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A Major Project Report on

ENVIRONMENTAL IMPACT ASSESSMENT OF MULTILAYER MILK PACKAGING THROUGH CRADLE-TO-GRAVE LIFE CYCLE ASSESSMENT

submitted in partial fulfilment of the requirement
for the award of the degree of

MASTER OF TECHNOLOGY IN ENVIRONMENTAL ENGINEERING

submitted by:

ADARSH KUMAR
(Enrollment No. 24/ENE/04)

under the supervision of

Mr. ANUNAY A. GOUR
Assistant Professor



Department of Environmental Science and Engineering
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)

Shahbad Daulatpur, Main Bawana Road, Delhi-110042, India

2024-2026



DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, **Adarsh Kumar**, Enrollment No. **24/ENE/04**, a student of M.Tech. Environmental Engineering, hereby declare that the major project titled **“ENVIRONMENTAL IMPACT ASSESSMENT OF MULTILAYER MILK PACKAGING THROUGH CRADLE-TO-GRAVE LIFE CYCLE ASSESSMENT”** which was submitted by me to the Department of Environmental Science and Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, diploma, associateship, fellowship, or other similar title or recognition.

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Date:-

Adarsh Kumar

(24/ENE/04)



DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the major project titled “ENVIRONMENTAL IMPACT ASSESSMENT OF MULTILAYER MILK PACKAGING THROUGH CRADLE-TO-GRAVE LIFE CYCLE ASSESSMENT”, submitted by **Mr. ADARSH KUMAR** (Enrollment No. **24/ENE/04**), Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision.

Mr. ANUNAY A. GOUR

(SUPERVISOR)

Assistant Professor, Department of Environmental Engineering
Delhi Technological University, Delhi

ABSTRACT

Rapidly evolving lifestyles in developing countries have driven an increased demand for multilayer packaging used for packaged milk and beverages. This growth in consumption is driven by multiple factors. For example, demand often spikes to three to five times normal levels during festive seasons, surpassing local limited production. The need to transport surplus milk from high-production regions to other areas is supported by the packaging's superior barrier properties, which provide an extended shelf life. The manufacturing of multilayer packaging has created many environmental concerns due to its multiple layering manufacturing composition of LDPE, paperboard, and aluminum; due to its difficult recycling and disposal.

This thesis utilizes material composition analysis and life cycle assessment (LCA) to assess environmental impact of manufacturing 10,000 units of 1-litre multilayer milk packs. The assessment follows a cradle-to-grave approach in line with the ISO standards, and it covers many impact categories including global warming potential, energy demand, total water consumption, and local/global resource depletion. The assessment was undertaken in the OpenLCA environment using impact assessment methods by ReCiPe 2016 v1.03, midpoint (H) sourced from the EcoInvent v3.12 database.

To analyze the composition of materials used in Multi-Layer Packaging (MLP), experimental characterization was conducted on standard 1-litre capacity, brick-shaped cartons. Parameters such as moisture content, total surface area and precise material composition ratio were determined through empirical laboratory testing to establish the physical baseline for the LCA study. These physical properties are critical for defining the system boundaries of data collection and calculating the exact quantity of raw materials required. Which are paperboard, low-density polyethylene (LDPE) and aluminum foil required for the Life Cycle Assessment (LCA). The quantification of these specific inputs and outputs of resources, helps the study to provide a precise model of the environmental burdens associated with the production of 10,000 units of packaged milk. This broad analysis encircles the entire product lifecycle, extending from the initial extraction of raw materials to final waste disposal.

ACKNOWLEDGEMENT

I extend my heartfelt thanks to my mentor, **Mr. Anunay A. Gour, Assistant Professor, Department of Environmental Science & Engineering, Delhi Technological University** for his expert guidance, consistent supervision, and unwavering patience. His insightful suggestions and practical advice were crucial in overcoming technical challenges and shaping the direction of this project.

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Adarsh Kumar
(24/ENE/04)

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CHAPTER 1

INTRODUCTION

1.1 Background

Various types of livestock serve as sources of milk for human consumption worldwide. Due to its liquid nature, milk requires containers for production, collection, storage, and distribution. The dairy sector required raw materials, which minimize working capital and optimize mechanical processes without structural failures of packet material. such as glass cracking, plastic pouches ruptured during daily process milk filling operations. The distribution infrastructure requires large capacity transport vehicles (>10 MT) for primary collection from centers to processing plants, while smaller pickup trucks (~3.5 MT) distribute to retail channels. Packaging materials must be selected based on light-weight and durable to withstand loading and unloading stresses without cracking, while also allowing for quick and accurate packet counting during delivery time. To maintain quality, these materials must be designed such that shelf life of contents is extended by providing protection against moisture, bacterial contamination, sunlight, and physical hazards. Selection of packaging options should prioritize minimizing environmental and social health impacts under their corporate social responsibility (CSR) by evaluating them according to the 3Rs, incineration, and landfilling, and their effects on air quality and local water systems.

