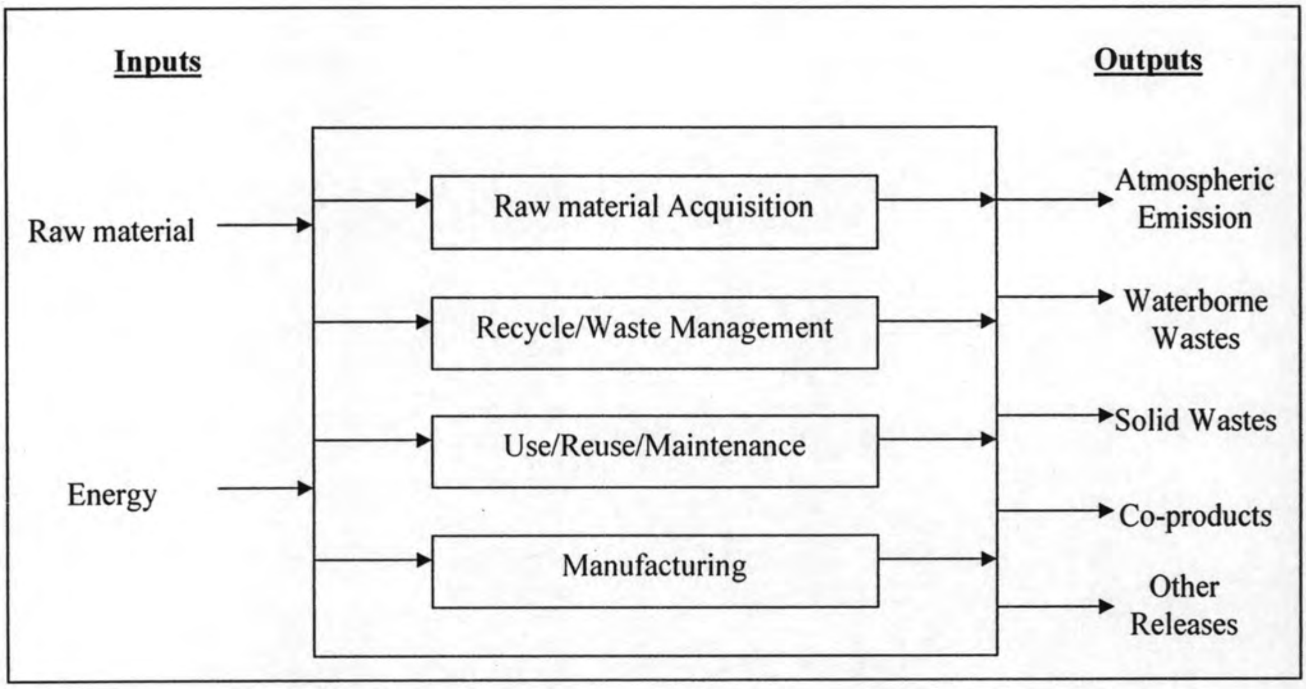

Figure 2.2 Life Cycle Stages and Boundaries

Instead of using an inventory table the outcome of the inventory analysis could be presented in another form; e.g. i) by aggregating quantities which are of particular individual interest, ii) the energy used, the volume of waste produced before of after processing, or the total space use. Another option is to aggregate certain types of interventions such as the total quantity of heavy metal. The inventory analysis requires an understanding of system theory and process engineering

According to ISO 14040 and ISO 14041, the inventory analysis is slip up into the following operational step:

- Preparing for data collection
- Data collection
- Validation of data
- Relating data to unit process
- Relating data to functional unit
- Allocation

- Data aggregation
- Refining the system boundaries

The inventory analysis and the tasks to be fulfilled can obviously be supported by a flow sheet for the considered product; an example of a flow sheet can be seen in figure 2.2. Each of the different phases can be made up from different single processes e.g. production of different kinds of raw material to be combined in the material production phase. The different phases are often connected by transport-processes.

2.2.3 Impact assessment

Impact assessment is the third phase in a life cycle assessment. According to ISO 14042 the following steps can be derived for the life cycle impacts assessment (LCIA) phases

- Selection of impact categories, category indicators, and characterization models.
- Assignments of LCI results (Classification)
- Calculation of category indicator results (Characterization)
- Calculation the magnitude of the category indicator results relative to reference information (Normalization)
- Grouping
- Weighting
- Data quality analysis

The ISO 14042 framework of the life cycle impact assessment is summarized in figure 2.3. ISO 14042 distinguishes mandatory element and optional elements. The first mandatory element is the selection and definition of impact categories, category indicators and models. In this step impact categories (e.g. climate change) are identified together with category indicators (e.g. infrared radioactive forcing) and model used to derive the characterization factors, i.e. the quantitative relationship between the interventions and the indicators. In the second mandatory element LCI results are assigned to category indicator results (Classification). In the last mandatory element, calculation of category indicator results (Characterization), requirements are provide for calculation of indicators results. These results of characterization are called indicator results or LCIA profile.

