Life Cycle Assessment (LCA) Study of Plastics Packaging Products

Central Pollution Control Board (CPCB)

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CONTENT

Abbreviations

LCA	Life Cycle Assessment
AG	Associated Gases
GHG	Green House Effect
GWP	Global Warming Potential
GED	Grass Energy Demand
CED	Cumulative Energy Demand
CO_2	Carbon Di oxide
PET	Polyethylene Terephthalate
PVC	Polyvinyl Chloride
PP	Polypropylene
HDPE	High Density Polyethylene
LDEP	Low Density Polyethylene
PLA	Poly Lactic Acid
VOC	Volatile Organic Compound
CC	Carbon Credit
ISO	International Standards Organization
CPCB	Central Pollution Control Board
ULB	Urban Local Bodies
CIPET	Central Instrutes of Plastic Engineering Technology

BACKGROUND OF THE LCA STUDY

Life-cycle of petro-based plastics is incomplete and remains on the landscape for several years. Besides, plastic products can be recycled 3 to 4 times only and after each recycling the product quality deteriorates and ultimately, it is dumped on land-fill site, leading to burden on the earth & damaging environment due to non-biodegradability. Hence, LCA of plastics and other products have been carried out by following four main stages, raw material, production/manufacturing stage, use stage and end-of-life stage. The environmental evaluation using LCA(as per ISO: 14040) approach is done by applying four steps, defining the goal and scope of the study energy and emissions (GHG) and establishing life cycle inventory (LCI) based on collection of literature and experimental data of the Life Cycle Impact Assessment (LCIA) (As per ISO: 14040). This report has been finalized in association with sponsored study carried out by CIPET on the “Life Cycle Assessment of Plastic Products” during 2012-13.The study has been made to draw a clear-cut distinction of environmental impact by different packaging products such as Plastics, Paper, Glass& Compostable Material. The Officials of the CIPET are appreciated for their concerted support in completion of the study along with Dr. S.K. Nigam, Additional Director of CPCB. The data compilation of report has been done by Ms. Gudiya Jaiswal, Scientific Assistant. It is hoped this report would be useful for Urban Local Bodies, Policy Makers, DGS&D and Corporate Offices in reduction of petro-based plastic products and encouraging compostable products.

EXECUTIVE SUMMARY

In India, approximately 707 million metric tons/year plastic products are manufactured, majority of the plastics material goes to packaging applications (Annual Report: 2015-16, MoC&F). In India about 80% of the plastics consumed used in packaging sector. Although the per capita consumption of plastic in India is only 9.7kg (Tata Strategic), less than to the world average. Petrochemical products permeate the entire spectrum of daily use items and cover almost every sphere of life like clothing, housing, construction, furniture, automobiles, household items, agriculture, horticulture, irrigation, packaging, medical appliances, electronics and electrical etc.

As per the study conducted by Central Pollution Control Board (CPCB) in 60 major cities of India, it has been observed that around 4059 T/day of plastic waste is generated from these cities. The fraction of plastic waste in total Municipal Solid Waste (MSW) varies from 3.10% (Chandigarh) to 12.47% (Surat). Average plastic waste generation is around 6.92% of MSW. With extrapolation of the plastic waste generation data from 60 major cities, it is estimated that around 25,940 T/day of plastic waste is generated in India. Data revealed that out of total plastic waste, around 94% waste comprises of thermoplastic content, which is recyclable such as PET, LDPE, HDPE, PVC etc. and remaining 6% belongs to the family of Thermoset and other categories of plastics such as SMC, FRP, multi-layered, thermocol etc., which is non-recyclable.

The impact of its use in environment has earned attention of social and political bodies for its proper management through various studies/approaches. In spite of various environmental impact, the plastics brought to the society, its increasing demand around the world has been a matter of concern recently since the finite energy resources of the earth i.e. fossil fuel which is getting depleted rapidly.

In the back drop of the above situation, the need of assessing the plastics product's life cycle has been arising in comparison with other products like paper, glass and bio-degradable & compostable products used in the packaging sectors, particularly in respect of energy consumption in various stages of the product's manufacturing. Considering its demand, Central Pollution Control Board (CPCB) sponsored a study to CIPET on Life

Cycle Assessment (LCA) of plastic packaging products to address various issues which triggers over riding concerns due to the use of plastics, in place of other materials. In this study, an effort has been made to adopt an approach to find out the various types of inputs/outputs energy data within the scope of specific boundary system of various packaging products like plastics, Polyethylene (PE),Polypropylene(PP) and Polyethylene Terephthalate (PET), glass, jute, woven sacks, paper and bio-degradable (compostable) products. The various data collected both by theoretical and practical studies of the product have been analyzed to find out their greenhouse effect in the environment. Based on the single point data on carbon equivalent of all the products within the scope of specific boundary limit, the greenhouse effect of the product studied are compared and recommendations for use of products are given.

The LCA assessment methodology is applied to determine the environmental impact categories associated life cycle, focusing on packaging decisions. The proposed analysis identifies the greatest environmental stressors on the supply chain, thereby supporting strategic and operative decisions towards more efficient and environmentally-friendly operations management and packaging choices.The LCA study includes the requirements of upstream processing energy (feed stock energy) of raw materials, process energy of the product from the materials, energy for use of products in which transport energy is combined and energy for disposal or recycling/composting/incineration/land filling at the end of the life as per boundary condition defined in fig.3of this report.

In this study, IPCC (International Panel on Climate Change), 2007approach has been used to translate the greenhouse gas emission generated by the life cycle scenarios into a single foot print. The approach is based on the principle of total/cumulative CO_2 equivalent for manufacturing the product in a boundary system (cumulative energy in the boundary system in terms of CO_2 equivalent + cumulative greenhouse gas emitted in terms of CO_2 equivalent) which causes global warming.

Special mention here is made that LCA results are based on the experimental data (emission data at various manufacturing sites) of products and various theoretical data collected from the literature. Since data related to energy requirement for various stages are not available, the total (cumulative) energy has been arrived based on the following assumptions.

1. Process energy of the product is calculated as 50 to 80% of the Gross Energy Demand (GED) which is sum of feed stock and process energy. [60,63]

2. Recycling energy is taken as 10 to 20% of the feed stock energy.
3. Use energy which includes also transport energy is taken as 5 – 10% of the feed stock energy.

<u>Note:</u> The percentage of energy required for different products in different stages of manufacturing are not same and vary depending on the size and type of products.

The study considered the cradle to grave life cycle of seven products. They were of various size and weight, but the data taken for calculation of each category of bags (both for CO_2 equivalent and energy conservation) is based on per kg material or products. According to the study it is found that **LCA of PLA**(Poly Lactic Acid)**has lowest greenhouse pollution**. LDPE has slightly higher LCA value than PP but all these plastics have lower LCA value than paper, woven sacks and jute. The glass has been the lowest, almost same as LCA like PP, but its use has been although been in certain cases encouraging because of hygienic characteristics of glass but not being practically competitive and attractive in comparison with plastics.

The merits and demerits of paper, jute and woven sacks have been discussed in detail in the report. Although, the value of LCA for glass is almost similar as PP and other plastic products, among the PLA it shows advantages compared to PP and PET in the categories of fossil resource consumption, global warming and summer smog. Considering the various merits of the PLA as discussed in the study in the light of the global warming potential due to CO_2 emission it can be concluded that PLA could be a better packaging material because it is renewable.

1. Introduction

Life Cycle Assessment (LCA) is a process to assess the potential environmental burden associated with a product, a process or an activity. Characteristics parts in a LCA are identifying and quantifying of energy flows and material flows and evaluating the environmental impacts that are associated with these flows. The assessments normally include the entire life cycle of the studied system (the studied system can be a product, a process or an activity) including material and energy raw ware acquisition, manufacture use and disposal/waste management. In LCA the environmental problem is more associated with the product from "the cradle to the grave", thus adding together all environmental burdens that are associated with the studied product during its whole life cycle or life time (figure 1)

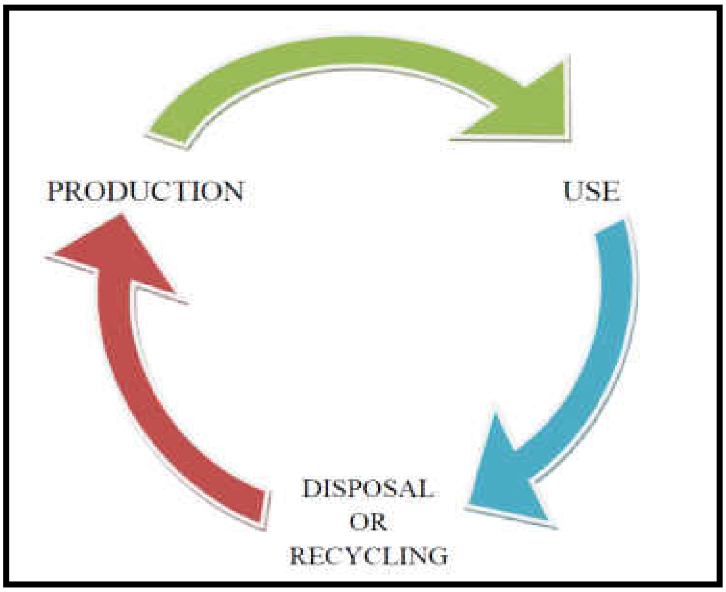


Figure1: Life cycle of product

LCA – which was originally known as Life Cycle Analysis is now meant for Life Cycle Assessment as per ISO: 14040

The LCA methodology studies how the observed system affects the environment and natural resources, thereby supporting system improvements and strengthening more sustainable strategies. Many recent studies apply the LCA approach and provide guidelines to elicit pro-environment actions in the food and beverage industry. Nowadays, world population has been increased rapidly especially in developing country like Malaysia. The rapid growth of population in a country has contributed to high production of waste. Municipal waste and industrial waste can bring unhealthy and unpleasant environment or even diseases to human being if the wastes are not managed properly.

One of the methods to reduce the production of waste is by understanding the Life Cycle Assessment of the products itself. Basically, Life Cycle Assessment is not a tool to reduce the production of waste. Instead, by conducting a Life Cycle Assessment, the researcher can be more understand on the environmental attributes of a product from raw materials to landfill disposal or recycle as a new product, across its entire life.

In this case, plastic is thoroughly investigated material because plastic waste is one of the components in municipal solid waste management. Besides, this is because there is least past research discussing on Life Cycle Assessment of plastics production. In addition, plastics are predominantly employed in packaging, construction and consumer products. The first commercial plastics were developed over one hundred years ago. Now plastics have not only replaced many wood, leather, paper, metal, glass and natural fiber products in many applications, but also have facilitated the development of entirely new types of products. The plastic fraction in municipal solid waste consists mainly of polyethylene (PE), polyethylene Terephthalate (PET), polyvinyl chloride (PVC), polypropylene (PP) and polystyrene (PS). Different types of plastics will perform differently in the environment, e.g. polyvinyl chloride (PVC) has caused concern because of their potential to cause environmental harms.

Plastic products are durable, which although having functional benefits, can cause problems at the end of products lives. As plastics have found more markets, the amounts of plastic produced become increases. This phenomenal growth was caused by the desirable properties of plastics and their adaptability to low-cost manufacturing techniques. The life cycle of plastic products includes production, transportation, use and disposal which have contributed to the release of waste emissions. This results in toxins existing in the water, air and food chain, bringing the people around the polluted area severe health problems. Recently, environmental groups are voicing serious concern about the possible damaging impact of plastics on the environmental. Plastic products and materials eventually contribute to the solid waste stream. Over the past 20 years, environmental issues have gained greater public recognition. Production, use and disposal of virtually all goods present potential health and environmental impacts. The general public has become more aware that consumption of manufacturing products and marketed services, as well as daily activities of our society, adversely

affects supplies of natural resources and the quality of the environment. These effects occur at all stages of the Life Cycle of a product, beginning with raw material acquisition and continuing through material manufacture and product fabrication. Plastic Waste management options such as composting, bio-gasification, incineration, burning, land filling and recycling.

Evolution of life cycle Assessment – Life cycle assessment (LCA) is a tool to evaluate the environmental effects of a product or process through its entire life cycle. The first attempt to look at extended product systems can be traced back to as early as the 1960s. This work mainly focused on calculating energy requirements.

An LCA entails examining the product from the extraction of raw material for the manufacturing process, through the production and use of the item to its final disposal and thus encompassing the entire production and of the item, to its final disposal, and thus encompassing the entire product system. Modern LCA methodology is rooted in the development of standards through the 1990s. The society for Environmental Toxicology and Chemistry (1991) published “A Technical Framework for Life Cycle Assessment,” the first attempt at an international LCA standard. It explicitly outlined the components of contemporary LCA: goal definition, inventory assessment, impact assessment and improvement analysis. By extending LCA beyond the mere quantification of material and energy flows, SETAC paved the way for the use of LCA as a comprehensive decision support tool. Similar developments took place sometime later in North Europe, particularly in the Scandinavia. In 1995, detailed LCA protocols were specified in the “Nordic Guidelines on Life Cycle Assessments” (Nordic Council of Ministers, 1995).

International Standards Organisation (ISO) – The ISO 14040 series Based on the work carried out by the Society for Environmental Toxicology and Chemistry (SETAC), the ISO has further developed and has managed to reach agreement among its global membership on a series of standards: the ISO 14040 series on Life Cycle Assessment. These ISO 14040 series are listed as below:

(a) ISO 14040 Environmental Management –Life Cycle Assessment –Principles and Framework (ISO, 1997).

(b) ISO 14041 Environmental Management –Life Cycle Assessment –Goals and Scope Definition and Life Cycle Inventory Analysis (ISO, 1998).

(c) ISO 14040 Environmental Management –Life Cycle Assessment –Life Cycle Impact Assessment (ISO/FDIS, 1999).

Plastic: -According to Central Pollution Control Board is define to means material which contains as an essential ingredient a high polymer such as Polyethylene Terephthalate, high density Polyethylene, Vinyl, low density Polyethylene, Polypropylene, Polystyrene resins, multi-materials like Acrylonitrile Butadiene Styrene (ABS), Polyphenyleneoxide, Polycarbonate, Polybutylene Terephthalate.

Types of Plastic

PET (Polyethylene Terephthalate) is an aromatic polyester (because it contains both carboxylic and benzene groups). It is prepared in a reaction between ethylene glycol and either Terephthalic acid or the dimethyl ester of Terephthalic acid.

PVC is made from oil and salt. The oil is 'cracked' to produce ethylene, and the salt is processed to produce chlorine. The two products are then combined to produce ethylene dichloride, which isfurther processed to produce the monomer vinyl chloride. This is then polymerised to make polyvinyl chloride (PVC). PVC is thermally unstable, so stabilisers and lubricants are added in a compounding process. This produces rigid PVC (often referred to as unplasticized PVC or PVC-U). Flexible PVC is made with the addition of plasticisers.

Polypropylene is made by polymerising Propylene. There are three main types of processes; for example, in the gas-phase process Propylene is dried over aluminium oxide and polymerised in a gas-phase reactor using a catalyst and activator. The polypropylene powder is separated using nitrogen, isopropyl alcohol and steam.