Market demand for packaging options govern the choices such as glass bottles, plastic pouches or multilayer packs. The multilayer packaging (MLP) is the preferred selection because its carbon footprint is 70% lower than that of plastic pouches [2, 6]. This preference is based on factors such as: the manufacturing of MLP requires less plastic as it is replaced by paperboard; the production process is straightforward and facilitates easy milk filling; the rectangular design optimizes truck space during distribution. Unlike glass bottles, MLP does not suffer from cracking issues during loading and unloading. MLP is a complex thin six-layer of paperboard, plastic, and aluminum sheet. Due to the prolonged shelf-life and pasteurization using ultra high temperature (UHT) process, it does not require refrigeration for several months.

1.2 Need of the Study

- MLP waste collection is lowest in India. Out of the total only 48% is collected. There is a scarcity of primary & localized data related to MLP in India.
- Policymakers and dairy cooperatives are unable to enforce or optimize these regulations without data on the environmental impact or ecological footprint of various disposal methods.
- Material Innovation: Eco friendly material (like bio-based LDPE).
- Sustainable claims: To simplify the complex 6-layer structure and boost recycling efficiency.
- Comparative Packaging Decisions: plastic vs glass vs multi-layer packaging in dairy industry.

Traditional plastic pouches and glass bottles. This research evaluates various phases from the extraction of raw materials and manufacturing to container assembly, liquid filling, and final retail distribution to identify strategies for reducing electricity use and collect data for resource depletion. Furthermore, this study aims to determine the most effective waste management strategies. To know/determine the value of recovery ratio which are collection from industry and household waste of MLP material that can be successfully reclaimed at the product's end-of-life. Data pertaining to the materials used, energy and water consumption, and emissions at each stage of the packaging life cycle was utilized. It also includes data of processes such as production, transportation, usage, and end-of-life treatments (recycling, landfill, or incineration).

1.3 Objectives:

The study aims to:

- Analyze the material composition of multilayer packaging (MLP) used for milk packaging.
- Develop a cradle-to-grave life cycle inventory (LCI) for MLP production and use.
- Evaluate the environmental impacts of MLP using Life Cycle Assessment (LCA) and OpenLCA.
- Assess environmental hotspots and improvement opportunities across the MLP life cycle.

CHAPTER 2

LITERATURE REVIEW

2.1 Multi-Layer Packet (MLP)

Multi-Layer packet(MLP) is one of the most common and most controversial materials in the modern packaging industry. It is the material used for the packaging for fast moving consumer goods like potato chip bags, dairy products, liquid beverages, etc. Here is a breakdown of how it is used, what it is made of, and the significant challenges it poses to manufacturing and waste management.

2.1.1 Need of MLP (MLPs are lightweight, flexible, and highly protective):-

- *Food Packaging*: mostly used for snacks (like chips and biscuits), coffee, tea, juice and spices. The layers block moisture, oxygen, and UV light, which prevents food from going stale or spoiling, dramatically extending shelf life.
- *Single-Serve Sachets (FMCG)*: Used for shampoo, ketchup, detergents, cosmetics and dairy industry products. This packaging makes products highly affordable and accessible in emerging markets.
- *Pharmaceuticals*: Used for medical pouches and certain blister packs that require a strict, sterile, moisture-free environment and away from sunlight directly. With all temperature maintenance of medicine to not change the properties.

2.1.2 Production Materials properties:-

As the name suggests, MLP is made by sandwiching several different materials together. A standard MLP packet usually consists of six layers:

- *Outer Layer (Printability)*: LDPE layer which provides a glossy surface for brand printing and structural strength.
- *Paper board layer (Strength)*: provide a strength of the body to more easily transfer of material and not rupture like plastic.
- *Adhesives LDPE*: LDPE is the layer between the bind together the aluminium and paper to each other, by lamination heating process.
- *Middle Layer (The Barrier)*: Normally Aluminum foil or a metallized plastic film. This is the important layer that blocks out sunlight, oxygen, and moisture.

- *Adhesives LDPE*: LDPE is the layer between the bind together the aluminium and ldpe layer which are direct contact to food, by lamination heating process.
- *Inner Layer (Sealability)*: Made of LDPE (Low-Density Polyethylene). Which acts as a direct food-contact barrier, to make airtight and prevent aluminium layer.