The next to mandatory elements there are three optional elements. In the first optional element (Normalization) the relative magnitude of category indicators to a reference value can be calculated. The second optional element is the grouping of indicators results. Then the impact categories are grouped into one of more sets involving descriptive sorting or a prioritizing ranking. The third optional element is weighting, which is a conversion of indicator results or normalized results by using numerical factors, aiming at converting and possible aggregating indicator results across impact categories into a single score or a small number of such scores. As last the optional element, data quality analysis can be performed in order to better understand the significance, the uncertainly and sensitivity of the LCIA results.

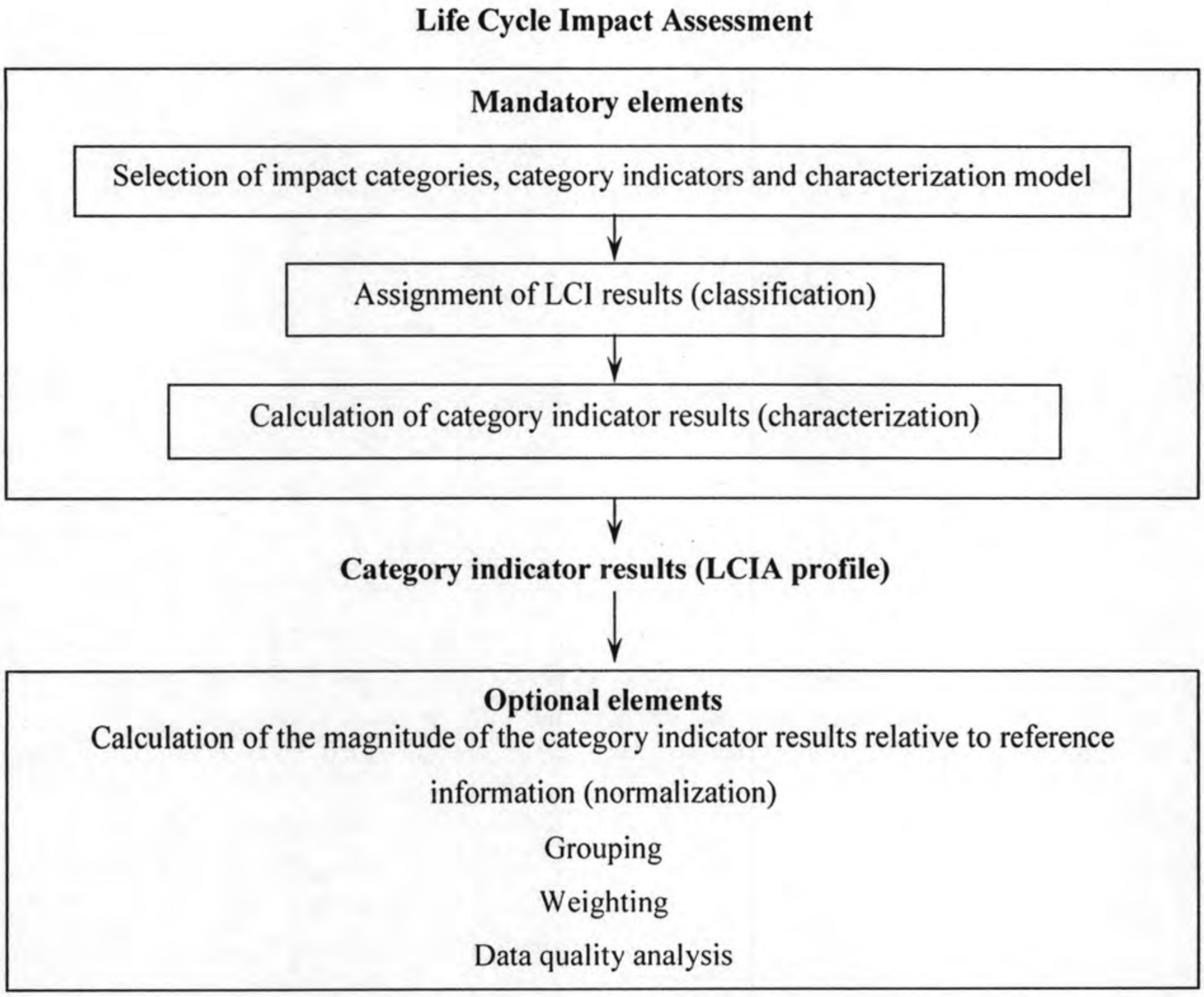

Figure 2.3 Element of LCA (ISO 14042, 2000)