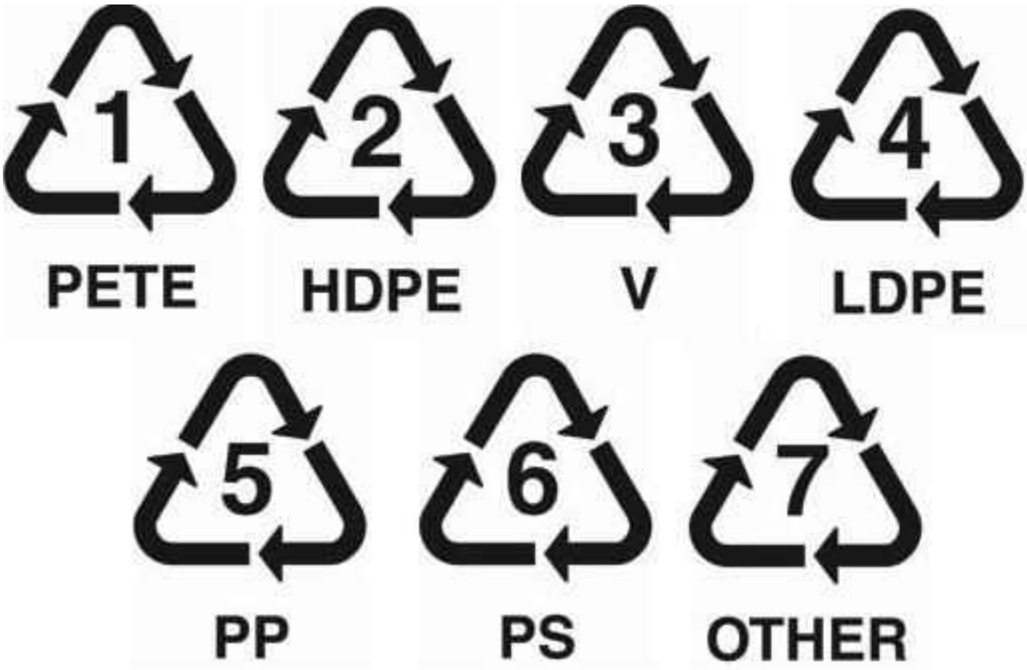
Polystyrene (Styrofoam): Polystyrene is formed by styrene molecules. The double bond between the CH_2 and CH parts of the molecule rearranges to form a bond with adjacent styrene molecules, thereby producing polystyrene. It can form a hard impact-resistant plastic for furniture, cabinets (for computer monitors and TVs), glasses and utensils.

Polypropylene (PP): In 1953, Karl Ziegler and Giulio Natta, working independently, prepared polypropylene from propylene monomers (CH_2=$CHCH_3$) and received the Nobel Prize in Chemistry in 1963. The various forms of polypropylene have different melting points and harnesses. Polypropylene is used in car trim, battery cases, bottles, tubes, filaments and bags.

Polyethylene, LDPE and HDPE: The most common polymer in plastics is polyethylene, which is made from ethylene monomers (CH_2=CH_2). The first polyethylene was made in 1934. Today, we call it low-density polyethylene (LDPE) because it will float in a mixture of alcohol and water. In LDPE, the polymer strands are entangled and loosely organized, so it's soft and flexible. It was first used to insulate electrical wires, but today it's used in films, wraps, bottles, disposable gloves and garbage bags.

In the 1950s, Karl Ziegler polymerized ethylene in the presence of various metals. The resulting polyethylene polymer was composed of mostly linear polymers. This linear form produced tighter, denser, more organized structures and is now called high-density polyethylene (HDPE). HDPE is a harder plastic with a higher melting point than LDPE, and it sinks in an alcohol-water mixture. HDPE was first introduced in the hula hoop, but today it's mostly used in containers.

Marking or Labelling



TYPES OF PLASTIC

Type of plastic	Main applications
Thermoplastics	
High-density polyethylene	Containers, toys, house wares, industrial wrapping and film, gas pipes.
Low-density polyethylene	Film, bags, toys, coatings, containers, pipes, cable insulation.
PET	Bottles, film, food packaging, synthetic insulation.
Polypropylene	Film, battery cases, microwave containers, crates, car parts, electrical components.
Polystyrene	Electrical appliances, thermal insulation, tape cassettes, cups, plates.
PVC	Window frames, pipes, flooring, wallpaper, bottles, cling film, toys, guttering, cable insulation, credit cards, medical products.
Polymethyl methacrylate (PMMA)	General appliance mouldings.
Polyamide	Films for packaging of foods such as oil,

	cheese and boil-in-the-bag products and for high temperature engineering applications.
ABS/SAN	Transparent all-weather sheet, electrical insulators, domestic appliances.
Thermosetting Plastics	
Epoxy resins	Adhesives, car components, components, sports equipment's, boats.
Polyurethane	Adhesives, appliances, car parts, electrical components, trainer soles, furniture foam.
Phenolic (phenol formaldehyde, urea formaldehyde)	Adhesives, appliances, car parts, electrical.
Furan resins	Manufacture of sustainable bio composite construction, cements, adhesives, coatings and casting/foundry resins.

Properties of Plastics and their Advantages

Property	**Examples**
Low cost	Can be cheaper than natural materials, for example, PET replacing feather down
Lightweight	Plastics are lighter than many conventional materials. For example, a paper carrier bag weighs roughly six times as much as a plastic carrier bag. A 1 litre plastic bottle for oil weighs only seven per cent of the equivalent glass bottle. This leads to reduced fuel consumption and transport costs
Durability	Greater durability of plastics in some applications compared with other materials such as metal, wood and glass is often a consequence of factors such as greater resistance to corrosion, strength and impermeability to water
High strength	Greater strength-to-weight ratio of many plastics compared to other materials means that less material is required. For example, use of polyamides in bullet-proof vests

Manufacturing versatility	Different plastic component parts can be integrated easily within a single product, which reduces processing and assembly costs. For example, a one-piece PVC window frame
Colour	Colour can be varied easily at the processing stage
Good thermal insulator	Polystyrene in building insulation
Low permeability to oxygen	PVC wrap to protect food, such as red meat, from exposure to the air
Impermeability to water	PVC waterproof flooring and coverings
Heat resistance	Polypropylene containers are a lightweight, low-cost alternative to glass, for example in use in microwaves
Electrical resistance	PVC and polypropylene wire and cable insulation
Corrosion resistance	Use of plastics in the building industry and car manufacture

Disadvantage of Plastic

Property	Explanation
Environmental Damage	A single plastic bag can take up to 1000 years, to decay completely
Threat To Animal Life	It has also been found to be responsible for the death of many animals, mainly on account of the suffocation encountered on eating them.
Suffocation	Not only animals, infants and young children have also been reported to have lost their life, on account of plastic bags.
Pollution	Plastic bags are not bio-degradable, the only way to get rid of them is to burn them up, causes water and land

	pollution
Non-renewable	The reason behind this is that they are made of petrochemicals, a non-renewable source of energy.
Disposal	Degradation of soil quality
Burning	It's cause's air pollution
Chemical Risk	they also interfere with our natural hormone levels which can cause serious problems to both males and females

1.1 Importance of LCA

The importance of LCA studies are summarized below: -

- It stops the problem of shifting environmental impacts.
- It can help to minimize secondary effects if used in conjunction with design.
- It can help to reduce environmental pollution and use of resources.
- It enables understanding of true and total costs (money and environment friendly manufacture and design).
- Use of environmental management, including LCA can often improve profitability.

1.2 Guidelines

The following guidelines are used for LCA study.

- ISO 14040:2006 outlining LCA principles and frame work.
- ISO 14044:2006 for requirements and guidelines.

1.3 Scope of LCA or LCA: Assessment Framework

In LCA study, it is difficult to consider all social, economic and environmental issues in a short period of time. However, considering environmental aspects of sustainability alone is possible and in the scope of this study. In this study the impact on environment of a product or system is basically focused or determined.

1.4 Stages of LCA

The LCA of a product is studied systematically as per the following steps.

- Goal scoping
- Inventory

- Impact Assessment
- Classification
- Characterization
- Normalization
- Valuation
- Improvement Assessment – interpretation.

2. Objective

The study has the following objectives.

a) To provide a comprehensive environmental model for production, usage and disposal of plastic packaging product by using the methodology of Life Cycle Assessment (LCA).
b) To produce life cycle data for packaging products (woven sack, plastic bottles, milk pouches, shopping bags) in terms of raw material energy demand & effect on pollution level (air & water pollution), usage, recycling reuse and final disposal.
c) Comparing the life cycle data of jute, paper, glass bottle, paper bags and also with compostable packaging material {PLA, a starch based (100% bio-based) packaging material}.

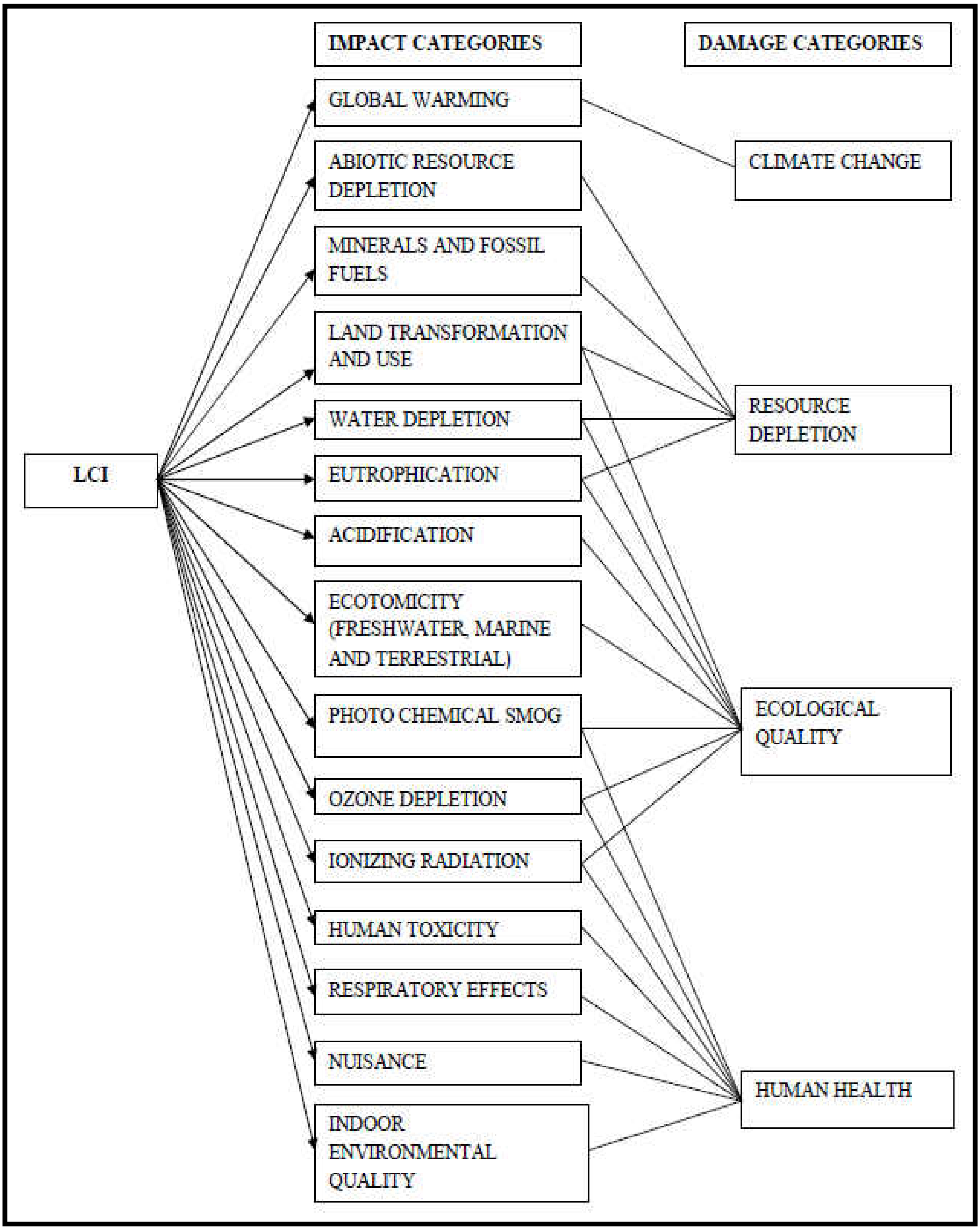


Figure 2: Life Cycle Impact of products

3. Defining the Scope

Since LCA is a multi-input and multi-output process, it is essential to know the relations between the studied product or material and each emission actually caused by it. Sometimes it is necessary to know the relationship between change in emission and change in composition. Sometimes it is not possible to measure emissions from certain products. Whatever may be the situation in order to define the scope of the study of LCA of a product, one should be aware of life cycle impact of the products (Figure. 2). In Life Cycle Inventory (LCI) and Life Cycle Assessments (LCA) usually a large number of ecological parameters are analyzed to evaluate and to compare process chain. Before LCI and LCA became common, comparable studies were conducted which focused on energy as the only parameter. These studies are often referred to as energy analysis. Here the input of primary energy to manufacture a good or to provide a service from all the required resources is determined. Energy analysis allows an initial estimate concerning the ecological burden especially if derived entities (energy related emissions) are calculated.

For comprehensive LCAs a large amount of data is needed and consequently a large effort is required in data acquisition. In other words, if the system studied is an extensive one or if little information is available, an energy analysis may be an appropriate approach to achieve initial insight into the environmental impacts. Taking into consideration of critical approach of LCA defining the scope of LCA in a specific model or boundary system for studying the comprehensive LCA of a product is essential.

Since the resources of plastics material are petrochemicals and no major damage impact of plastics material taken under the study (PET, PE & bio-degradable plastics) has shown except in global warming effect the scope of LCA study for these materials has been confined to energy consumed for production of these materials and the emissions related to global warming. According to IPCC (Inter-Governmental Panel on Climate Change), the emission of the following six in house gases are responsible for major climate change.

a. Carbon dioxide CO_2
b. Methane CH_4
c. Nitrous oxide N_2O
d. Perfluoro Carbon PFC

e. Sulphur Hexafluoride SF
f. Hydrofluoro carbons HFC.
g. Chlorofluorocarbons CFC

It has been observed that the above mentioned gases are mainly originated from the various industrial processes. Therefore, considering the impact of the processes of the plastics in the environment is shown in the Table 1.

The scope of LCA study has been considered as per the boundary system defined in figure 3. Following the same boundary system, LCA of other materials or products have also been studied. The energy consumed in the production & recycling or disposal of products and their corresponding CO_2 equivalent are given in Table 2, based on literature. However, in addition to the emissions of CO_2 and CH_4 which mainly come from plastics processing the emissions of other gases like N_2O, SO_2 and VOC are also taken into consideration for LCA study of the products (wherever the data is available).