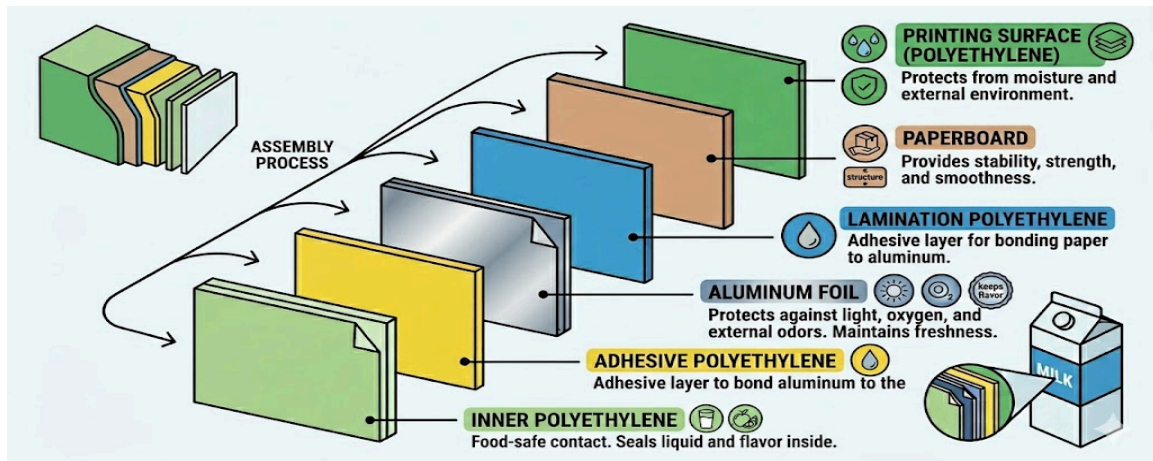


Figure 2.1: Six-layer of MLP

2.1.3 Issues with Manufacturing:-

While highly productive MLP comes with several industrial and environmental emission-

- **High Energy Consumption**: The process of extrusion raw materials and lamination (melting, pressing, and binding) requires some amounts of heat from electric energy.
- **Toxic Emissions**: The industrial adhesives, inks, and solvents used to bind and print the layers often release Volatile Organic Compounds (VOCs), which require ventilation fans and remove polluted air to protect factory workers health and local air quality.
- **Production wastes/Scrap**: manufacturing errors, cutting parts according to design, material lamination process issue(machine failure, delaminates) and quality check failure of filling product(company returns the product from retail shops).

2.1.4 Issues with Waste Management:-

Waste management of MLP is converted into the biggest problem in the coming future. It is currently at the center of the global plastic pollution crisis for many reasons:-

- *Technologically Difficult to Recycle:* First step paperboard separated using high pressure more water to remove paper upper-layer of MLP by hydraulic removal process in machine. The other side separates multi-layer plastic with aluminium. In the second step recycling facilities melt plastics based on their melting points. Because MLP is a bond as a sandwich of different ldpe and Al, it cannot be melted down together. So separating the layers chemically or mechanically is currently much too expensive and energy-intensive to be done at a commercial scale.
- *No Economic Value:* It cannot be easily recycled. so, it has no resale value. Informal rag pickers will usually leave MLP from the waste collection point because scrap dealers will not buy it.
- *Environmental mess up:* MLP packets are lightweight. Even when air blows are thrown in a trash bin, they can easily fly away by the wind, leading them to clog drainage systems, pollute rivers, and end up in the ocean.
- *Toxic Disposal:* Multilayer packaging (MLP) recovered from waste disposal sites is for incineration. Catch fire the mix of chemical adhesives, plastics, and metallic inks releases highly toxic fumes, which are dioxins(organic waste) and furans(carbon compound). If covered in a landfill, it will not decompose for centuries, lastly possibly breaking down into harmful microplastics.

2.2 Survey report on solid waste management:- Based on the current scenario, the policies and the operational challenges based on recent scientific literature.

2.2.1 The Scale of the Problem

Since 2020 the average person in India uses far less multilayer packaging (MLP) than someone in the west, the country's massive population means the total adds up fast, resulting in a staggering 15 million tons of MLP waste every single year. The majority of India's recycling process is done by a network of waste pickers which primarily recycle plastic and paper waste. With the help of their efforts, around 58% of the total waste generated is recovered. Meanwhile the remaining 42% is still a major cause of concern, as it usually ends up being dumped, burned, or left unmanaged. Over some period of

time, this waste finds its way into streets, drainage systems, and natural environments. Thus, creating problems such as blocked drains and groundwater pollution.