2.2.3.1 Selection of methods and impact categories

An important step is the selection of the appropriate impact categories. The choice is guided by the goal of the study. An important help in the process of selecting impact categories is the definition of so-called endpoints. Endpoints are to be understood as issues of environmental concern, like human health, extinction of species, available of resource for future generation etc. ISO does not recommend using certain endpoint, but requires a careful selection and definition of endpoint first. After that impact categories can be selected, as long as the environmental model that links the impact category to the endpoint is clearly described. It is not necessary to describe this link quantitatively.

The LCI results are characterised to produce a number of impact category indicators. According to ISO, one must document the environmental relevance of each indicator by describing the link to the endpoints. Endpoint can be selected by the practitioner, as long as the reasons for including or excluding endpoints are clearly documented.

2.2.3.2 Classification

The classification element aims to assign inventory input and output data to categories. The assignment of inventory data is the simplest or minimum level of life cycle impact assessment. This can be used to identify and flag issues associated with inventory input and output data. At this stage, there is an implicit assumption of 'less is better' and excludes several important considerations such as differences in potency or environment persistence.

Classification is qualitative step based on scientific analysis of relevant environmental process. The inventory result of an LCA usually contains hundreds of different emissions and resource extraction parameters. Once the relevant impact categories are determined these LCI results must be assigned to these impact categories. For example, CO2 and CH4 are both assigned to the impact category 'Global warming', while SO2 and NH3 are both assigned to an impact category acidification. It is possible to assign emission to more than one impact category at the same time: for example SO2, may also be assigned to an impact category like Human health, or Respiratory diseases.

2.2.3.3 Characterisation

Once the impact categories are defined and the LCI results are assigned to these impact categories, it is necessary to define characterisation factor. These factors should reflect the relative contribution of an LCI results to the impact category indicator result.

For example, on a time scale of 100 years the contribution of 1 kg CH_4 to global warming is 42 times as high as the emission of 1 kg CO_2. This means if the charaterisation factor of CO_2 is 1, the characterization of CH_4 is 42. Thus, the impact category indicator result for global warming can be calculated by multiplying the LCI result with the characterization factor.

2.2.3.4 Normalisation

Normalisation is a procedure needed to show to what extent an impact category has a significant contribution to overall environmental problem. This is done by dividing the impact category indicators by a 'Normal' value. There are different ways to determine the 'Normal' value. The most common procedure is to determine the impact category indicators for a region during a year, and if desired, divide this result by the number of inhabitants in the area. Normalisation serves two purposes:

- Impact categories that contribute only a very small amount compared to other impact categories can be left out of consideration, thus reducing the number of issues that need to be evaluated.
- The normalized results show the order of magnitude of the environmental problems generated by the products life cycle, compared to the total environmental loads in Europe.

Normalisation results can provide input to grouping or weighting, as described in the next subsections, or can help directly judge the relative importance of different impact categories within an LCA study. However, it should be noted that direct application implies acceptance of the ratios of different impacts as they exist today, meaning that, for example, the total current effects of global warming and ecotoxicological effects in Europe would be considered to be of equivalent importance.

2.2.3.5 Grouping and ranking

Grouping is a qualitative, or semi-quantitative, process that involves sorting and/or ranking results across impact categories. Grouping may result in a broad ranking, or hierarchy, of impact categories with respect to their importance. Such a ranking can provide structure to help draw conclusions on the relative importance of different impact categories. In order to avoid weighting, while making results easier to interpret, impact category indicators may be grouped and ranked:

- Impact category indicators that have some common features may be presented as a group. For example, one can for a group of impact category indicators with Global, regional and local significance.
- Ranking refers to a procedure, where impact categories are sorted by panel in a descending order of significance.
- Both procedures can be used to present the results.

2.2.3.6 Damage assessment

The method presented here will all still be difficult to interpret, as there is a wide range of impact category indicators. To simplify interpretation further, a grouping procedure can be in the Eco-indicator methodology. In these methods, the category indicators are defined close to one of the three endpoints to achieve an optimum environmental relevance. The impact category indicators that refer to the same endpoint are all defined in such a way that the unit of the indicator result is the same.