Table 1: Sources of emissions

PROCESS		EMISSION					
		CO_2	CH_4	NO_2	PFC	SFC	HFC
MINERAL PRODUCTS	Cement Production						
	Lime Production	■					
	Life Store Used	■					
	Soda ash Production & Use	■					
	Fletton Brick Manufacture	■	■				
CHEMICAL INDUSTRY	Ammonia	■	■				
	Nitric acid			■			
	Adipic acid			■			
	Urea			■			
	Carbide	■	■				
	Caprolactam			■			
	Petrochemical		■				
METAL PRODUCTION	Iron, Steel & Ferrous alloys	■	■				
	Aluminum	■			■		
	Magnesium					■	■
	Other metal	■					
ENERGY INDUSTRY	Coal Mining		■				
	Solid Fuel Transformation	■					
	Oil Production	■	■				
	Gas Production & Distribution	■	■				
	Venting/Flaring from oil/gas production	■	■				
OTHERS	Production of Halo carbons				■		■
	Use of Halocarbon & SF_6				■	■	■
	Organic Waste management		■				

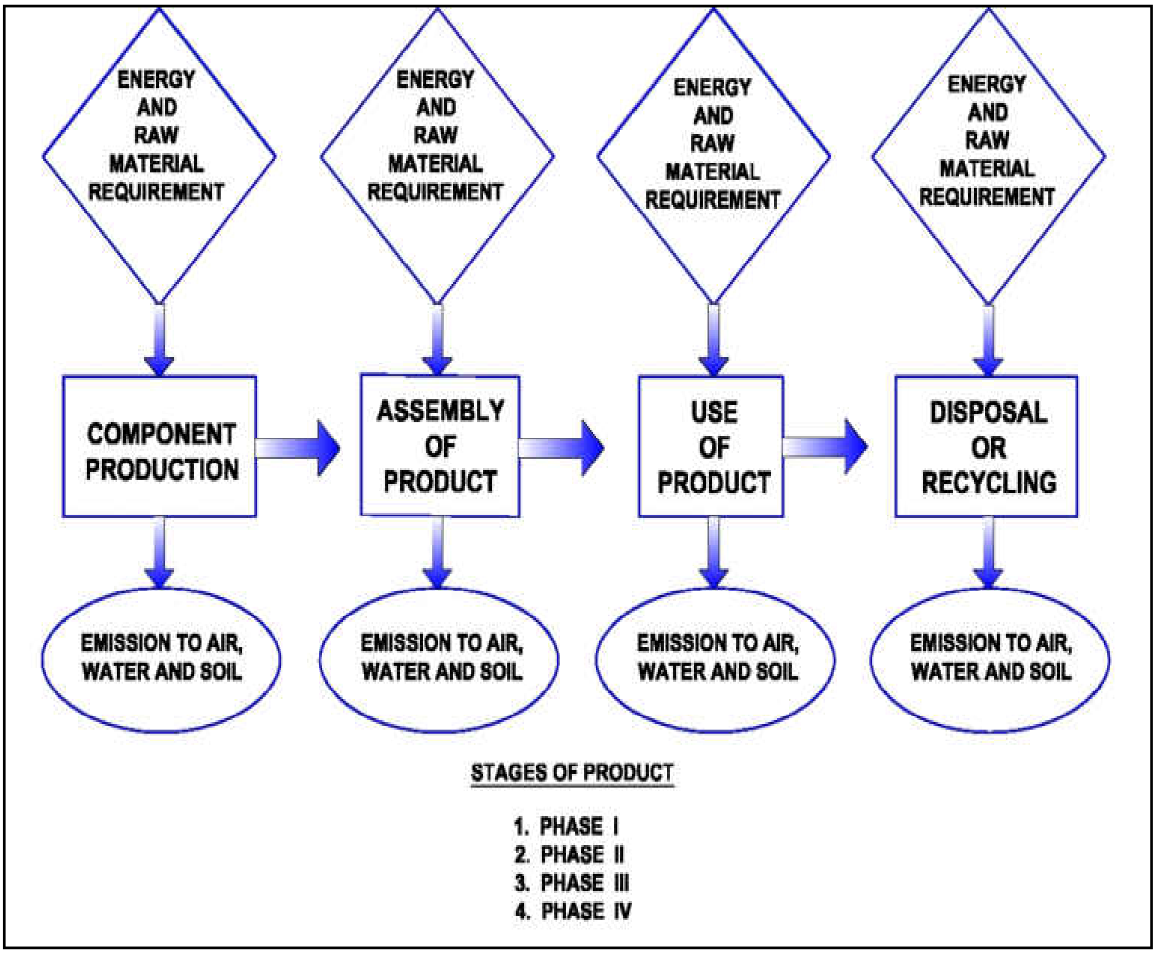


Figure 3: Consideration of emission in various stages of product

Table 2: Energy consumed in production and recycling or disposal of products and CO_2equivalent.

S. No.	Stage of Products	Energy (GJ/Ton)	$KgCO_2$ equivalent/ Ton
	Glass		
1	Extraction of sand and other raw material	21.5	**5.1**
2	Refining of Raw material		
3	Manufacturing of Glass	61.0	
4	Total	82.5	
	Paper (Craft Paper)		
1	Fetching and chopping of trees	50.9	**30.2**
2	Grinding, Pulping and Bleaching		
3	Bleached Paper Production		
4	Recycling of Paper	17.7	
5	Total	68.6	
	LDPE Films		
1	Extraction & Raw material, Polymerization,	80.0	**2.76**
2	Resin Manufacturing, Polymer Granulation		
3	Manufacturing Plastic Product		
4	Recycling	25.0	
5	Total	105.0	
	PET Film		
1	Raw Material	81.0	**3.4**
2	Polymer Granules		
3	Manufacturing PET Product		
4	Recycling of PET	19.1	
5	Total	100.1	
	PLA		
1	Raw Material	59.0	**1.8**
2	Polymer Granules		
3	Manufacturing of PLA Product		
4	Recycling of PLA	13.0	
5	Total	72.0	

4. **Impact and classification, inventory data and inventory indicator**

Life Cycle Assessment (LCA) -Life Cycle Assessment (LCA) is the science of measuring the environmental impact of products and services over their entire life cycle from cradle to grave.

A Life Cycle Assessment model is actually at least three different models.

1. A techno-sphere input-output models that describe the human activities in extracting, modifying, discarding and using energy and materials.
2. An emissions and resource model that estimates resource degradation and pollution emissions linked to the techno-sphere model, for example the emissions of air pollutants from burning a certain amount of fossil fuel in a boiler.
3. An environmental impact model that uses the resource and emission model outputs to estimate the impacts on the environment and the economy. The classic example is that of global climate change which is modeled in accordance with the work of the Intergovernmental Panel on Climate Change, yielding units of CO_2 equivalents.

All of the outputs of these models are expressed relevant to the functional unit of the product in question, for example covering a square meter of floor for 30 years, or delivering 1 kWh of energy to the point of use. The use of a functional unit is what allows LCAs to provide the environmental results to the user in terms that are relevant to the user.

A carbon footprint is a kind of LCA that only reports Climate Change impacts. Normally LCA covers all relevant impact categories, and it is therefore known as the holistic yardstick of environmental performance. Life Cycle impact assessment results are indicators of impacts, not measurements of actual impacts on the environment. For example, LCA does not measure the loss of particular ecosystems, besides LCA provides indicators of aggregate losses in all ecosystems across the life cycle.

Table 3: Classification of Inventory Data according to selected impact categories and Inventory Indicators.

Classification of Impact Categories	Inventory Data	Inventory Indicators
Cumulative energy demand (CED)	Fossil, Nuclear, Renewable	MJ Energy Equivalent
Resource consumption	Crude Oil, Natural Gas, Brown Coal, Hard Coal etc.	Kgcrude oil equivalent
Climate Change (Global Warming)	CO_2- fossil, CH_4, N_2O, C_2F_2, CF_4, C_2F_6, CCl_4,R_{22}	kg CO_2 equivalent
Summer Smog (POCP/NCPOCP)	CH_4, NMVOC,Benzene, Formaldehyde,Ethyl Acetate,VOC, Ethanol	kg Ethane equivalent
Eutrophication	NO_X, NH_3, COD, N-compound, P-compound	kg- PO_4 equivalent
Acidification	NO_X, NH_3, SO_2, HCl, HF, H_2S	kg- SO_2 equivalent
Human Toxicity	As, Cd, Cr, Ni, Dioxin, Benzene	kg- As equivalent

NO_X = (Calculation ofNO_2) and NH_3 = terrestrial eutrophication

COD = Chemical Oxygen Demand,

N,P= Aquatic eutrophication as Chromium (VI)

VOC= Volatile Organic Compound

NMVOC= Non- Methane Volatile Organic Compound

POCP = Photochemical Ozone Creation Potential

NCPOCP= Nitrogen Corrected POCP

5. Identifying and quantifying the requirement of energy and emitted gases

In the present study two items are taken into consideration

1. Total energy consumed during the entire LCA study of selected products.
2. Green House Gas Emission.

In order to properly identify the class on the input data required in the total LCA of the products. For each product the manufacturing diagram has been given in this text. From the flow diagram, various inputs are identified and their energy is taken into consideration in various phases and also output data of the emitted gases are also measured practically wherever possible. Some data are collected theoretically where data measurement could not be made possible.

5.1 Collection of data for glass bottles

Glass bottle manufacturing process:

The complete flow diagram of manufacturing of glass bottle is shown in figure 4. Glass is produced in two step processes and then shaped to make it suitable for a variety of applications.

Step 1: Batch mixing

The mixture of ingredients (Silica, Na_2CO_3, $CaCO_3$ and recycled glass, together with small quantities of various other minor to manufacture ingredients) are mixedin a rotary mixer to ensure an even mix of ingredients and fed into the furnace.

Step 2: Batch melting

The mixture is heated to 1500-1550^oC, where the ingredients melt, various chemical reactions take place and CO_2 and SO_3 are evolved.

Shaping plate glass

The molten glass is cooled to 1000^oC in a drawing canal, and then drawn up a tower (the drawing tower) where it is pressed into the desired width and thickness, and cools to 280^oC. Individual plates of glass are snapped off at the top of the tower and further cooled before being put into storage.

Molding glass containers

Here molten glass is channeled off in fore hearths (heated channels), where it is slowly cooled to temperatures of 1100–1150^oC to increase its viscosity. Precisely weighed slugs of glass are cut off, molded with compressed air, cooled slowly in annealing (special ovens) and coated with a special spray to prevent scratching. The manufacturing process and the life cycle assessment of glass bottles is shown in figure 4.

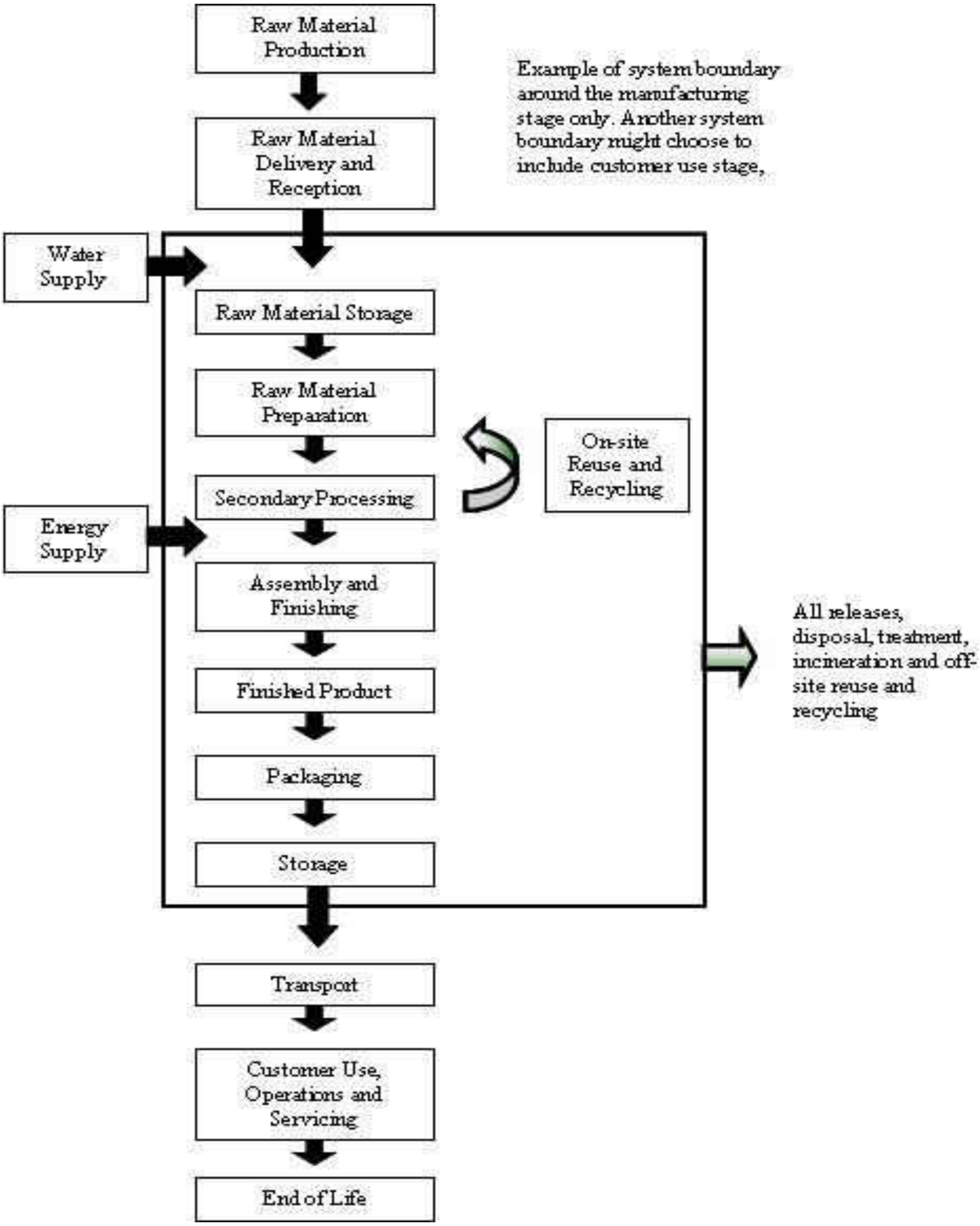


Figure 4:- Flow chart of glass bottle manufacturing.

In table 4, 5 & 6 various data are shown related to the manufacturing of glass bottles.

Table 4: Energy and water consumption during the LCA of one tone of glass bottles.

Phases (I-IV)	Energy Consumption (MJ)	Water Consumption (Ltr)
Phase I	3798	N Av.
Phase II	14799.6	35418
Phase III	11667.6	
Phase IV	10998	11310
Total	**37465.2**	**46728**

5:Emission of Gases during the Loaf one tone of glass bottles.

Phases (I-IV)	Emission of Gases (kg)										
	Responsible for Green House Effect*							Other Gases			
	CO_2	CH_4	N_2O	SF_6	HFCs	PFCs	CFCs	CO	NO_X	SO_X	Dust
Phase I	381		-	-	-	-	-	-	0.99	1.33	-
Phase II	1199		-	-	-	-	-	0.45	5.31	8.7	0.716
Phase III			-	-	-	-	-				
Phase IV	-		-	-	-	-	-	-	2.1	3.44	0.637
Total	**1580**		**-**	**-**	**-**	**-**	**-**	**0.45**	**8.4**	**13.47**	**1.353**

* Other greenhouse gases which could not be collected

Table 6: Carbon dioxide equivalents corresponding to the total energy consumed & emissions of gases during the LCA of one tone of glass bottle.

Glass Bottles	CO_2 Eqvt. (in kg)**
Energy	8325.6
CO_2	1580
Total	**9905.6**

**only CO_2 contribution to greenhouse effect has been considered.

5.2 Collection of data for Polyethylene Terephthalate(PET) Bottles

Manufacturing process:

The manufacturing of bottles from PET primary granules is done in 2 steps.

Step 1: Making of preforms by using standard types of injection molding machines.

Step 2: Blow stretch forming of bottles from preforms.

During this process, the preforms are heated to softening temperature in an infrared oven and then are moved to the stretch forming mould. Compressed air is blown through a nozzle into perform, pressing the soft material to the walls of the mould. After cooling down, the bottle is released from the mould.

The manufacturing process and the life cycle assessment of PET bottles is shown in figure 5.