2.2.2 End-of-Life Management of MLP Waste in the Indian Context

Multilayer packaging (MLP) yields negligible residual value, resulting in its systematic exclusion from collection by informal waste pickers. Furthermore, the technical complexity of MLPs precludes standard mechanical recycling. Consequently, India has developed two primary alternative applications for end-of-life management:

- *Co-processing in Cement Kilns:* Non-recyclable waste streams, primarily MLPs comprising LDPE and aluminum layers, are diverted to cement manufacturers for use as an alternative fuel source. It is estimated that approximately 0.25 million tonnes of MLP waste undergo annual co-processing within blast furnaces in India.
- *Road Construction:* India has established pioneering methodologies for the integration of shredded plastic waste, including MLPs, with bitumen for pavement applications. This integration enhances the durability and moisture resistance of asphalt while simultaneously mitigating the volume of plastic directed to landfills.

2.2.3 Extended Producer Responsibility (EPR) Policy Framework

In 2016, India introduced a new and thorough policy, the Extended Producer Responsibility (EPR) framework through the Plastic Waste Management Rules. The primary goal of this policy is to reallocate the financial responsibility for waste management from municipal bodies back to the original producers.

- Legal obligations for these brand owners, producers, and importers of plastic are now required to collect and process a defined proportion of the plastic packaging they distribute.
- A centralized online portal facilitates producer registration and the exchange of EPR certificates, establishing a financial system that subsidizes the recovery of low-value materials such as multilayer packaging (MLP).

2.2.4 Challenges in Waste Management

Regardless of progressive policies, executing the collection and recovery of MLPs remains incredibly tedious due to ground-level realities:

- *Poor Source Segregation:* Around 48% of the municipal solid-waste is segregated at national level. When MLPs are mixed with wet organic waste, they become

heavily contaminated, making them unfit even for co-processing without expensive cleaning [3].

- **Dependence on the Informal Sector:** The entire collection network relies on informal workers who often operate without standard safety guidelines, adequate wages, or formal job security. Because their livelihood depends on the weight and resale value of the materials they collect, there is no organic incentive for them to pick up lightweight.

2.2.5 Relevant Literature Review

Table 2.1 explains about the different types of research papers which are done on the topic of Experimental laboratory testing, chemical analysis, shelf-life monitoring, Field surveys, stakeholder interviews, life cycle inventory in Cradle-to-grave by five phases. Finally a report about the impact assessment of different emissions came out from the manufacturer of MLP.

Table 2.1: Summary of Relevant Literature Review

<i>Highlight</i>	<i>Reference</i>
Experimental laboratory testing, chemical analysis, shelf-life monitoring of microfiltered milk under controlled temperatures.	[62, 67, 68, 69, 72]
Field surveys, stakeholder interviews, quantitative supply chain analysis of waste management practices.	[3, 76]
ISO 14040/44 compliant Life Cycle Assessment(LCA) analyzing carbon footprint, energy usage, and material sourcing.	[6, 8, 9, 19, 20, 40]
Establish standardized scientific methodologies and coefficients for calculating and mitigating anthropogenic greenhouse gas emissions.	[6, 10, 27, 47]
Cradle-to-gate thermodynamic and chemical inventory analysis of ethylene polymerization and polymer extraction.	[5, 17]

Life Cycle Inventory (LCI) parameters for processing, energy recovery, and disposal of post-consumer waste.	[4, 9, 16, 22, 24, 32, 33, 34, 42, 70]
FOUR/five-phase life cycle Inventory compilation (Raw materials, Processing, Transport, Use/Refrigeration, EoL) for water, fuel and electricity needs.	[15, 37, 38, 39]
To calculate the inventory input data of resources, manufacturing for different products.	[4, 9, 22, 70]
Mathematical characterization modeling, structural mass-intensity analysis, impact translation for LCA.	[2, 6, 21, 26, 41, 43, 65, 71]
Compare the holistic environmental impacts of diverse packaging materials (HDPE, LDPE, glass, cartons), for liquid dairy distribution.	[1,12, 25, 30, 36, 46, 47, 49, 50, 57, 62, 67]
To emission evaluation impact checking by openLCA.	[27, 35]
Report on Generation on Management of Wasted Food, waste collection of MLP, and sustainable recycle process.	[7, 11, 18, 23, 29, 30, 31, 44, 45, 51, 52, 54, 55, 56, 58, 59, 60, 64,73, 74, 75]

2.3 Research Gaps

- Almost all research studies omitted the impact of MLP printing within the LCA framework.
- Existing literature primarily focuses on five-layer MLP structures, while limited research has been conducted on six-layer MLP systems.
- The composition analysis of MLP samples is not done in the recent literature.
- Existing literature mostly does not explain Advanced recycling technologies, how to reduce water consumption to separate paper boards from MLP.