This allows addition of the indicator results per group. This means that the indicator results can be presented as three indicators at endpoint level without any subjective weighting. Interpreting three instead of a multiple set of indicators is much easier. The figure 2.4 illustrates this procedure. The procedure allows to reduce the number of impact categories to just three of 14 without subjective weighting

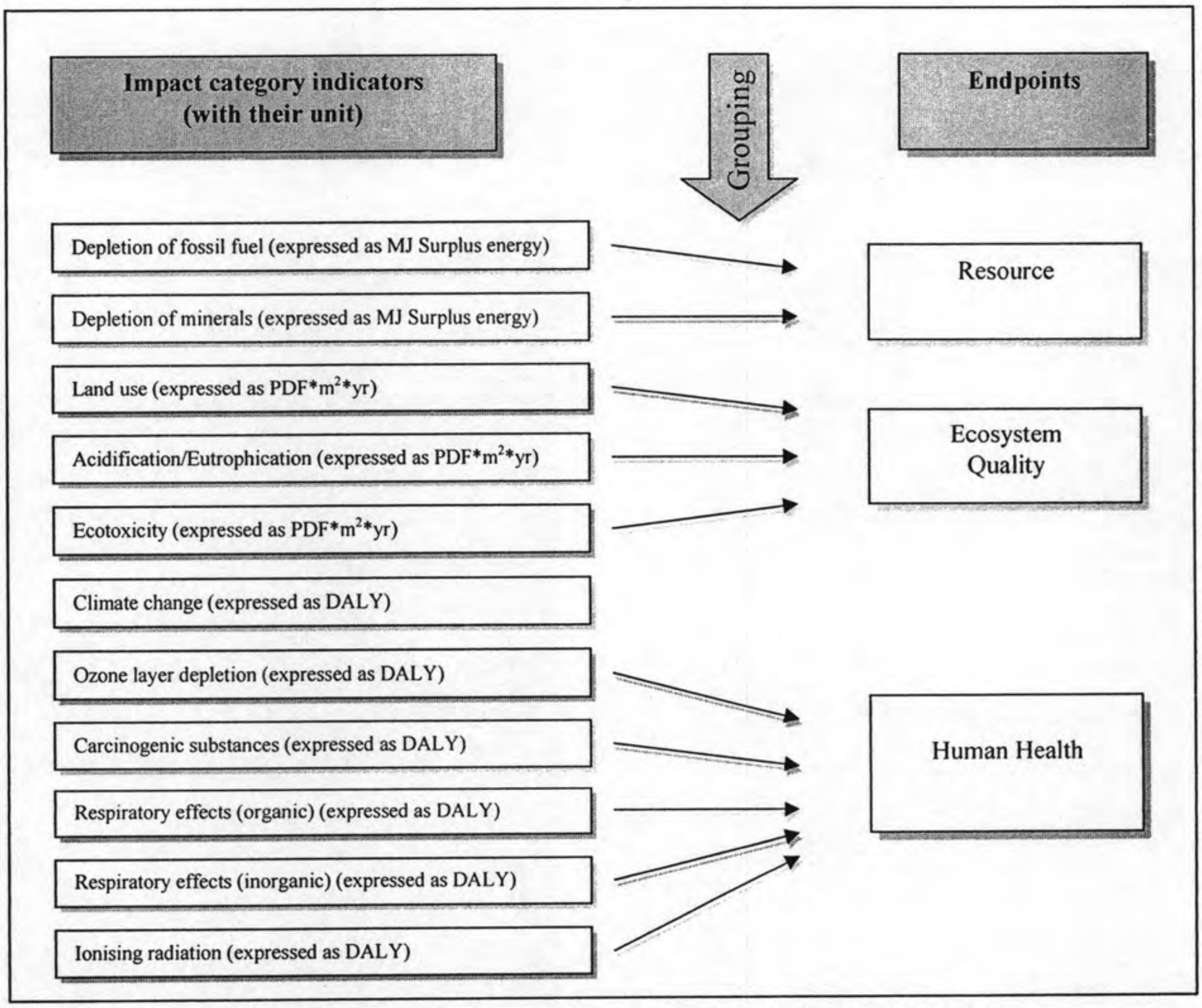

Figure 2.4 The grouping option on the Eco-indicator 99 method

2.3.3.7 Weighting

Weighting is the most controversial and most difficult step in life cycle impact assessment. Weighting (also sometimes referred to as ''valuation'' in some LCA circles) refers to using numerical factors based on value choices to facilitate comparison across impact category indicators (or normalised results). Methods for weighting can be classified in different ways:

1. A distinction can be made between methods based on impact indicators defined early (at midpoints) or late (e.g. at endpoints or for areas of protection), in the impact chain.
2. A second distinction is between three major groups of methods:
   - Monetisation (here used as an umbrella term for all methods which have a monetary measure involved in the weighting factors).
   - Panel (a group of methods where the relative importance of damages, impact categories or interventions is derived from a group of people through surveys).
   - Distance to target (where characterisation results are related to target levels)
3. A third distinction exists between expressed preference methods and revealed preference methods. Panel methods, as well as some monetisation methods, are based on expressed preferences. On the other hand, some monetisation methods are based on revealed preferences. These monetised weighting factors are derived from reactions to different situations of individuals and/or organisations, such as insurance payouts, health care expenditures, fines, costs incurred for environmental cleanups and ecotaxes.

The aim of the impact assessment step in LCA is to make these transparent. The LCIA is, therefore, not a discipline of 'hard' natural scientific work with true or false results. It can more likely be understood as the bridging between natural science and social as the scope of considered phenomena and values of society get linked each other.

2.2.4 Interpretation

Interpretation is the forth phase of LCA in which the findings from the inventory analysis and the impact assessment are combined together in line with the defined goal and scope. The findings of this interpretation may take the form of conclusions are recommendations to decision-makers, consistent with the goal and scope of the study. According to ISO 14043, the interpretation phase is split up into three elements:

- Identification of the significant issues based on the based on the results of the LCI and LCIA phases of LCA
- Evaluation which considers completeness, sensitivity and consistency check
- Conclusions, recommendations and reporting

In the interpretation, the results from the inventory analysis and the used elements of the impact assessment are combined together with the goal and scope of the study in order to draw conclusions. This concludes answering questions posed in the goal and scope definition of the study.

The interpretation following the impact assessment, results from any sensitivity and uncertainty should be used. Such analysis may have been performed as parts of earlier phases and elements. However, in the interpretation phase, it can and should be of an encompassing nature. As a part of the interpretation phase, the information from all previous phases and elements, including qualitative information and information on uncertainties, is brought together. This encompassing information is compared with the goal of the study and conclusions are drawn on the environmental implications of the results. Recommendation to decision makers may be formulated.

The role of interpretation will probably depend on the application, the stakeholders and beneficiaries of the study, although it is not clear how. The role of the interpretation may also depend on the inputs to it. The role may be different if no impact assessment at all has performed, or if the end point of the impact assessment is the classification or the characterization compared to if also valuation has been performed. In the latter case, the interpretation may be different if only one valuation method has been used, or if several methods and datasets have been used in parallel.

2.3 THE LCA SOFTWARE TOOL

Environmental processes are often very complex and convoluted. This makes it difficult to model an LCA. Additionally LCA is often data intensive. Computers and adequate software tools are thus used to support the user in managing and editing these amounts of data. LCA software further helps to structure the modelled scenario, displaying the process chains and presenting and analysing the results. LCA software tools can be used whenever the method of LCA is applied.

The main reason for using LCA is to calculate the environmental aspects and potential impact associated with a product (ISO 14040). Also environmental hot spots (processes that have a large impact on the environment) can be identified. A more environmentally-friendly production process can thus be developed where they are most effective. LCA can also be used for a cleaner approach to production. It can help to improve and optimize resource management, which leads to a more efficient use of materials and energy.

LCA therefore is used mainly for comparing different options and for deciding which option is best for the environment. LCA and LCA software are thus used as a support tool in decision taking.

Example of LCA software tools:

ECO-it	Eco-Indicator Tool for environmentally friendly design - PRé Consultants
EDIP	Environmental design of industrial products - Danish EPA
EIOLCA	Economic Input-Output LCA at Carnegie Mellon University

Table 2.1 Comparison of LCA software tools

	EDIP PC-tool	EPS4.0 Design System	Gabi 3	SimaPro4.0	TEAM	Umberto3.5
Country	Denmark	Sweden	Germany	Netherlands	France	Germany
Amount of sold patents	100	>200	250	>600	>200	>350
Analytical time	< 1 week	< 1 week	< 1 month	< 1 day	< 1 day	< 1 week
Method	EDIP, Environmental method	EPS	Eco Indicator + Create your own method	EI95, EI99, EP97, CML, EDIP, EPS	CML, EPA, IPCC, CVCH	Eco Indicator, Swiss eco point
According to ISO 14040	+	+	+	+	+	+
Show in table	+	+	+	+	+	+
Show in graph	+	+	+	+	+	+
Data improvement	-	Every year	-	Every 2 years	Every year	-
Show impact category	+	+	+	+	+	+
Able to comparison	+	+	+	+	+	+
Have database	+	+	+	+	+	+
Add database	+	+	+	+	+	+