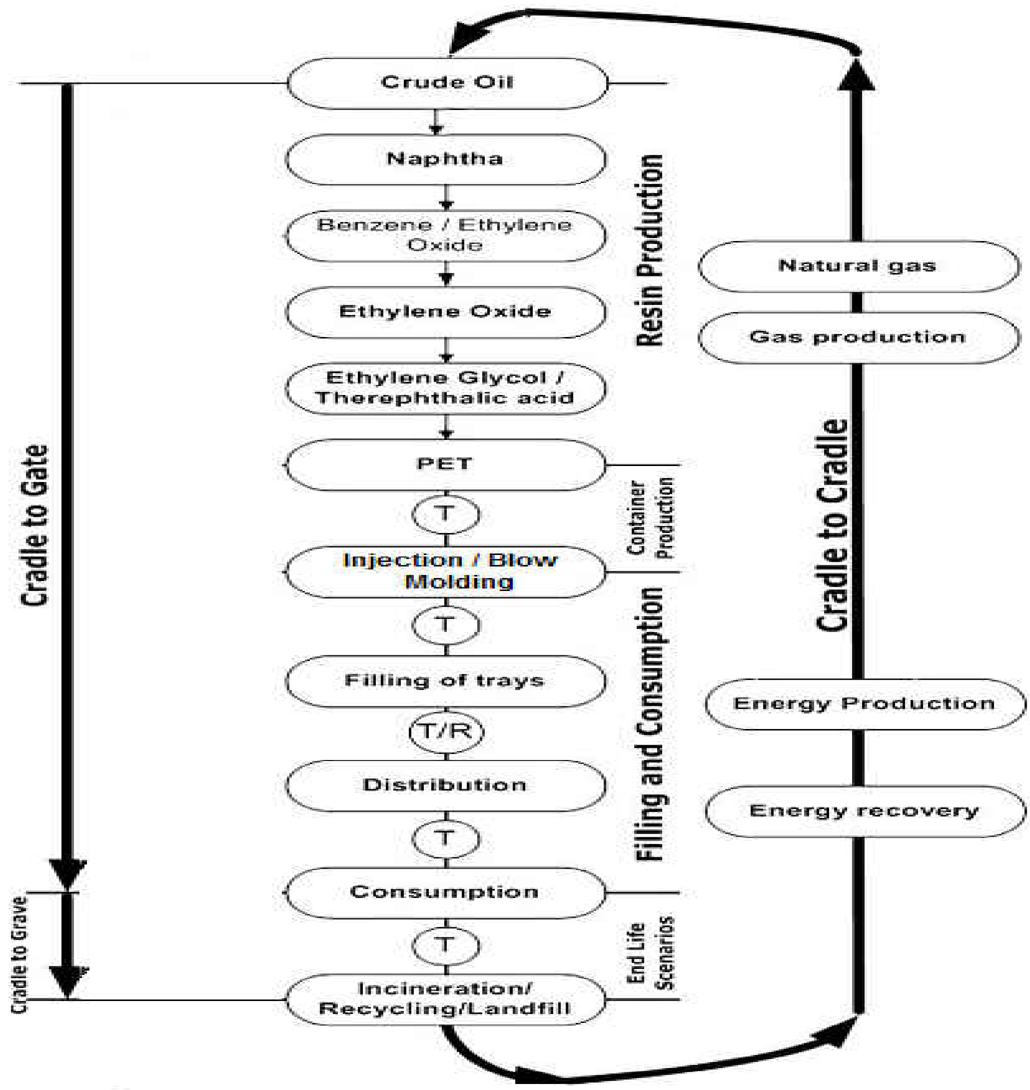


Figure 5: Flow diagram ofLCA of PET bottles.

In table 7, 8 & 9 various data are shown related to the manufacturing of PET bottles.

Table 7:Gross of Energy, Water consumption during the LCAof one tone ofPET bottles.

Phases (I-IV)	Energy Consumption (MJ)	Water Consumption (Ltr)
Phase I	17697.6	N Av.
Phase II	7765.2	7150
Phase III	914.4	200
Phase IV	5274	179
Total	**31651.2**	**7529**

Table 8: Emission of gases during the LCA of one tone ofPET bottles.

Phases (I-IV)	Emission of Gases (kg)*										
	Responsible for Green House Effect							Other Gases			
	CO_2	CH_4	N_2O	SF_6	HFCs	PFCs	CFCs	CO	NO_X	SO_X	Dust
Phase I	591	-	-	-	-	-	-	0.0003	0.0014	0.0003	0.25
Phase II	72	-	-	-	-	-	-	5.68	0.05	0.005	0.15
Phase III	150	-	-	-	-	-	-	8.2	0.39	1.02	0.15
Phase IV	188	-	-	-	-	-	-	6.3	0.119	3.53	0.16
Total	**1001**	**-**	**-**	**-**	**-**	**-**	**-**	**20.18**	**0.5604**	**4.5553**	**0.71**

*other greenhouse gases which could not be collected

Table 9: Carbon dioxide equivalents corresponding to thetotal energy consumed & emissions of gases during the LCA of one tone of PET bottle.

PET Bottles	CO_2 Eqvt. (in Kg)**
Energy	7033.6
CO_2	1001
Total	**8034.6**

** Only CO_2 contribution to greenhouse effect has been considered.

5.3 Collection of data for Milk Pouches

Figure 6shows the various steps oflife cycle assessment ofmilk pouches, which is produce from LDPE material.

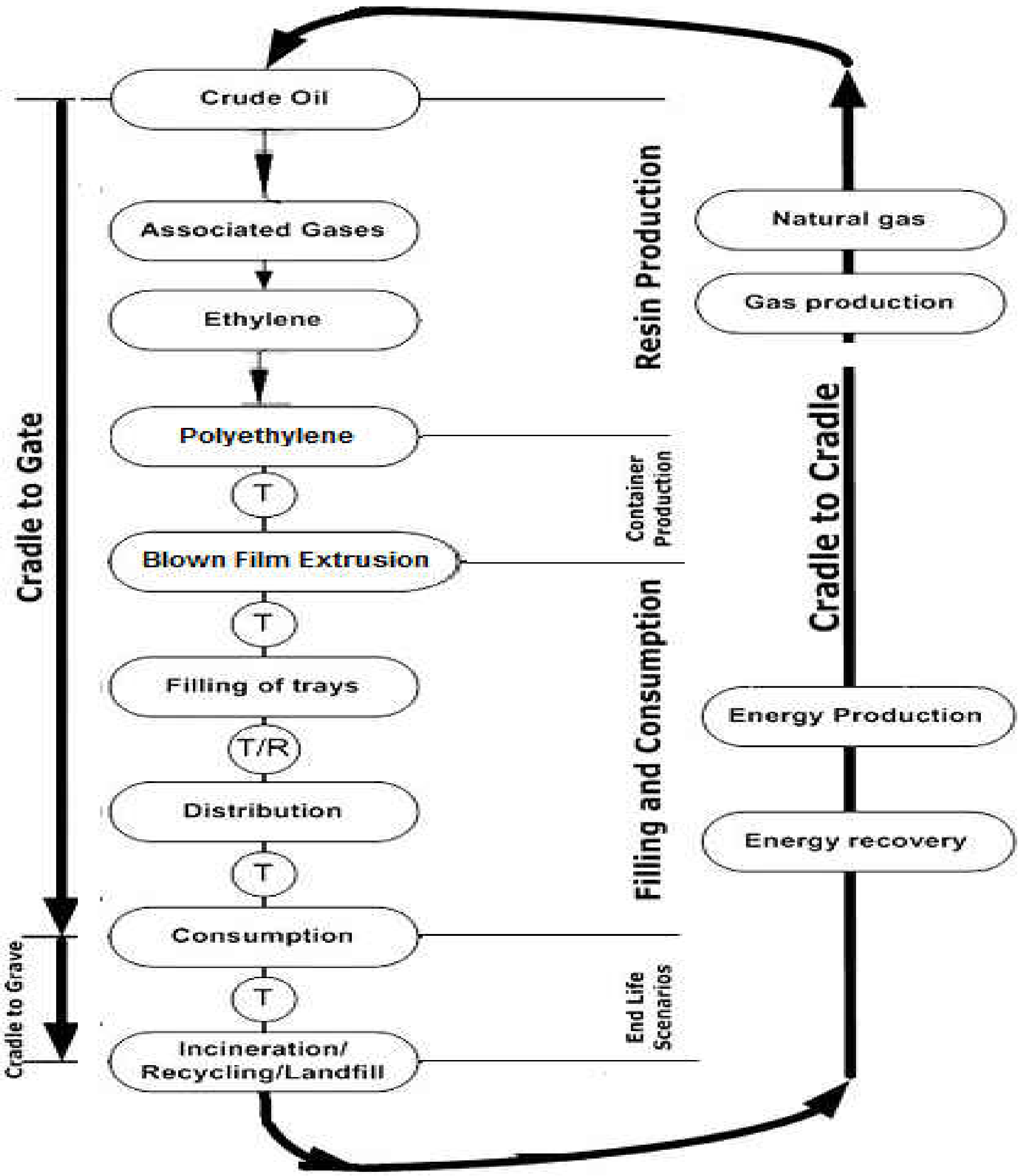


Figure 6: Flow diagram of LCA of milk pouch.

In table 10, 11, & 12 various data are shown related to the manufacturing of milk pouches.

Table 10:Energy& Water consumption during the LCA of one tone of milk pouches.

Phases (I-IV)	Energy Consumption (MJ)	Water Consumption (Ltr)
Phase I	8215.2	1627
Phase II	1526.4	501
Phase III	2304	4
Phase IV	3240	5
Total	**15285.6**	**3005**

Table 11: Emission ofgases during the LCA of one toneof milk pouches.

Phases (I-IV)	Emission of Gases (kg)*										
	Responsible for Green House Effect							Other Gases			
	CO_2	CH_4	N_2O	SF_6	HFCs	PFCs	CFCs	CO	NO_X	SO_X	Dust
Phase I	648		-	-	-	-	-	0.39	0.6	0.059	0.0093
Phase II	50.8		-	-	-	-	-	0.1	0.002	0.00016	0.01
Phase III	1.52		-	-	-	-	-	0.002	0.017	0.024	0.0028
Phase IV	2.32		-	-	-	-	-	0.005	0.02	0.026	0.0036
Total	**702.64**		**-**	**-**	**-**	**-**	**-**	**0.497**	**0.639**	**0.10916**	**0.0257**

* Other greenhouse gases which could not be collected.

Table 12: Carbon dioxide equivalents corresponding to the total energy consumed & emissions of gases during the LCA of one tone of milk pouch.

Milk Pouches	CO_2Eqvt. (in kg)**
Energy	3396.8
CO_2	702.64
Total	**4099.44**

**Only CO_2 contribution to greenhouse effect has been considered.

5.4 Collection of data for jute bags

The flow chart of manufacturing process and life cycle assessment of jutebags is shown in figure 7.

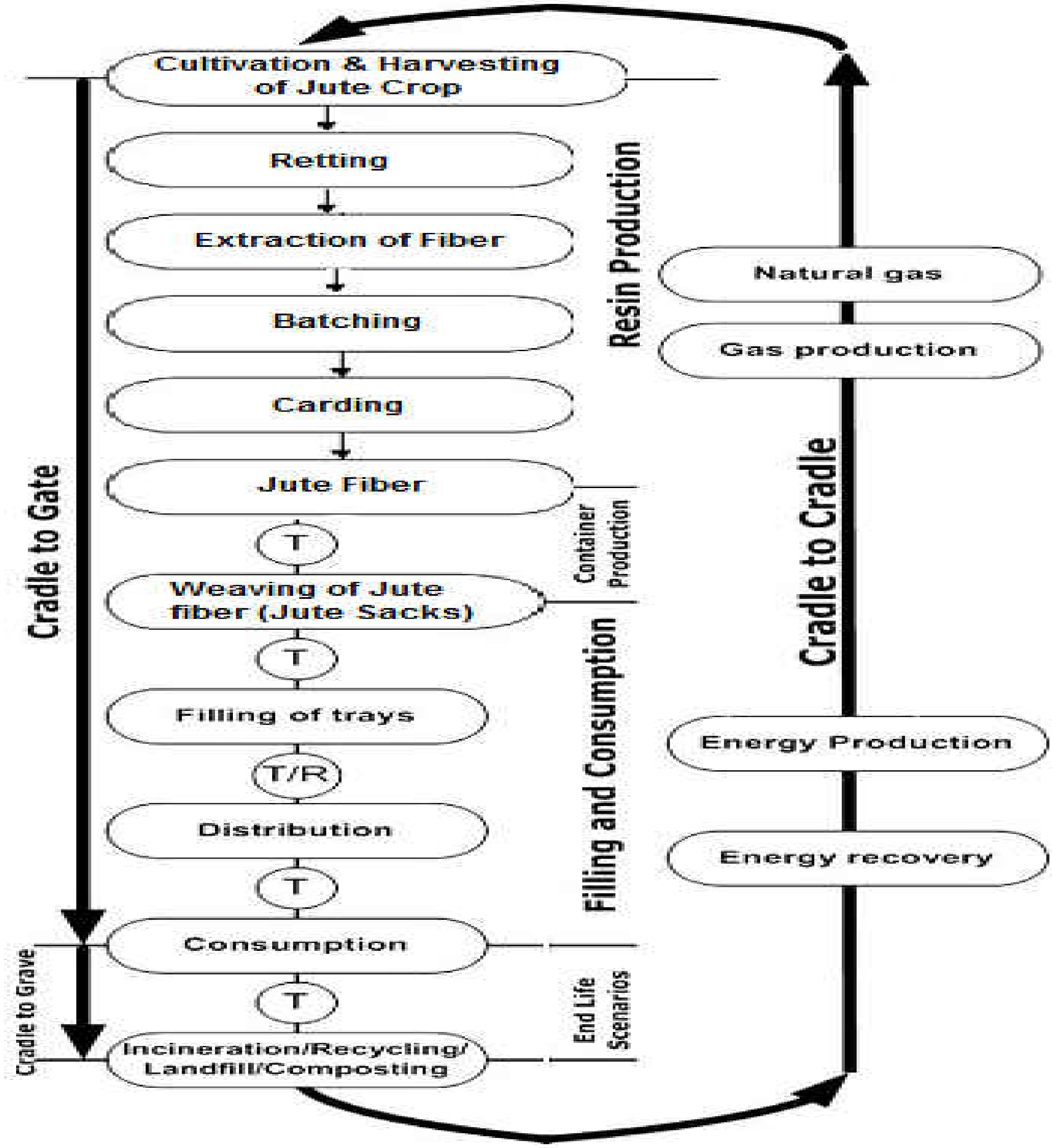


Figure 7: Flow chart of manufacturing process of jute bags.

In table 13, 14, & 15 various data are shown related to the manufacturing of Jute Bags.

Table 13: Energy & Water consumption during the LCA of one tone of jute bags.

Phases (I-IV)	Energy Consumption (MJ)	Water Consumption (Ltr)
Phase I	N.A.	N. A.
Phase II	12398.4	97640
Phase III	13968	3880
Phase IV	N.A.	NA
Total	**26366.4**	**101520**

Table 14: Emission of gases during the LCA of one tone of jute bags.

Phases (I-IV)	Emission of Gases (kg)*										
	Responsible for Green House Effect							Other Gases			
	CO_2	CH_4	N_2O	SF_6	HFCs	PFCs	CFCs	CO	NO_X	SO_X	Dust
Phase I		-	-	-	-	-	-	-	-	-	-
Phase II	6.61	-	-	-	-	-	-	0.054	0.068	0.134	0.067
Phase III		-	-	-	-	-	-				
Phase IV		-	-	-	-	-	-	-	-	-	-
Total	**6.61**	-	-	-	-	-	-	**0.054**	**0.068**	**0.134**	**0.067**

*Other greenhouse gases which could not be collected.

Table 15: CO_2 equivalents corresponding to the total energy consumed & emissions of gases during the LCA of one tone of jute bags.