- Limited research has been conducted on improving the recycling efficiency of LDPE and aluminum layers.
- Comparison of MLP made using bio-based and fossil-based materials.
- Only a few articles study the integration of consumer behavior and misperceptions (greenwashing) [3, 18].
- There is a lack of region-specific Life Cycle Assessment (LCA) frameworks for evaluating MLP systems.
- Scarcity of geographical and infrastructure data about distribution and collection of waste at Tier-I, Tier-II and Tier-III cities.

2.4 Objectives:

The study aims to:

- Analyze the material composition of multilayer packaging (MLP) used for milk packaging.
- Develop a cradle-to-grave life cycle inventory (LCI) for MLP production and use.
- Evaluate the environmental impacts of MLP using Life Cycle Assessment (LCA) and OpenLCA.
- Assess environmental hotspots and improvement opportunities across the MLP life cycle.

2.5 Scope

- Area of one liter capacity MLP sample.
- Analysis of the material composition of MLP samples.
- Determination of moisture content in Three MLP samples.
- Make a framework Method of Life Cycle Assessment (LCA) for MLP production phase wise.
- Life Cycle Inventory (LCI) Analysis, (Emission Evaluation and Impact Checking via OpenLCA).
- Route Optimization Analysis: The logistical operation involved a transportation distance of 1,652 km for the extraction of aluminum from Koraput, Odisha. The transport vehicle, characterized by a 10-metric-ton capacity, maintains a fuel efficiency of 3.5 km per liter as specified by the manufacturer's technical data.

CHAPTER 3

METHODOLOGY

The LCA-based environmental impacts assessment undertaken in this study utilizes a cradle-to-grave approach as per the following international standard as presented in Table 3.1.

Table 3.1 Explains the reasons to need for ISO 14040 and ISO 14044 [8, 9, 10].

<i>Standard</i>	<i>Purpose</i>
ISO 14040:2006 - principles and framework	Global acceptance of research data, to define: ● Goal and Scope Definition ● Life Cycle Inventory (LCI) ● Life Cycle Impact Assessment (LCIA) ● Data Interpretation ● Types of approach(cradle-to-grave) ● Help to Global Comparison of LCA result of similar product and service.
ISO 14044:2006 - requirements and guidelines.	● Ensures scientifically verified, internationally accepted LCA procedures. ● Functional Unit Definition. ● Governs data collection, validation, and calculations for system inputs and outputs. ● Provides requirements for selecting and calculating environmental impact categories. ● Enforces strict data quality through Data Quality Requirements (DQR) ● Dictates reporting structures and third-party validation to prevent greenwashing and ensure fair comparisons.

3.1 Literature Search Methodology

Literature survey has been undertaken using the following details:

- *Database:* Scopus, ScienceDirect and Google Scholar.
- *Keywords:* “Dairy packaging materials”, “Life Cycle Assessment (LCA)”, “ISO 14040/14044”, “OpenLCA”, “multilayer pack” and “solid waste management in multilayer pack”.
- *Inclusion/Exclusion Criteria:* life cycle inventories, and lab-scale testing studies published globally. General web pages and non-scientific reports were excluded. Relevant reports published by government agencies and news sources were also reviewed.
- *Categorization:* Materials Science (biodegradable and polymer packaging), Environmental Science (LCA, carbon footprint, Method), and Dairy Technology (physicochemical preservation and packaging process).
- *Year:* 2020-2025.
- *Number of articles assessed:* A total of 77 peer-reviewed scientific articles were selected from 325 articles identified through Google Scholar and 18 articles retrieved from Scopus after applying the inclusion and exclusion criteria. applying various filters such as open access, language and regional, etc.
- *Leading topics:* packaging material extraction, process of manufacturing hotspot of environment impact, LCA Inventory data and emission impact studies of dairy supply chains.

This study was conducted in two stages, as described below.

3.2. Stage 1- MATERIAL COMPOSITION of MLP

Parameters such as moisture content (empty pack), mass-to-volume ratio, and material composition of a MLP of one-litre capacity, brick-shaped milk packets were found out [1,2]. The following step-by-step procedure was used to determine the physical composition by the weight ratio of the MLP.