IDEMAT	Delft University Clean Technology Institute Interduct Environmental Product Development
KCL-ECO	KCL LCA software
LCAiT	CIT EkoLogik (Chalmers Industriteknik)
SimaPro	for Windows - PRé Consultants
TEAM(TM)	Tools for Environmental Analysis and Management - Ecobalance, Inc.
Umberto	An advanced software tool for Life Cycle Assessment - Institut für Umweltinformatik

2.4 WOOD PLASTIC COMPOSITES

2.4.1Composite material

The term composite originally arose in engineering when two or more materials were combined in order to rectify some shortcoming of a particularly useful component. However because composites are usually used for their structural properties, the definition can be restricted to include only those materials that contain a reinforcement supported by a matrix material. Composite materials were developed because no single, homogeneous structural material could be found that had all of the desired attributes for a given application. The advantages of composite are that they usually exhibit the vast qualities of their constituents and often some qualities that neither constituent possessed. The properties that can be improved by forming a composite material include strength, stiffness, weight, electrical conductivity and thermal conductivity.

2.4.2 Wood Plastics Composites (WPC)

Wood-plastics composites (WPC) are a new group of materials that are generating interest in both the UK and overseas. The term 'WPC' covers an extremely wide range of composite materials using plastics ranging from polypropylene to PVC and binders/fillers ranging from wood flour to flax. These new materials extend the current concept of 'wood composites' from the traditional compressed materials such as particle- board and medium density fibreboard (MDF) into new areas and, more importantly, a new generation of high performance products. The first generation of 'wood composites' were a combination of recycled wood flour or chips and binders. The range of raw materials gives a wide range of properties and the high wood content of some products (up to 70%). These were ideal for relatively undemanding applications. The new and rapidly developing generation of WPC 'wood composites' have good mechanical properties, high dimensional stability and can be used to produce complex shapes. They are tough, stable and can be extruded to high dimensional tolerances. The new WPC materials are high technology products for the most demanding applications. The most common types of the new WPCs are produced by mixing wood flour and plastics to produce a material that can be processed just like a plastic but has the best features of wood and plastics. The wood can be from sawdust and scrap wood products. This means that no additional wood resources are depleted in WPCs, waste products that currently cost money for disposal are now a valuable resource - recycling can be both profitable and ethical. The plastic can be from recycled plastic bags and recycled battery case materials although in demanding applications new plastics materials are used. The recycling ethos is to use materials recovered from short life cycle applications in long life cycle applications. A wide variation of mechanical and physical properties can be developed through an appropriate compounding of polymer and fillers.

Current applications for WPCs are largely in finished products such as decking, cladding and window frames. In the USA, the market for WPC products has grown at a rate of 100% per year for the last 5 years and this is increasing as new applications are found for the materials. A particular growth area is in structural engineering applications that use the physical properties of WPC to the limits. WPCs can be used for products traditionally manufactured from timber and PVC-U and typical applications , example, are Lumber, decking and railing, window profiles, wall studs, door frames, furniture, pallets, fencing, docks, siding, architectural profiles, louvers and automotive components.

2.4.3 History and Current Situation of Wood Plastics Composites (WPC)

In the United States, WPCs have been produced for several decades, but they were produced even earlier in Europe. However, major growth in the United States did not occur until fairly recently. This section describes some historical developments in the U.S. WPC industry through the mid-1990s. In 1983, American Woodstock, now part of Lear Corporation in Sheboygan, Wisconsin, began producing automotive prointerior substrates using Italian extrusion technology. Polypropylene with approximately 50 percent wood flour was extruded into a flat sheet that was then formed into various shapes for interior automotive paneling. This was one of the first major applications of WPC technology in the United States. In the early 1990s, Advanced Environmental Recycling Technologiesand a division of Mobil Chemical Company that later became Trex began producing solid WPCs consisting of approximately 50 percent wood fiber in polyethylene. These composites were sold as deck boards, landscape timbers, picnic tables, and industrial flooring. Similar composites were milled into window and door component profiles. Today, the decking market is the largest and fastest growing WPC market. Also in the early 1990s, Strandex Corporation patented technology for extruding high wood fiber content composites directly to final shape without the need for milling or further forming. Strandex has continued to licence its evolving technology. Andersen Corporation (Bayport, Minnesota) began producing wood fiber-reinforced PVC subsills for French doors in 1993. Further devolopment led to a wood-PVC composite window line. These products allowed Andersen to recycle wastes from both wood and plastic processing operations. The market for WPC window and door profiles has continued to grow. In 1996, several US. companies began producing a pelletized feedstock from wood (or other natural fibers) and plastic. These companies provide compounded pellets for many processors who do not want to blend their own material. Since the mid-l990s, activity in the WPC industry has increased dramatically. Technology is developing quickly and many manufacturers have begun to produce WPCs. In 1991, the First International Conference on Woodfiber-Plastic Composites was convened in Madison, Wisconsin, with the intent of bringing together researchers and industrial representatives from both the plastics and forest products industries to share ideas and technology on