Jute Bags	CO_2Eqvt. (in kg)**
Energy	5859.2
CO_2	6.6
Total	**5865.8**

**only CO_2 contribution to greenhouse effect has been considered.

5.5 Collection of Data for Polypropylene(PP) woven sacks

The manufacturing process and the life cycle assessment of woven sacks bags of Polypropylene is shown in figure 8.

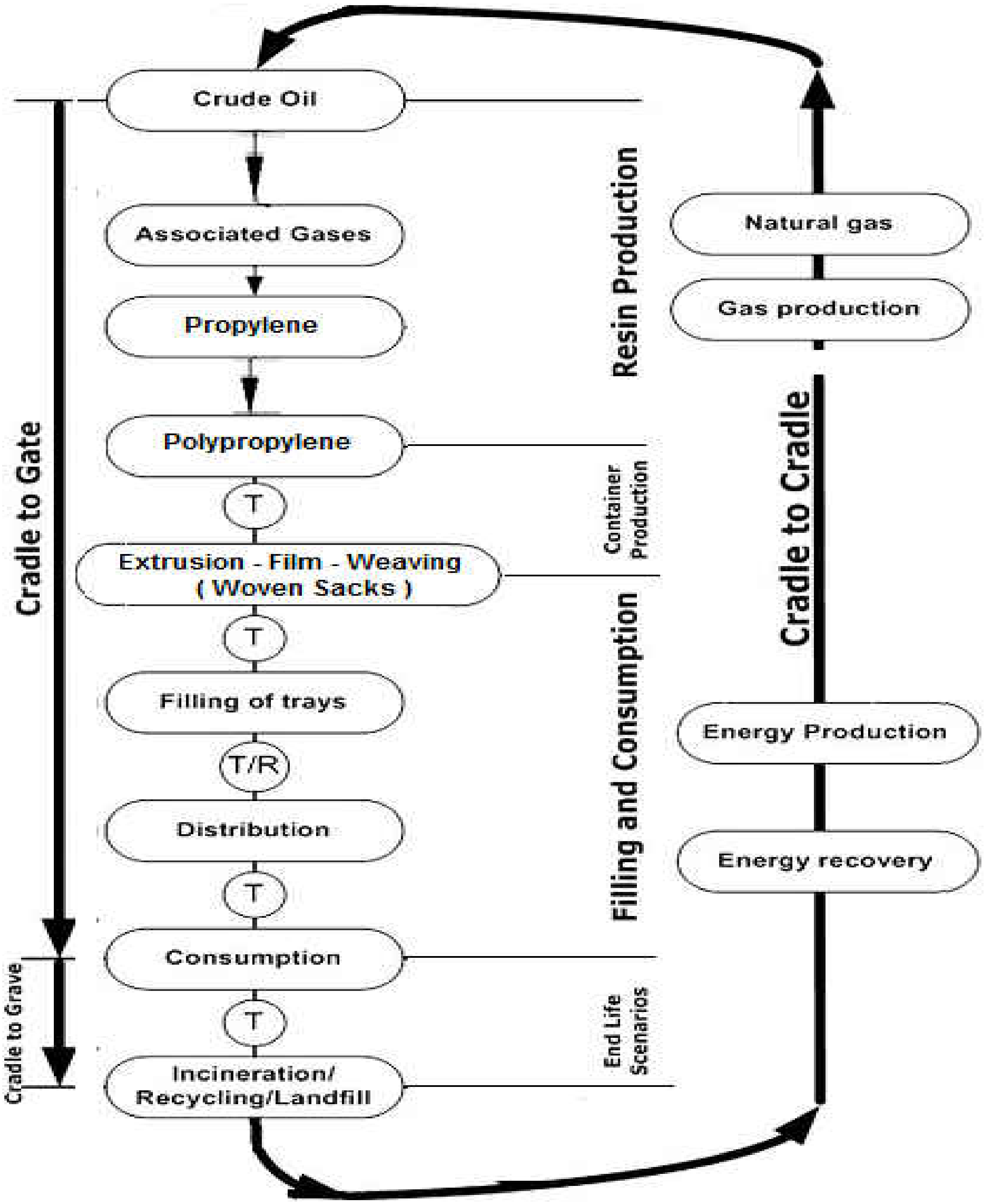


Figure 8: Flow chart of manufacturing process of PP woven sacks.

In table 16, 17, & 18 various data are shown related to the manufacturing of PP woven sacks.

Table 16: Energy &Water consumption during the LCA of one tone of PP woven sacks.

Phases (I-IV)	Energy Consumption (MJ)	Water Consumption (Ltr)
Phase I	10882.8	N.A.
Phase II	1645.2	113000
Phase III	3600	250
Phase IV	1198.8	N.A.
Total	**17326.8**	**113250**

Table 17: Emission of gases during the LCA of one tone of PP woven sacks.

Phases (I-IV)	Emission of Gases (kg)*										
	Responsible for Green House Effect							Other Gasesx10^{-6}			
	CO_2	CH_4	N_2O	SF_6	HFCs	PFCs	CFCs	CO	NO_X	SO_X	Dust
Phase I	-	-	-	-	-	-	-	-	-	-	-
Phase II	-	-	-	-	-	-	-	-	-	-	-
Phase III	-	-	-	-	-	-	-	-	-	-	-
Phase IV	-	-	-	-	-	-	-	-	-	-	-
Total	**20.82**	-	-	-	-	-	-	**0.002946**	**0.2976**	**0.024403**	**177**

*Other greenhouse gases which could not be collected.

Table 18: Carbon dioxide equivalents corresponding to the total energy consumed& emissions of gases during the LCA of one tone of PP woven sacks.

PP woven Sacks	CO_2Eqvt. (in kg)**
Energy	3850.4
CO_2	20.8
Total	**3871.2**

** Only CO_2 contribution to greenhouse effect has been considered.

5.6 Collection of data for Paper bags

Manufacturing of Paper bags

The manufacturing process and the life cycle assessment of Paper bags is shown in figure 9.

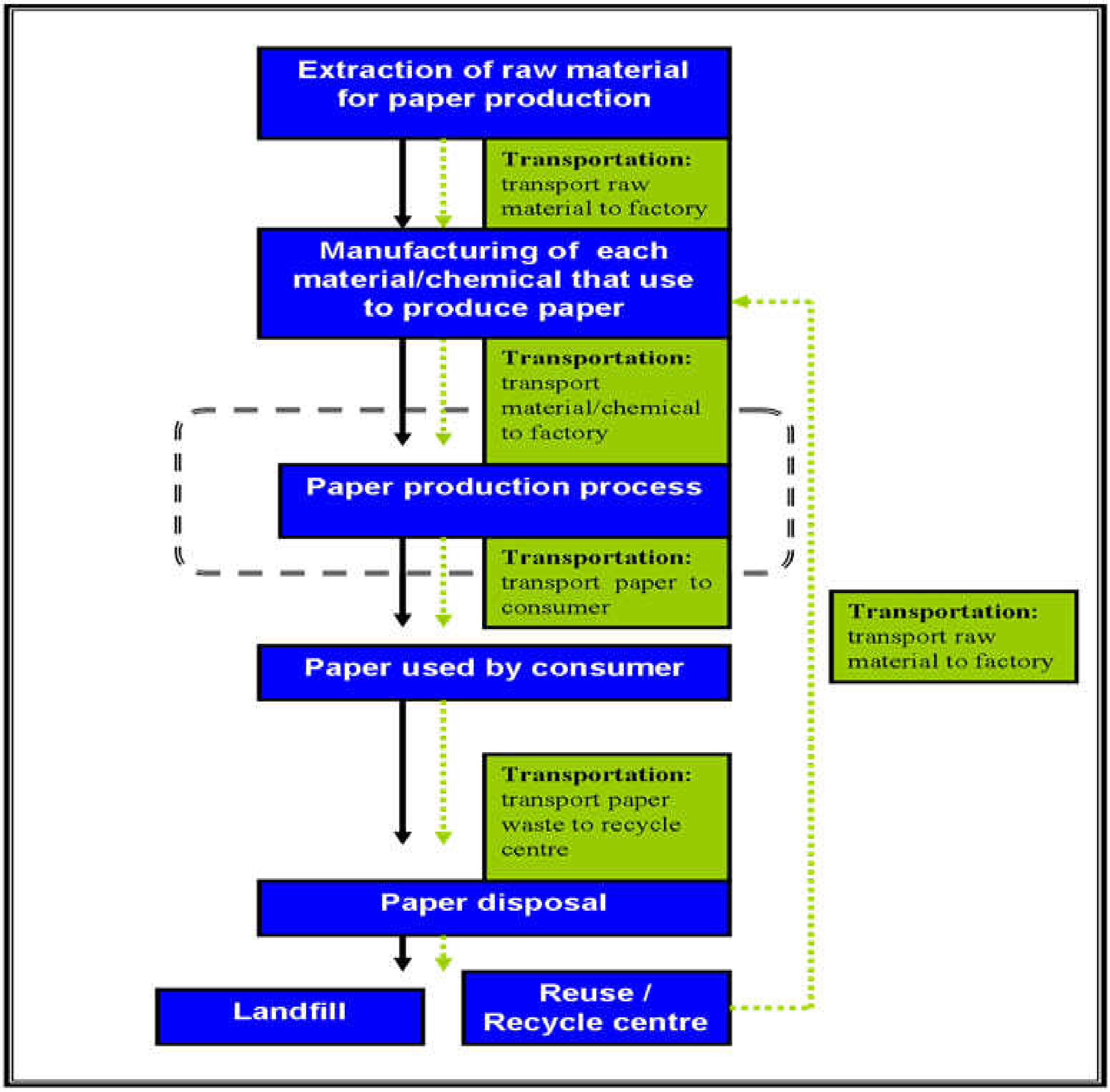


Figure 9: Flow chart for LCA of paper bag process

In table 19, 20 & 21 various data are shown related to the manufacturing of Paper bags.

Table 19: Energy &Water consumption during the LCA of one tone of paper bags.

Phases (I-IV)	Energy Consumption (MJ)	Water Consumption (Ltr)
Phase I	914.4	0
Phase II	84999.6	250000
Phase III	7992	Nil
Phase IV	4482	131000
Total	**98388**	**381000**

Table 20: Emission of gases during the LCA of one tone of paper bags.

Phases (I-IV)	Emission of Gases (kg)*										
	Responsible for Green House Effect							Other Gases			
	CO_2	CH_4	N_2O	SF_6	HFCs	PFCs	CFCs	CO	NO_X	SO_X	Dust
Phase I	-		-	-	-	-	-	-	-	-	-
Phase II	4581		-	-	-	-	-	0.2	7.09	14	5.71
Phase III	131		-	-	-	-	-	0.16	0.027	0.07	0.017
Phase IV	277		-	-	-	-	-	N.Av.	6.28	13.78	N.Av.
Total	**4989**		**-**	**-**	**-**	**-**	**-**	**0.36**	**13.397**	**27.85**	**5.727**

* Other greenhouse gases which could not be collected.

Table 21: CO_2 equivalents corresponding to the total energy consumed & emissions of gases during the LCA of one tone of paper bags.

Paper bags	CO_2 Eqvt. (in kg)**
Energy	21864
CO_2	4989
Total	**26853**

** Only CO_2 contribution to greenhouse effect has been considered.

5.7 Collection of data for high density polyethylene (HDPE) bags

Manufacturing of HDPE bags

The manufacturing process and the life cycle assessment of bags of polyethylene is shown in figure10.

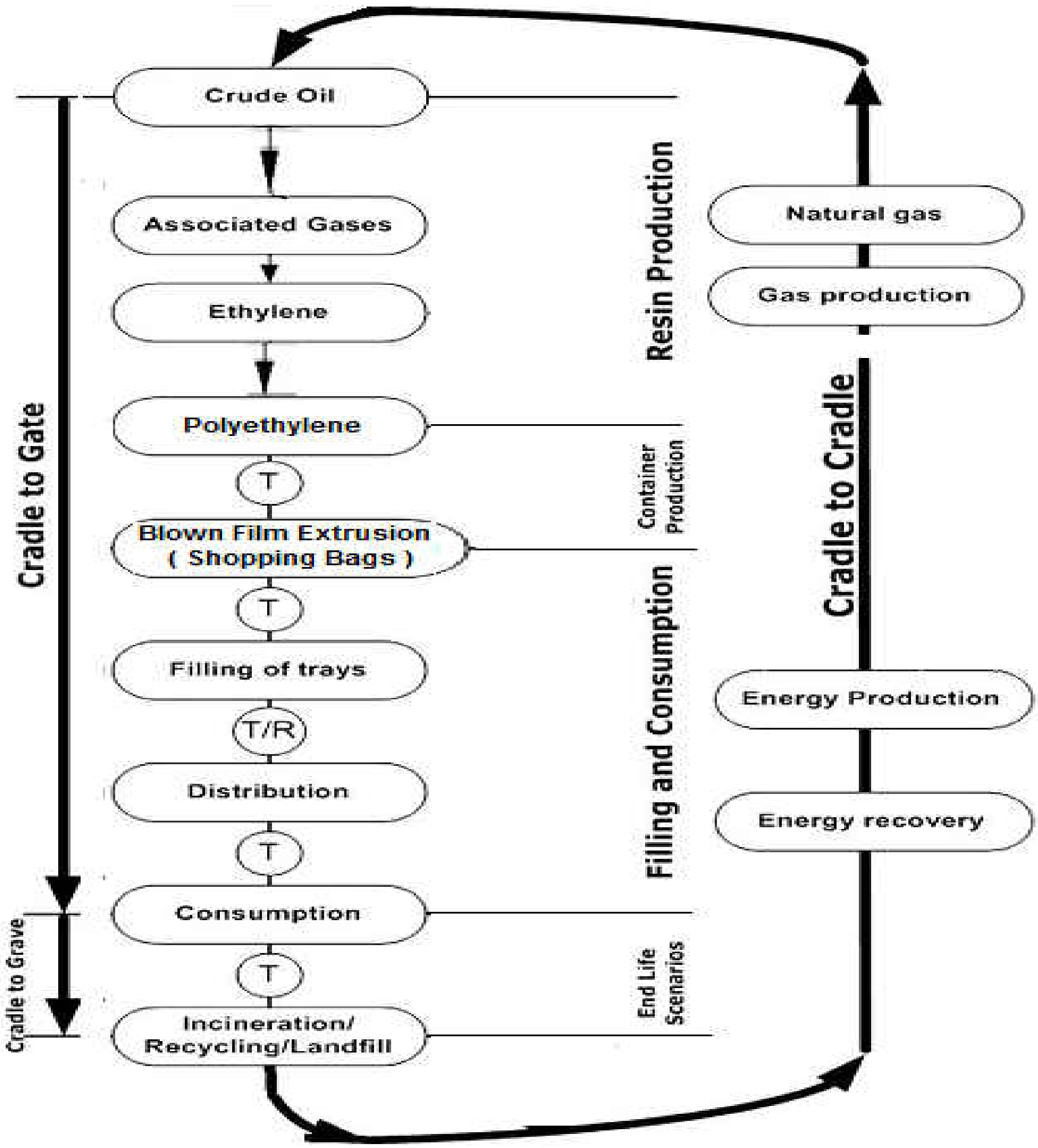


Figure 10: Flow chart for LCA of HDPE bag process

In table 22, 23 & 24 various data are shown related to the manufacturing of HDPE bags.

Table 22:Energy & Water consumption during the LCA of one tone of HDPE bags.

Phases (I-IV)	Energy Consumption (MJ)	Water Consumption (Ltr)
Phase I	8215.2	1344
Phase II	2455.2	1321
Phase III	2304	250
Phase IV	3240	400
Total	**16214.4**	**3069**

Table 23: Emission ofgases during the LCA ofone tone of HDPE bags.