- *STEP 1:* Sample preparation and pre-treatment (post-consumed multilayer packaging containers were collected and cleaned to remove any small amount of milk.)
- *STEP 2:* Determine the total weight of each container, each without moisture, using the Moisture Analyzer(Sartorius MA37 model) and laboratory oven. (The samples were dried in a laboratory oven, at a temperature of 105 degrees for 6 hours, and to ensure a dry weight, they are checked using the weight checking machine).calculate the moisture content in MLP.
- *STEP 3:* Determination of the material composition ratio.
 - The total mass of one multilayer package was determined. the surface area covered by the container.
 - Cut the sample into small pieces (approx. 1 cm x 1 cm).
 - Manually separated the outer layer of paper fiber (pulp) using water, leaving the plastic polymer and aluminum (LDPE + Al) laminate.
 - Treated the remaining (LDPE + Al) layer with a hydrochloric acid (HCl) solvent to remove the plastic films from the aluminum; calculated the weight of the aluminum (Al) and LDPE for the 1 cm² sample and converted it to the total weight by multiplying it by the total surface area.

Note:-

- A. The HCl solvent extraction process results in a ~10% loss of aluminum weight over a duration of 10 minutes in the solution.
- B. Weak acids such as acetic acid may provide a safer alternative for material separation. but strong acids like HCl are generally present in laboratories and must be diluted. (0.1 Molarity dilute, for 10min)
- C. For Safety: Concentrated HCl produces heat and hydrogen gas. This requires proper ventilation and skin protection; do not handle it directly and take all necessary precautions.

3.3 Stage 2- Life Cycle Assessment

The assessment was undertaken in the OpenLCA environment using impact assessment methods by ReCiPe 2016v1.03, midpoint(H) sourced from the EcoInvent v3.12 database. The cradle-to-grave inventory included fuel consumption, electricity requirements, renewable and non-renewable energy sources, and overall resource consumption.

Functional Unit: The functional unit considered for this project is 10,000 units of 1-litre milk MLP.

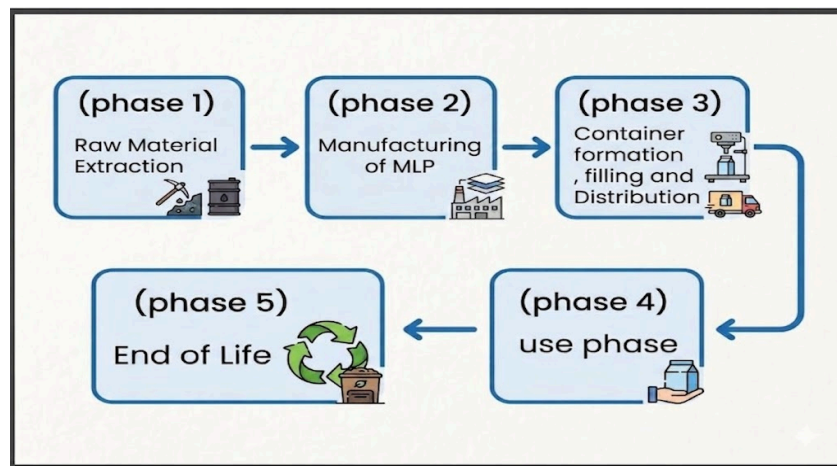


Figure 3.1. 5-Phases of Production

3.3.1 Extraction phase (Phase-I)

Raw material, energy consumption requirements were calculated, along with the total water demand. The primary aim of evaluating the extraction phase life-cycle impact is to perform a detailed quantification of all energy flows, material streams, and emissions associated with the acquisition of raw materials {specifically paperboard pulp, aluminum foil, and low-density polyethylene (LDPE)} (All calculations were performed using the material composition data presented in Table 4.1.)

3.3.1.1 UNIT PROCESSES FLOWS MODEL OF MATERIAL EXTRACTION FOR MLP MANUFACTURE.

PAPERBOARD: Forestry operation, wood harvesting, screening, pulp production, and paperboard.

ALUMINIUM: Bauxite mining, ore collection, primary crushing, screening, aluminum refining, and aluminum.

LDPE: Oil extraction, shipping (transport by ship/train), refining, cracking of naphtha to production of ethylene, and polymerization of ethylene-LDPE.

3.3.1.2 DATA COLLECTION

PRIMARY DATA: On-site specific production records to define fuel consumption accordingly: electricity (coal-based), transport types, and the amount of fuel used to cover the total distance, and total water consumption.

SECONDARY DATA:- Validated openLCA databases, document data vintage, research paper on different LCA data, geographical representativeness and different measurement methods.

QUALITY ASSESSMENT:- Firstly, define the baseline study: what amount of raw material needs to be studied, e.g., for 3.1 kg of plastic, how much petroleum is needed to study.