WPCs. A similar conference (Progress in Woodfibre-Plastic Composites) began in Toronto, Ontario, the following year and is being held in alternating years. These conferences have grown steadily in the 1990s, and additional conferences have been held in North America and elsewhere as the market has grown. For example, a WPC conference was held by Plastics Technology Magazine and Polymer Process Communications in December 2000, in Baltimore, Maryland. Although the WPC industry is still only a fraction of a percent of the total wood products industry, it has made significant inroads in certain markets. Current end product manufacturers are an interesting mix of large and small manufacturers from both the plastics and forest products industries. According to a recent market study, the WPC market was 320,000 metric tons (700 million lb.) in 2001, and the volume is expected to more than double by 2005.

2.4.4 Polymer matrices

Throughout the 1970s and 1980s, thermosetting resins have been the principal type of matrix used for high-performance composites. The main disadvantages of these resins are low strain to failure and brittleness, lengthy cure cycles, moisture absorption and its deleterious effects on mechanical properties and the preclusion of forming operations certain kinds of repair once the matrix has been fully cured. Some of these problems can be overcome by using a thermoplastic polymer for the matrix. Compared with thermosets these materials usually have a higher strain to failure and lower moisture absorption, they can be shaped when heated and repaired, do not require a lengthy cure cycle and have a very long storage life at ambient temperature. Their principal disadvantage has been the difficulties in fabricating wood flour reinforced composites.

Ideally the thermoplastic polymer matrix should have a high softening point and resistance against pyrolysis and chemical degradation. These are properties that may be shown by crystalline polymers with a rigid backbone chain, regularly spaced substituents and strong interchain forces due to Van der Walls or polar interactions. Polymer properties usually show a marked reduction at the glass transition temperature, Tg, but crystalline materials have useful properties retention until close to Tm, the crystalline melting point, as the crystalline phase holds the molecular chain together. Practically, it necessary to compromise between the desired properties and the ability to process the polymer without causing degradation. Aromatic segments in the main polymer chain can be use to increase chain stiffness and reduce susceptibility to pyrolysis while ether linkages increase chain flexibility. Among the thermoplastic polymer used as matrices are polyethylene (PE), polypropylene (PP), poly(vinyl chloride) (PVC), polystyrene (PS), polysulfone, aromatic polyketone and polyimide. The most popular matrices are PP and PVC which are in the commodity plastic group.

2.4.4.1 Poly(vinyl chloride) (PVC)

PVC is one of the world's major bulk polymers, 16.4 million tons were produced worldwide in 1987. This might appear surprising because the polymer suffers from a number of disadvantages, the raw polymer start to decompose at about 100 °C, well below its melting point of 150-200 °C, and it degrades in the presence of light. It has poor mechanical properties and a relatively low softening point, between 70 and 80 °C.

The polymer owes its popularity to its versatility. The polymer itself is commercially inert and nonflammable, burning only in the presence of a source of ignition. It is compatible with many additives, including plasticizers, heat stabilizers, lubricants, fillers and other polymers. These additives enable the polymer to be processed easily by a wide range of techniques without the fear of degradation to produce article with a variety of mechanical properties. The articles may be rigid, such as house sidings, rain gutters and window frames, or flexible, as in cable insulation, medical tubing and plastic gloves. PVC is transparent and can be used to make clear bottles and sheet. Finally it is one of the least expensive plastic resins.

Approximately 75% of world's PVC is produced by the suspension polymerization process in which the polymerization is carried out inside vinyl chloride monomer (VCM) droplets disperse in water. The products are in the form of porous 100-150 m. diameter grains.