Phases (I-IV)	Emission of Gases (kg)*										
	Responsible for Green House Effect							Other Gases x10^{-6}			
	CO_2	CH_4	N_2O	SF_6	HFCs	PFCs	CFCs	CO	NO_X	SO_X	Dust
Phase I	-	-	-	-	-	-	-	-	-	-	-
Phase II	-	-	-	-	-	-	-	-	-	-	-
Phase III	-	-	-	-	-	-	-	-	-	-	-
Phase IV	-	-	-	-	-	-	-	-	-	-	-
Total	**702.64**	-	-	-	-	-	-	**0.0029**	**0.2978**	**0.0244**	**177**

* Other greenhouse gases which could not be collected.

Table 24: Carbon dioxide equivalents corresponding to the total energy consumed & emissions of gases during the LCA of one tone of HDPE bags

HDPE Bags	CO_2 Eqvt. (in kg)**
Energy	3603.2
CO_2	702.64
Total	**4305.84**

** Only CO_2contribution to greenhouse effect has been considered.

5.8 Collection of Data for Paper cups

In table 25, 26 & 27 various data are shown related to the manufacturing of Paper cups.

Table 25:Energy & Water consumption during the LCAof one tone of Paper cups.

Phases (I-IV)	Energy Consumption (MJ)	Water Consumption (Ltr)
Phase I	914.4	Nil
Phase II	84999.6	250000
Phase III	3528	
Phase IV	4482	131000
Total	**93924**	**381000**

Table 26: Emission of gases during the LCA ofone tone of paper cups

Phases (I-IV)	Emission of Gases (kg)*										
	Responsible for Green House Effect							Other Gases			
	CO_2	CH_4	N_2O	SF_6	HFCs	PFCs	CFCs	CO	NO_X	SO_X	Dust
Phase I	-	-	-	-	-	-	-	-			
Phase II	4581	-	-	-	-	-	-	0.2	7.09	14	5.71
Phase III	131	-	-	-	-	-	-	0.16	0.027	10	3
Phase IV	277	-	-	-	-	-	-	-	6.28	13.78	0
Total	**4989**	-	-	-	-	-	-	**0.36**	**13.397**	**37.78**	**8.71**

* Other greenhouse gases which could not be collected.

Table 27: Carbon dioxide equivalents corresponding to the total energy consumed & emissions of gases during the LCA of one tone of Paper cups.

Paper Cup	CO_2 Eqvt. (kg)**
Energy	20872
CO_2	4989
Total	**25861**

** Only CO_2 contribution to greenhouse effect has been considered.

5.9 Collection of Data for Polypropylene (PP) cups

Manufacturing ofPP cups

The manufacturing process and the life cycle assessment of Polypropylene cups is shown in figure 11.

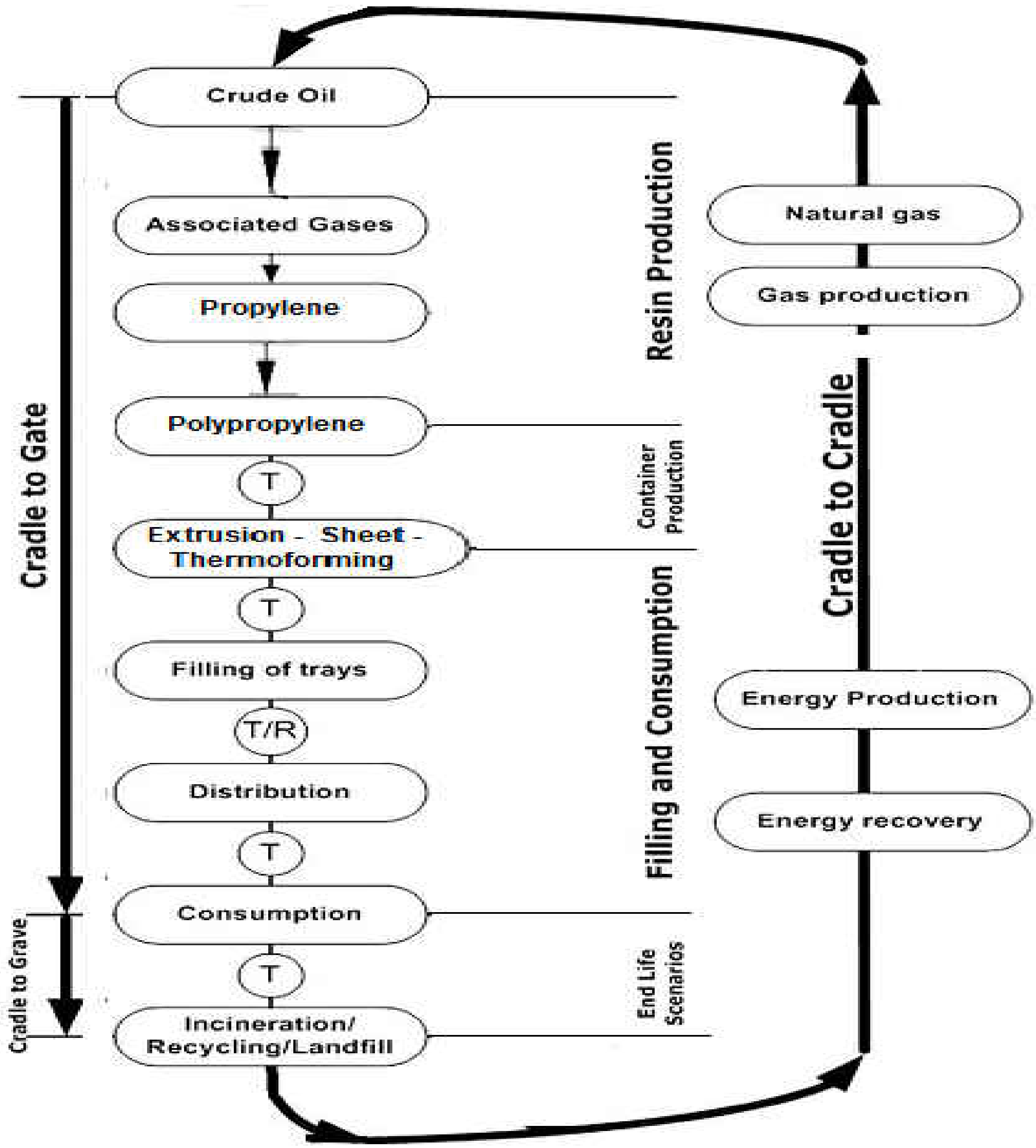


Figure 11:Flow chart for LCA of PP cups.

In table 28, 29 & 30 various data are shown related to the manufacturing of PP cups.

Table 28: Energy& Water consumption during the LCAof one tone ofPP Cups

Phases (I-IV)	Energy Consumption (MJ)	Water Consumption (Ltr)
Phase I	10882.8	174600
Phase II	1645.2	113000
Phase III	18702	250
Phase IV		67
Total	**31230**	**287917**

Table 29: Emission of gases during the LCA of one tone ofPP cups

Phases (I-IV)	Emission of Gases (kg)*										
	Responsible for Green House Effect							Other Gases x 10^{-6}			
	CO_2	CH_4	N_2O	SF_6	HFCs	PFCs	CFCs	CO	NO_X	SO_X	Dust
Phase I	-	-	-	-	-	-	-	-	-	-	-
Phase II	-	-	-	-	-	-	-	-	-	-	-
Phase III	-	-	-	-	-	-	-	-	-	-	-
Phase IV	-	-	-	-	-	-	-	-	-	-	-
Total	**689.1**	-	-	-	-	-	-	**0.0029**	**0.3067**	**0.0138**	**73.55**

* Other greenhouse gases which could not be collected.

Table 30: Carbon dioxide equivalents corresponding to the total energy consumed & emissions of gases during the LCA of one tone of PP cups

PP cups	CO_2 Eqvt. (kg)**
Energy	6940
CO_2	689.1
Total	**7629.1**

** Only CO_2 contribution to greenhouse effect has been considered.

5.10 Collection of data for compostable plastics bags.

The manufacturing process and the life cycle assessment ofcompostable plastic bags is shown in figure 12.

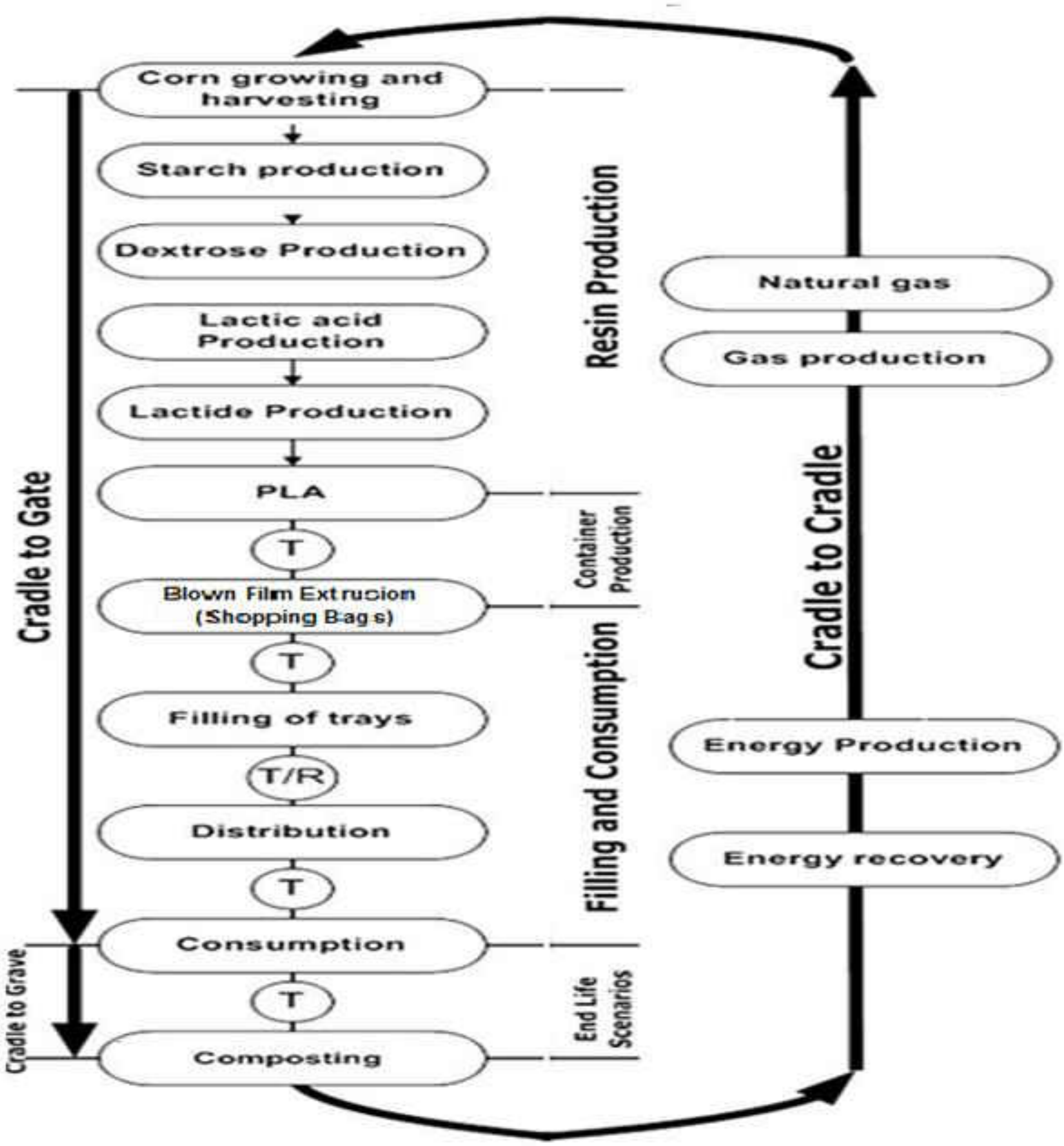


Figure 12: Production of PLA – non-solvent process

In table 31, 32 & 33various data are shown related to the manufacturing of compostable bags.

Table 31:Energy & Water consumption during the production of one ton of Compostable bags.

Phases (I-IV)	Energy Consumption (MJ)	Water Consumption (Ltr)
Phase I	N.A.	N.A.
Phase II	N.A.	N.A.
Phase III	4734	100
Phase IV	1342.8	NIL
Total	**6076.8**	**100**

Table 32: Emission of gases during the LCA of one ton of compostable bags.

Phases (I-IV)	Emission of Gases (kg)*										
	Responsible for Green House Effect							Other Gases X 10^{-6}			
	CO_2	CH_4	N_2O	SF_6	HFCs	PFCs	CFCs	CO	NO_X	SO_X	Dust
Phase I	-	-	-	-	-	-	-	-	-	-	-
Phase II	-	-	-	-	-	-	-	-	-	-	-
Phase III	-	-	-	-	-	-	-	-	0.005036	0.006636	36.54
Phase IV	-	-	-	-	-	-	-	-	0.003463	0.002222	10.9427
Total	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.008499**	**0.008858**	**47.4827**

*other greenhouse gases which could not be collected.

Table 33: Carbon dioxide equivalents corresponding to the total energy consumed &emission of gases during the LCA of one ton of compostable plastic bags.

PP cups	CO_2 Eqvt. (kg)**
Energy	1350.4
CO_2	-
Total	**1350.4**

** Other CO_2 Contribution to greenhouse effect has been considered.

6. CO_2 Equivalent of Green House Gases

A wide range of emission contributes to global warming impact category geologically. Six gases as discussed in this study are responsible for global warming. Common Global Warming Potential(GWP) chemicals are CO_2 and Methane but the release of methane has 23 times more impact than the release of CO_2.Therefore, the CO_2 equivalent of an emission of methane is 23 times to the CO_2release.Nitrous oxide is 300 times more powerful than CO_2.Other gases, such as chlorofluorocarbons, or CFCs (which have been banned in much of the world because they also degrade the ozone layer), have heat-trapping potential thousands of times greater than CO_2. But because their concentrations are much lower than CO_2, none of these gases adds as much warmth to the atmosphere as CO_2 does.

The substances used for calculating the global warming are shown below along with the respective CO_2 equivalent values expressed as global warming potential.

Table34: Global Warming Potential for materials taken into account in this study.

Green House Gases	Per Ton CO_2 equivalent (GWP)
Carbon dioxide (CO_2) 1Ton	1
Methane (CH_4) 1 Ton	23.00
Nitrous Oxide (N_2O)1 Ton	310
HFC 1 Ton	3000-5000
PFC 1 Ton	6500-9200
SF_6 1 Ton	23900

The summation of the six chemicals multiplied by their equivalent value lead to the Global Warming Impact which is measured in CO_2 equivalent.

7. Normalization of Green House Warming Potential of various products.

Normalization is a technique for changing impact indicator values with different units into a common unit-less format. This is achieved by dividing the impact category value by a selected reference quantity (this quantity in India 1.4 tons).This process increases the comparability of data among various impact categories as the categories are reduced to the same scale.

8. Energy requirement for manufacturing of plastics and other products

In the life cycle assessment study of various products effort has been made to collect both practical and theoretical data related to energy required for manufacturing the product including the recycling and the emission data in their stages of products and recycling or disposal wherever possible. Since availability of the practical data in many cases were rare, efforts has been made to collect theoretical data from literature and the findings are as follows for the similar type of plastics and other products.The data presented in the table are in line with the data mentioned in the literature [1 - 14] and are in the close range of the mentioned value as reported by various authors and not a duplicated but approximated.