3.3.2 Production of MLP (Phase-II)

Once the raw material acquisition phase is complete, the gate-to-gate (raw materials enter the front gate of a factory to the moment the finished product leaves the back gate of that same factory.) Life Cycle Assessment (LCA) study shifts focus to the manufacturing facility. At this stage, the collected materials arrive at the factory, then the manufacturing process is done to be transformed into finished MLP rolls. The study outlines specific unit processes required for producing these packaging rolls. This involves a systematic collection of data regarding fuel and energy resource consumption, which is recorded in accordance with established manufacturing rules and based on the total 10,000 number of productions.

3.3.2.1 Flow chart of process for manufacturing of MLP:

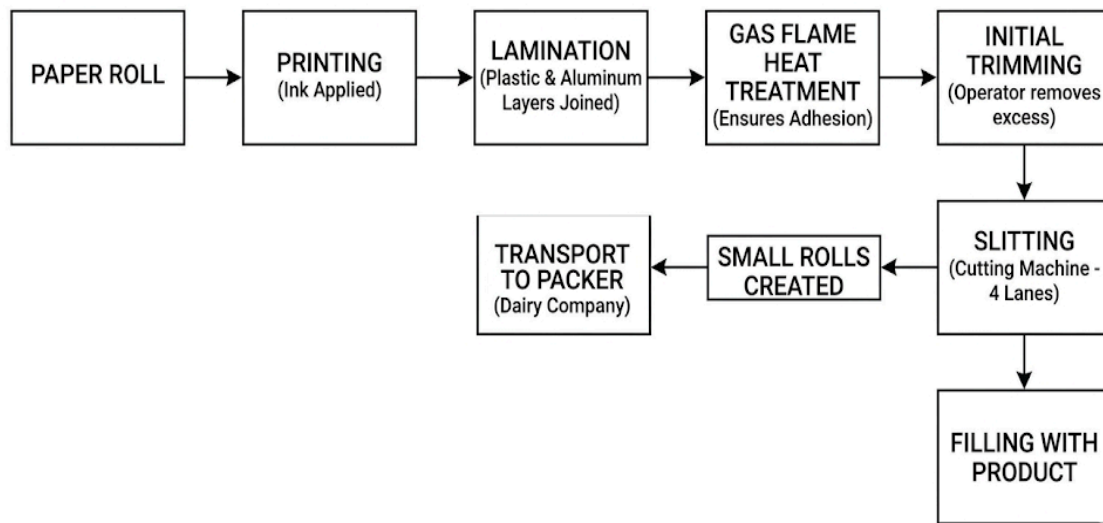


Figure 3.2- Multilayer Pack manufacturing Flowchart

3.3.2.2 Data collection process :

Primary Data: Primary inventory data was acquired from actual manufacturing records. To accurately quantify resource inputs, a controlled production batch of 10,000 1-litre multilayer milk packets was established as the baseline. The data collection focused on two primary operational inputs:

- The total coal-generated electricity consumed during the thermal lamination process, and the specific other process of machines (printing, roll formation, pressing).
- Vehicular diesel fuel required for the logistical distribution of the packaging rolls from MLP plant to the dairy company.

SECONDARY DATA:- compression of other research paper data and other types of data collection processes before the visit to the multilayer packaging factory. (Life cycle inventory of the production of roll packaging of multilayer packs to transport other dairy container forming industries.)

QUALITY ASSESSMENT:- to better collect data, to define a baseline of 10,000 liters, and accordingly determine the quantity needed, including the energy, fuel, and water consumption.

3.3.3 Container Formation, Filling, and Distribution (Phase-III): After manufacturing of MLP, printing, and transport to the dairy industry. Then internal plant operations start which are to convert MLP's roll in container form, then the filling process is done. Both processes are done in only one machine, Show we can not neglect the filling process. After the complete process of milk packing then preparing for the distribution process.

3.3.3.1 UNIT PROCESSES FLOWS MODEL

Roll Unwinding → Container Formation → Milk Filling → Carton Sealing/CHECK → Batch & Date Coding → Final Distribution

3.3.3.2 Data collection method

PRIMARY DATA:- in the dairy industry, production records of 10000 liters of milk capacity, to consume resources accordingly, need electricity(coal-based), transport types with the amount of diesel-type fuel consumption used to cover the total distance to retail/distributor and total water consumption for cooling of the adhesive heat press.

SECONDARY DATA:- compression of other research paper data and other types of data collection process before the visit to the dairy industry (life cycle inventory of production of packaging).

QUALITY ASSESSMENT: To better collect data, define the baseline (10000 liters) amount, and determine the quantity needed, including energy, fuel, and water consumption.

3.3.4 Use Phase (Phase-IV):

After the distribution of MLP milk reaches retail shops, where it consumes electricity for refrigeration. Electricity consumption has been determined by using refrigerator model sticker/specification labels. Storage time of these packets have been assumed to be 3 months (90 days).