2.4.4.2 Polypropylene (PP)

Polypropylene (PP), a thermoplastic polymer which entered to commercial production in 1957, was the first of stereorisomer polymer. Polypropylene differ from polyethylene because there is a methyl group attached to every other carbon atom, which stiffens the chain, the polymer does not crystallize until the stereospecific catylysts were developed by Natta and Ziegler. Crystallinity is responsible for the stiffness and solvent resistance of the commercial plastic.

Polypropylene is used in a variety of process to produce a wide range of products. The most valuable property of polypropylene is versatility. It can be tailored to many fabrication methods and applications. Some properties that are usually considered inherent advantages of polypropylene are low density, excellent chemical resistance, good stiffness/toughness balance, great range of special purpose grades, and low cost (especially per unit volume)

2.4.4.3 Wood flour

Wood flour is a finely ground wood, fried wood product, fibrous in structure that acts as reinforcing material for plastics. It is made mostly from soft wood, chiefly pine, and spruce. Wood flour is made from sawdust, chip and shavings by grinding in a buhstone mill and has the appearance of wheat flour. Wood flour is composed largely of cellulose in content. Compared to others filler in plastics, it offer many advantages such as lower cost, no health hazard, lower density etc.

Wood flour is already being employed in thermoplastic in an industrial scale. Its use results in the following advantages because wood flour is cheap filler, reduce plastic used and properties changes are acceptable.

2.4.5 Polymer processing

The manufacture of thermoplastic composites is often a two-step process. The raw materials are first mixed together in a process called compounding, and the compounded material is then formed into a product. Compounding is the feeding and dispersing of fillers and additives in the molten polymer. Many options are available for compounding, using either batch or continuous mixers. The compounded material can be immediately pressed or shaped into an end product or formed into pellets for future processing. Some product manufacturing options for WPCs force molten material through a die (sheet or profile extrusion), into a cold mold (injection molding), between calenders (calendering), or between mold halves. Combining the compounding and product manufacturing steps is called in-line processing. The majority of WPCs are manufactured by profile extrusion, in which molten composite material is forced through a die to make a continuous profile of the desired shape. Extrusion lends itself to processing the high viscosity of the molten WPC blends and to shaping the long, continuous profiles common to building materials. These profiles can be a simple solid shape, or highly engineered and hollow. Outputs up to 3 m/min. (10 ft./min.) are currently possible. Although extrusion is by far the most common processing method for WPCs, the processors use a variety of extruder types and proessing strategies. Some processors run compounded pellets through single-screw extruders to form the final shape. Others compound and extrude final shapes in one step using twin-screw extruders as shown in Figure 2.5. Some processors use two extruders in tandem, one for compounding and the other for profiling. Moisture can be removed from the wood component before processing during a separate compounding step (or in the first extruder in a tandem process), or by using the first part of an extruder as a dryer in some in-line processes.

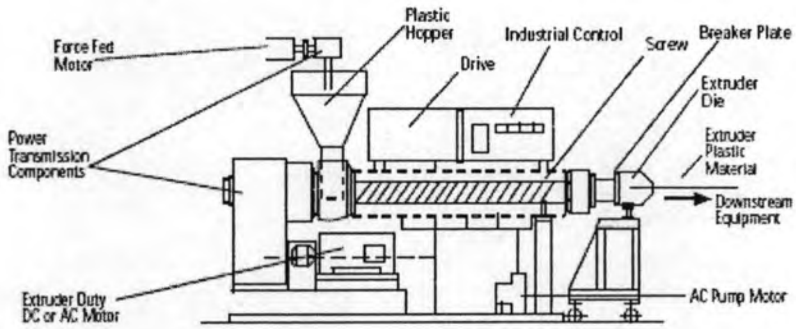

Fig 2.5 Basic extruder machine

Equipment has been developed for many aspects of WPC processing, including materials handling, drying and feeding systems, extruder design, die design, and downstream equipment (i.e., equipment needed after extrusion, such as cooling tanks, pullers, and cut-off saws). Equipment manufacturers have partnered to develop complete processing lines specifically for WPCs. Some manufacturers are licensing new extrusion technologies that are very different from conventional extrusion processing. Compounders specializing in wood and other natural fibers mixed with thermoplastics have fueled growth in several markets. These compounders supply preblended, free-flowing pellets that can be reheated and formed into products by a variety of processing methods. The pellets are a boon to manufacturers who do not typically do their own compounding or do not wish to compound in-line (for example, most single-screw profilers molding companies). Other processing technologies such as injection molding and compression molding are also used to produce WPCs, but the total poundage is much less than what is produced with extrusion. These alternative processing methods have advantages when processing of a continuous piece is not desired or a more complicated shape is needed. Composite formulation must be adjusted to meet processing requirements.