Table35:CO_2 equivalent per kilogram of different products

Products	Stages	Energy (MJ/kg)	KgCO_2 Equiv/kg	Total KgCO_2 Equiv/kg	kgCO_2Equiv/kgbased on feed stock
Plastics bags	Feed Stock Processing and Others	110.00	7.92	10.80	3.00
	Recycling	40.00	2.88		
Glassbags	Feed Stock Processing and Others	92.48	6.6	8.32	5.78
	Recycling	23.12	1.69		
PET bags	Feed Stock Processing and Others	81.00	5.80	7.80	3.40
	Recycling	29.00	2.00		
PLA bags	Feed Stock Processing and Others	54.00	3.80	5.60	1.80
	Recycling	26.00	1.80		
Paper bags	Feed Stock Processing and Others	50.90	3.60	5.90	5.50
	Recycling	33.0	2.30		
Jute bags	Feed Stock Processing and Others	2366.9	170.4	173.78	11.00
	Recycling	46.75	3.366		
PP bags	Feed Stock Processing and Others	66.00	4.75	70.75	3.31
	Recycling	9.20	0.66		

9. The energy consumption data of various products and their CO_2 Equivalents

Although the data in the above mentioned table35 are collected from the literature and concluding enough to decide about the LCA rank of the products in terms of greenhouse gas emitter or global warmer but the recent study of manufacturing of the following products by table 36. Some agencies in Europe and some scientific groups in china revealed different global warming impact and which justify their presence in the market based on the economic scenario.

Table36: Energy consumed for manufacturing plastics and other bags and their CO_2 equivalents.

Sr. No.	Products	Energy (MJ/kg)	$kgCO_2$ Equiv/kg
1	LDPE bag	150.00	10.80
2	Paper bag	710.00	51.10
3	Glass bottle	115.6	8.32
4	PET bottle	109.00	7.80
5	PLA bag	80.00	5.70
6	Woven Bags (HDPE/PP)	320.00	23.00
7	Jute bag	3793.00	273.00
8	PP bags	72.0	5.23

If the total energy used in the manufacturing of the above products are added with the corresponding total CO_2 emission equivalent of the products, then the total CO_2 equivalent for manufacturing the products in a boundary system of energy and emissions (which causes Global Warming) can be given in the table37.

Table37:Total CO_2 equivalent for manufacturing the products in a boundary system of energy and emissions (which causes Global Warming) with carbon credit.

Sr.No.	(Product)	Average bag weight (kg)	$kgCO_2$Eqiv./kgin Manufacturing	$kgCO_2$Eqiv./kgin Emission during LCA	Total $kgCO_2$ Eqiv./kg	Normalised valu
1	**LDPE bag**	0.0075	10.80	0.072	10.872	0.0108*1.4=0.015
2	**Paper bag**	0.055	51.10	4.90	56	0.056*1.4=0.078
3	**Glass bottle**	0.327	8.32	1.50	9.82	0.0098*1.4=0.013
4	**PET bottle**	0.024	7.80	1.00	8.08	0.0080*1.4=0.011
5	**PLA bag**	0.015	5.70	-	5.70	0.0057*1.4=0.00
6	**Woven bags (HDPE/PP)**	0.120	23.00	0.0702	23.07	0.0230*1.4=0.032
7	**Jute bag**	0.190	273.00	0.006	273.006	0.2730*1.4=0.382
8	**PP (non-woven) bag**	0.107	5.23	0.689	13.549	0.0135*1.4=0.018

[Ref: 21,34,42,46,47,61

Considering the CO_2 Equivalent data given in table 37 as real time manufacturing in the industrial environment and used in the market place and further recycling or disposal, these data are taken into consideration for adding with CO_2 equivalent emission data (which are practically collected based on three sample collection) for calculating total $kgCO_2$ equivalent of the product in table 37 in the entire life cycle.

The CO_2 equivalent for energy is calculated based on relationship.

22 GJ Energy = 1600 kg CO_2 equivalent/ Ton[15]

The $kgCO_2$ equivalent of the product emitted during disposal has been taken into consideration and shown in table 38.

Table 38: Total CO_2 equivalent for manufacturing the products in a boundary system of energy and emissions which causes Global Warming (without carbon credit).

Sr. No.	(Product)	Average bag weight (kg)	$KgCO_2$ Eqiv./kgin Manufacturing	$kgCO_2$ Eqiv./kg in Emission during LCA	$kgCO_2$ Eqiv./Kgin Emission during LCA (disposal stage)	Total $kgCO_2$ Eqiv./kg	Normalized value
1	**LDPE bag**	0.0075	10.80	0.072	5.04	15.912	0.01591*1.4=0.022274
2	**Paper bag**	0.055	51.10	4.90	1.814	57.81	0.0578*1.4=0.08092
3	**Glass bottle**	0.327	8.32	1.50	0.85	10.67	0.0106*1.4=0.01372
4	**PET bottle**	0.024	7.80	1.00	4.93	13.01	0.01301*1.4=0.018214
5	**PLA bag**	0.015	5.70	-	3.84	9.54	0.0095*1.4=0.0133
6	**Woven bag (HDPE/PP)**	0.120	23.00	0.0702	1.85	23.25	0.0232*1.4=0.03248
7	**Jute bag**	0.190	273.00	0.006	1.120	274.12	0.2741*1.4=0.38374
8	**PP (non-woven) bag**	0.107	5.23	0.689	1.85	15.399	0.0153*1.4=0.02142

10. Normalization

The above data of CO_2equivalent (table 38)of the products were normalized by multiplying with 1.4 MT (CO_2 emissions per capita in India)[15] equivalent which resulted in unit less number for each products and the normalized CO_2 equivalent values are shown in figure 13& 14 and their comparison has been shown in 15.

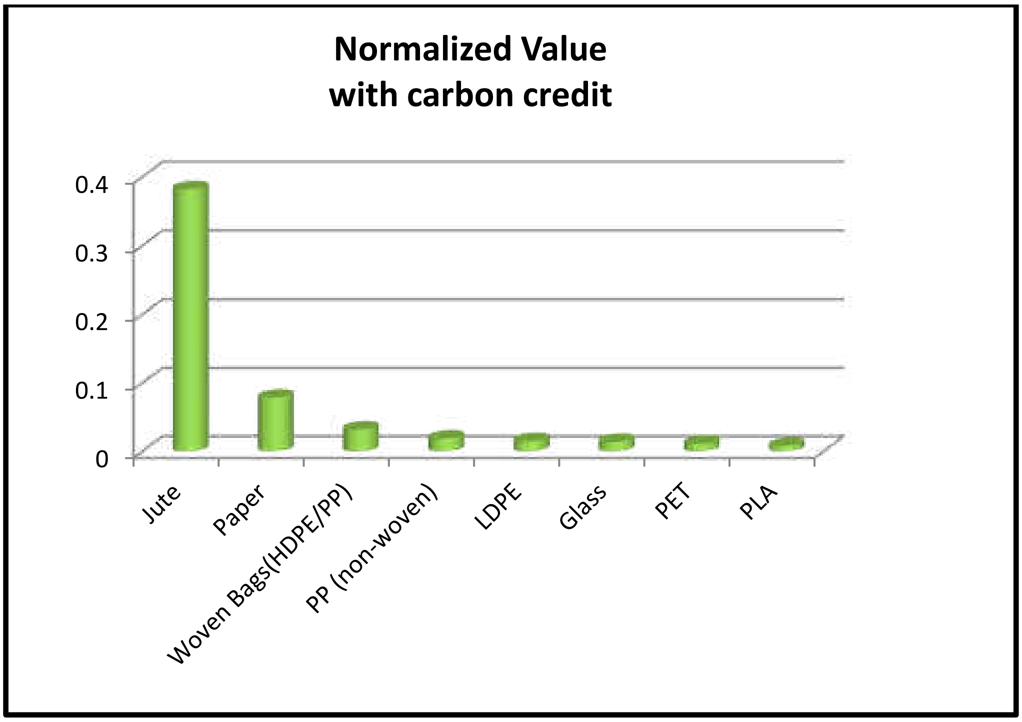


Figure 13:Normalized CO_2 equiv. value vs. products with carbon credit.

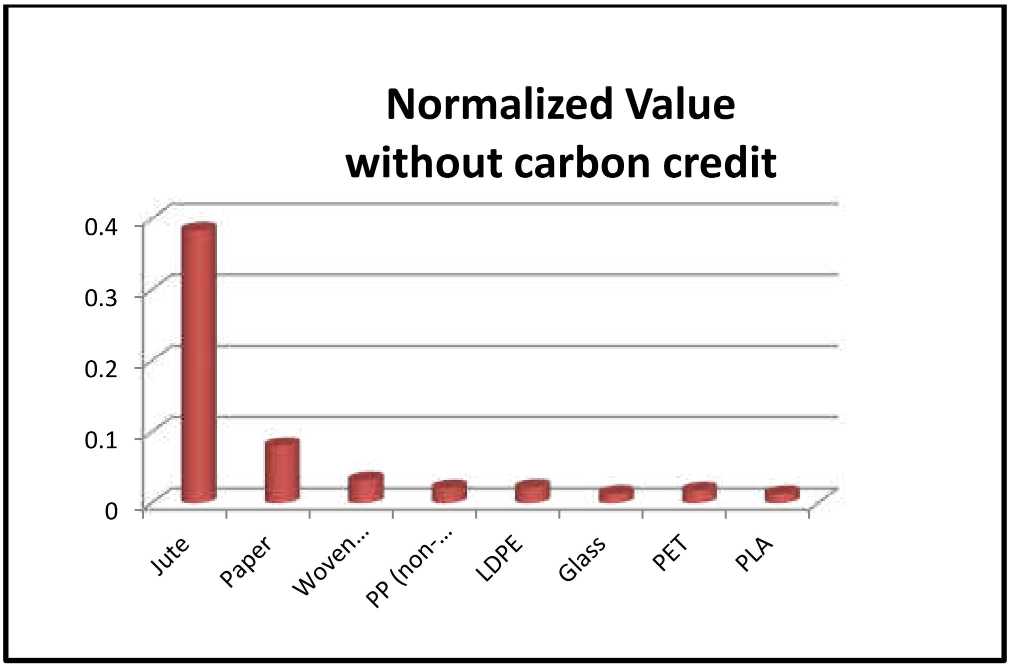


Figure 14:Normalized CO_2 equiv. value vs. products without carbon credit.

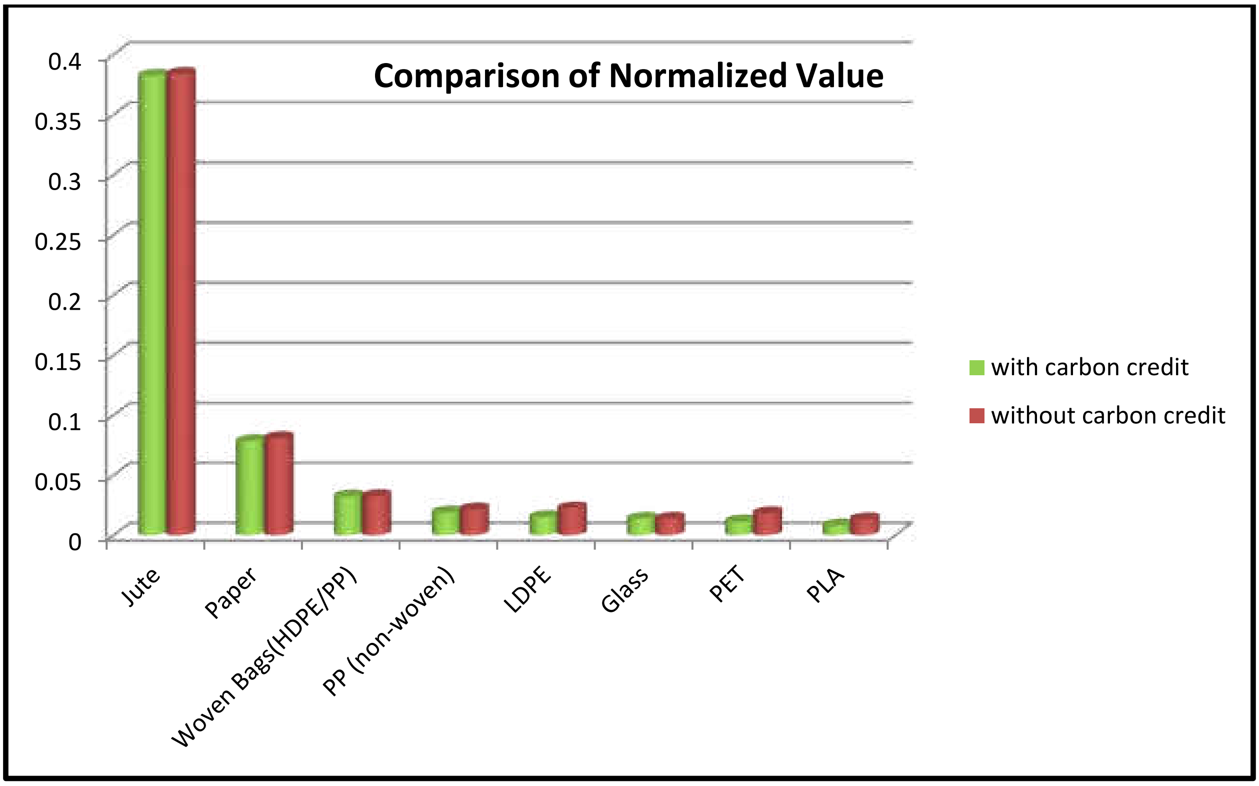


Figure 15: Comparison ofnormalized CO_2 equiv. value vs. products, with & without carbon credit.

11. Volatile Organic Compound (VOC)

VOCs are large group of gases easily vaporizable liquids including various group of organic (carbon containing) chemicals. Most are color less and odorless. Non- Methane Volatile Organic Compounds (NMVOC) describe this group excluding the particular case of Methane. They are also called non methane hydrocarbon which are important constituents of the atmosphere that contribute both to the condensation capacity of the atmosphere and to the formation of secondary organic aerosol.

NMVOC also include cyclohexane, 1,1,1-trichloroethane, or Acetone. Sometimes NMVOC is also used as the sum parameters for emission where NMVOC emission is added upper weight into one figure. In the absence of more detailed data this is considered as a very coarse parameter for the pollution e.g. for summer smog on indoor pollution.

12. Toxicity and other effect come by volume production

During the PE and PET life cycle system, emission of gases like NO_x and NH_3 (responsible for nitrification), CFC_{11} (responsible for ozone deputation) SO_2(responsible for acidification), Ethylene (responsible for summer smog) and

Iso-Propane, benzene, 1,2- di chloroethane (responsible for human toxicity) has been reported in the literature.

The element responsible for toxicity are lead (Pb), chromium (Cr) which are available in polyethylene in trace amount. Their concentration levels in PE are estimated as 45±14 mg/kg for Pb and 14± 6 mg/kg for chemicals. They come into human contact when they are used in PE since their migration is well below applicable safety level. The study conducted on PET packaging material indicates that it does not leave any toxic effect on health of human. However, it is reported that some unknown and unidentified contaminant in PET contribute to hormonal activity in packaged mineral water, but researchers claim that this is contrary to the established facts that PET is inert and has no harmful effect on human. Therefore, it needs further investigation. On the other hand, PET industry stands by its record of safety and reliability as a packaging material. Since they claim that

PET itself is biologically inert and safe during handling and is not a hazardous if inhaled. No evidence of toxicity has been detected in the feeding studies using animals studies also said that PET is also not geotaxis. It is also found that monomer and typical PET intermediate are essentially nontoxic and pose no threat to human health. It is important that chemistry of compounds that are used to manufacture PET shows no evidence or estrogenic activity. There is significant evidence that demonstrates that the use of PET is not concern and in perfectly safe in packaging of products.

13. Conclusion

The LCA study includes the requirements of upstream processing energy (feed stock energy) of raw materials, process energy of the product from the materials, energy for use of products in which transport energy is combined and energy for disposal or recycling/composting/incineration/land filling at the end of life as per boundary condition defined in figure 3of this report.

In this study only IPCC (International Panel on Climate Change), 2007approach has been used to translate the greenhouse gas emission generated by the life cycle scenarios into a single foot print. The approach of calculating LCA study of the product is based on the principle of total/cumulative CO_2 equivalent for manufacturing the product in a boundary system (cumulative energy in the boundary system in terms of CO_2 equivalent) + cumulative greenhouse gas emitted in terms of CO_2 equivalent) which causes global warming potential.

Special mention here is made that LCA results are derived based on the experimental data (emission data at various manufacturing site of products and various theoretical data collected from the literature). Since data related to energy requirement for various stages are not available, the total cumulative energy has been taken based on the following assumptions.

1. Process energy of the product is calculated as 50 to 80% of the gross energy demand (GED) which is sum of feed stock and process energy.
2. Recycling energy is taken as 10 to 20% of the Cumulative Energy Demand (CED).
3. Use energy which includes also transport energy is taken as 5 – 10% of the CED energy.
4. Feedstock energy of the product varies from 20-50% of the CED.

The percentage of energy required for different products in different stages of manufacturing are not same and vary depending on size and kind of products.

13.1. LDPE BAGS

The detailed steps involved in the manufacturing of LDPE bag/milk pouch has been shown in fig.6.More or less similar process steps of manufacturing other LDPE bags are involved. In the entire process total/cumulative energy demand has been derived and the corresponding CO_2 equivalent is calculated which is given in Table 35.

While calculating this data it has been taken into consideration that LDPE bag is recycled (80% recycled + 20% burnt) at least 3 times and then used for land filling or controlled incineration. Cumulative energy required for LDPE bag has been again rechecked with the literature data and it is found that the energy required is within the specified range for such type of products (it varies depending on size and end user applications). The same data for different products has been shown in Table36 and has been used in calculating cumulative CO_2 equivalent in Table 37(excluding the emitted CO_2 equivalent in disposal stage) and after normalization, it is converted into a single point index data. This is considered as LCA data 0.01512 for LDPE as per this method of study. Special mention is hereby being made for total CO_2 equivalent data for LDPE based on only gross energy consumption and recycling as mentioned in the Table 2 is far less than manufacturing of plastics bags which involves many intense energy consumption stages of manufacturing. Moreover, Table35 and 37 data do not include CO_2 emission data at the disposal stage, which is normally 3.8 kgCO_2 per kg of LDPE when it is burnt or incinerated. When it is recycled it is less than that even. So the total CO_2 equivalent for LDPE material could be 2.76 + 5.4 (considering 80%

incinerated + 20% land filling) = 8.16 which is less than the data given in Table 36. The value is different because energy calculation is based on estimation not on exactly derived data.

Table 36 data does not include the emission due to incineration, since correct data for greenhouse gas emissions for most of the products during composting/recycling incineration is not available. The normalized CO_2equivalent data shown in Table 37 is reflecting the data with carbon credit. Table 38 is reflecting the data without carbon credit due to emission ofCO_2 at disposal stage.

13.2: GLASS BOTTLE

The LCA for glass bottle 0.01372 is derived in the same way as LCA for LDPE bag and result is given in Table 37. In this respect it is to be mentioned that in the calculation of LCA for glass recycling energy of glass has been considered on the basis of its actual recycling, reuse and refilling. Although glass bottle 100% recyclable but in actual practice maximum 75% are recycled and 25% are wasted or damaged. The 5 to 6% of the total energy is used for transportation and which appears to be costlier as compare to cost of transportation of other materials because glass is heavier than other materials compared in this study. Hence it has more GHG emission.

Manufacturing impact of glass on the environment has been shown in Table 39 qualitatively in which it is found that acidification effect of glass is more than paper, since there is less CO_2 emission because of recycling emission data in the recycling stage has not been taken into consideration (exact data is not available). It has no land fill contamination. Its human toxicity potential for photochemical, ozone, creation potential and terrestrial eco-toxicity is less than plastic. It is suggested that if glass bottle is manufactured with improved by reducing weight by 20% than its environmental impact can be reduced further. The data in Table 37 it reveals that glass is by far the most suitable packaging material to retain quality of contained products and least damaging on environment.With increased recycling through proper waste management system and reducing weight with new technologies glass packaging can be the choice for future needs. Advance manufacturing technology for reduction of waste (less material design) could be costly and the cost of product may go higher than other packaging material. Therefore, it could be difficult for glass to compete with other materials.

Table 39: Impact analysis of different products.

Environmental Impact	Paper	Jute	Glass	Plastic LDPE	Woven Sacks	PLA	PET
Energy conversation	Poor, needs, relatively high energy to run machinery	High, 54 MJ/Kg energy can be saved		Very high, needs relatively less energy to make	High		
Water conversation	Poor, need large quantity to make	Not used		Excellent, little water required	Water consumption high		Good
Waste to energy conversation	Poor, paper bags generates seven times more solid waste than recyclable plastics bags		Poor, more need energy to make and wash	Excellent	Good	Biodegradable plastics producer significantly more municipal solid waste than recycle plastic bags	Good
Recyclable	Partial		Partial	Total	Majority		Majority
Land Fill Contaminants	Contribute to methane gas and leaches		None(inert)	None inert	None	More the PE	
Air pollutants when properly incinerated	Virtually none	None	Does not burn	None	None		
Impact on Ozone Layer	Less ozone depleter than LDPE	None	Positive contribution	Positive contribution	Positive contribution	Less than PET	More Than PLA
Acidification	Seven times of plastics	Less than PLA	More than paper			Five time of plastic LDPE (More than PET)	
Eutrophication	More than plastic	Less than PLA					More than PLA
Human Toxicity		No	No	Inert and non-toxic			PET is more toxic than PLA
Smog				Less than PLA	Less than Paper (in plastics heavy elements may be more than paper	More than PET	
CO_2 Global Warming Potential	2.3 times of plastic CO_2 equivalent	More than plastics		Less CO_2 equivalent	More than normal plastics but less than Jute	Less than PET	

[Ref: 46,48,53]

The other drawback of glass is that the energy cannot be recovered from the damage material. Therefore, it cannot conserve energy. This would give the chance of remanufacturing the glass which may generate toxic and greenhouse gases. Bringing 100% recycling condition for glass products is theoretically possible but it is practically difficult because of transportation, handling and manufacturing difficulties with finest technology and washing which need more energy. Moreover, acidification potential for glass is more than PET plastics and therefore manufacturing of glass is more polluting than plastics in this respect. In this context it is to be mentioned that when PET bottle replaces glass bottle much advantages are achieved. The impact on environment becomes much less than glass bottle. In this context it is also to be mentioned that when PET bottle replaces glass bottles much advantage is achieved, the impact on environment become much less than glass bottle since glass is heavier than plastic during its transportation more VOC and NO_x are emitted from diesel engine of the vehicle.

13.3: PET BOTTLE

Based on LCA study the normalized CO_2 equivalent for PET bottles 0.0112(derived from theoretical and practical data related to manufacturing stages as per the defined boundary conditions given in Table 37). While calculating this data emission of green house gases during recycling/burning stages has not been taken into consideration since they are not available. In India 42% PET bottles are recycled, 38% are used in landfill and 20% are burnt and 0% reused according to the study done by some other authors. Generally, when PET is incinerated about 4.98 kgCO_2/kg of resin is emitted for which carbon credit has been given in Table 37. Due to which the value of the normalized CO_2 equivalent is less than LDPE and PP. The PET is heavier than PP so cost of transportation is more than PP and more consumer waste is generated. The CO_2 emission values for PLA, PET and PS for a scenario of mixed disposal (recycling 40%, incineration 30% and landfill 30%) are almost the same as the CO_2 emissions for 100% landfill, as reported by other authors.

13.4: PP BAG

The normalized CO_2 equivalent for PP bags has been given in Table 37 which indicates its effect on the environment. As like LDPE, PP is also 80% recycled and 20% burnt and after three times of recycling 80% is burnt (controlled condition for recovery of energy) and 20% is sent to landfill. However, smaller products like cups are disposed through 100% incineration for energy production (under control conditions) or land filling. Since the practical data for gas emitted during disposal stage is not available it has not been taken into consideration for normalized CO_2 calculation for polypropylene bag. Taking into consideration of normal disposal process the equivalent emission can be taken as 1.97 kgCO_2 per kg but when recycling is done 100% it can be taken as1.53 kgCO_2/kg.

13.5: PAPER BAG

The LCA as normalized CO_2 equivalent index for paper has been calculated and given in Table 37. In this study the CO_2 emission (4 kg per kg of paper) at disposal stage has not been taken into consideration for keeping uniformity in calculation of LCA index for all the products. Paper is 80% recycled and 20% refilled in its used pattern. Since manufacturing energy requirement of paper is more than plastic and paper is not fully recyclable and contributes in methane generation. It has 2-3 times more global warming potential than plastic. It has very strong acidification effect. The products and process of paper bag requires the usage of larger volume of water as compared to plastic bags and can cost significantly higher than plastic bags.

13.6: PLA BAG

The normalized CO_2 for PLA is 0.008 (given in the table 37). The calculation is based on with carbon credit i.e. emission at disposal stage has not been taken into account. PLA systems shows clear advantages compared to the PE, PP and PET with regard to the use of fossil energy resources, processing energy, an denergy requirement for transportation as per the defined boundary conditions Table 37.

Table 40:Comparisonof Green House Gas Summary for Cold Drink Cups of PLA, High Impact Polystyrene (HIPS),PP and PET.(In gm. carbon dioxide equivalent per 4536kgresin).

Green House gases	PLA	HIPS	PP	PET
CO_2	407,570	470,516	290,306	616,836
NO_2	16,665	161	184	180
CFC/HCFC/HFC	0.0019	213	4,188	274
CH_4	85,303	104,909	50,333	101
Methylene chloride CH_2Cl_2	0.012	1.26	1.07	1.61
HCFC-22$CHClF_2$	246	418	175	263
Total	509.784	576.218	345.187	717.847

[Ref: 63]

A major different, however is that the carbon is of bio mass origin, so its return to the atmosphere is part of a natural cycle and would not be viewed as a contribution to increase greenhouse gases. Thus, PLA bio-based polymer can contribute substantially to reduce environmental impact related to material use. They produce greenhouse gases much lower than PE and other conventional plastics (Table 37). However, it is observed in case of PP plastic cups total greenhouse gases emission is less compared to PLA cups (Table 40). PP cups require less process energy than PLA cups. For other impact categories comparison of PLA system with the alternative system do not show clear trend. This result for acidification terrestrial eutrophication and PM-10 (dust) shows disadvantage of PLA when compare to PET, PE and PP systems. For aquatic eutrophication PLA shows environmental advantage if compared to PP but show disadvantage in comparison with PET it is reported that when bioorganic carbon is included in the GWP value of PLA, GWP of PLA drops 3.4 kgCO_2 to lower value at least by 62.5% making it superior to PP and HDPE. Carbon credit is given due to fact that all the calculations are not based on practical results but combination of practical and theoretical assumptions. Although CO_2 emission equivalent of disposing PLA can be more than 3.4 if PLA is composted and can be pushed lowered below 3.4 by incinerating. Composting of PLA is preferred to incineration in order to avoid impact of PLA incineration. Although PLA composting of PLA is preferred but it is not in practice because of the high cost of industrial facility requirement for composting PLA as per standard which cause more GHG emission due to methane(table 41). So something 50% incineration and 50% land fill is done. However, a significant emission of CO_2 can be reduced if PLA is recycled fully.

Table 41: Global Warming Potential and Related Carbon Equivalent of GHGs.

Green House Gases	**Quantity (kg)**	**Global warming Potential (CO_2 Eq.)**	**Carbon Equivalent (kgof Carbon)**
Carbon Dioxide	1	1	0.27
Methane	1	21	5.67
Nitrous Oxide	1	310	83.7

[Ref: 52]

13.7: PP WOVEN SACKS

The normalized CO_2equivalent as index of LCA is 0.0322 of global warming potential for PP woven sacks has been shown in Table 37.

The emission of CO_2 for the materials like jute, paper and woven sacks has approximately the same profile during disposal stage. However, during production of jute remarkable high amount of CH_4 is emitted. The comparative study on emission during transportation also shows significantly excess generation ofCO_2 and NOx as compared to that in case of PP – HDPE woven sacks.

13.8: JUTE BAGS

The normalized CO_2 equivalent as index of LCA effect has been calculated as 0.3822 and shown in table 37and the consumption of energy in manufacturing, water requirement and emitted gases from the manufacturing process indicates that jute bag is less environment friendly than woven sacks. However, in the production of jute, less toxic chemicals are produced compared to paper bag.

14: HIGHLIGHTS OF THE STUDY

From the impact analysis of the products selected for this study, it can be concluded that composting of PLA products like cups, bags may result in reduced greenhouse gas emission compared to incineration. Before final conclusions, few facts are being summarized about PLA. [Ref: 44]

1. The total energy requirements in terms of CO_2 equivalents for bio-polymers (PLA) are less than petrochemical polymers.
2. The bio-degradable polymer PLA shows lower energy requirements than PP with reduced CO_2 emission when it is composted.
3. Normally, it is mentioned that cumulative energy requirement for PLA (cradle to factory gate) is 20 – 30% below that for PE, while GHG emissions are about 15 to 20% lower.
4. Bio-polymers and natural fibers typically enable savings of around 20% energy and CO_2 emission.
5. The other impact like acidification potential of PLA can be reduced to a significant level if it is 100% composted.
6. The table 37 taken into account of PLA disposal via composting and the positive credit in CO_2 emissions and energy savings resulting from this process.
7. The study taken into account the energy requirement and emissions (CO_2) during the disposal stage of other products in accordance with the normal practice in India.
8. Incineration practice with energy recovery is a common option.

9. This LCA did not take into account the costs of machinery for composting and incineration.

Finally, the study finds that PLA has advantages over the fossil polymer in consumption of non-renewable energy, climate change and summer smog categories. emissions of other greenhouses gases during manufacturing, transportation & disposal of PLA in comparison with CO_2 is so low and sometimes beyond detectable limit that their impact in the Indian climatic condition is not so alarming and significant and therefore, their impact has not been taken into consideration in this study.

Bio-degradable PLA bag is designed for composting as per the municipal &industrial standards. In such a situation land fill is the better option considering that degradation process of PLA is slow and appreciable quantities of greenhouse gases will not be generated (CO_2 and methane are generated at slow rate).

In the Life cycle study, it has been observed that the major deviation ofkg$CO_2$of products is in CED in manufacturing and not in CO_2 emission in disposal stage. Therefore, in the manufacturing of the products much attention should be given in the reduction of CO_2 due to the energy consumption in the manufacturing process and hence process improvement of the product and redesigning for weight reduction so as to reduce the cost of the product and facilitate competing with other products.

In spite of all the above points which are discussed favoring PLA or not favoring PLA according to the evidence, it is convincingly understood that due to increasing depletion of fossil fuel the application of PLA should be made favorable by applying different suitable options of both for manufacturing at cheaper costs and disposal with less environmental impact. Ultimately LCA provides an insight into environmental impacts that can vary in complexity and data requirements. The data needed not only in the form of a carbon foot print but also as an understanding of the relevance of the other impacts. It could be driver for innovation which could lead to potential cost savings.

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