3.3.4.1 UNIT PROCESSES FLOWS MODEL

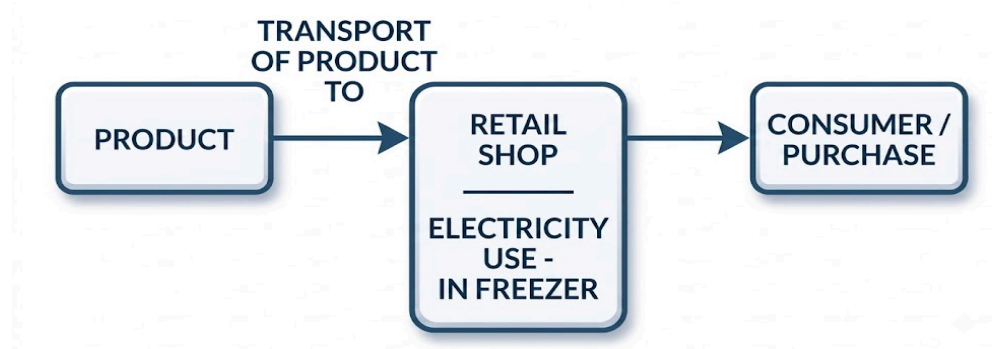


Figure 3.3 - Use Phase at Retail Shops

3.3.4.2 DATA COLLECTION.

Methodology steps in use phase:-

- Identify Refrigerator Wattage: Find the appliance nameplate (generally outside and front of the fridge) to locate the power rating. A standard use in a shop refrigerator typically runs approximately 200 watts when the compressor is not an issue.
- Factor in Duty Cycle: A refrigerator does not run at full power 24 hours a day. The compressor cycles on and off to maintain the temperature. On average, a refrigerator compressor runs for about 12 hours per day (50% duty cycle).
- Calculate Daily Energy Consumption: To find the daily consumption in kilowatt-hours (kWh), multiply the power rating by the operational hours and divide by 1,000 to convert watts to kilowatts:
- Project for 90 Days, consumption of electricity.
- The number of refrigerators(capacity 200 liters) needed is calculated.
- Total energy demand of all refrigerators.
- Converter into GJ consumption of electricity.

3.3.5 End-of-Life Phase (Phase-V): Waste management systems for MLP, have three options: recycle, incineration and Landfill.

- Recycle:- in this process use a machine to separate paper boards by water and recycle the paper for other use according to that process. Resources use water for pulping, electricity for machines to separate paper from MLP.
- Incineration:- Main resource used to transport fuel to transfer waste collection point to processing facility, combustion needs little amount of fuel to catch fire

according to the need of waste type. Recovery of energy: the MLP waste material used to produce heat in industry/power and convert it into a usable form like electricity or steam. It depends on the percentage of flammable material ratio of products (MLP is 90% and 85%).

- Landfill:- Main resource required transport fuel (to collect waste from household to collection point and then transfer to landfill dumping area; some fuel used for that heavy machine to manage the scientific dumping). Environmental concerns in the future have for a long time generated toxic liquid(leaching) and methane emission.

3.3.5.1 UNIT PROCESSES FLOWS MODEL FOR WASTE TREATMENT



Figure 3.4 - End of life and waste treatment

3.3.5.2 DATA COLLECTION

System boundaries: Data is collected for both Upstream (recycling) and Downstream (landfill) conditions to clearly understand the fuel, energy required, and the amount of energy recovered from the incineration process in waste management.

Primary data collection:

- To check routes of transport to cover the distance, types of vehicles (diesel truck).
- Input of waste material capacity, which is measured in metric tons.
- In sorting operations, maximums are done manually, in some mechanical facilities, electricity, water and fuel. In the multilayer packaging operation, to recycle facilities, 10kg of paperboard requires 160 liters of water, but they mostly choose the easy way: dumping it in a landfill [4,7]
- In the output inventory, water use for treatment, landfill and incineration emission (methane, carbon monoxide, carbon dioxide) needs to be added.

3.4 OpenLCA Tool using Methodology:

OpenLCA makes working with a dataset much more manageable to choose according to product type. To calculating Mass balance is required on both sides, encompassing the input inventory (service and resource use) and the output inventory (the product created 10,000 units of MLP, water used to treat waste, the remaining parts of multilayer pack from manufacturing cuts and sorting, and the emissions produced from the starting phase of production to the final landfill) [17,18,23].

3.4.1 Database Selection: The ecoinvent 3.12 Cutoff system model was chosen for this assessment because it is widely trusted on Indian manufacture condition and more similar aligns with ISO 14044 standards and the GHG Protocol. A major benefit of the cut-off approach handles environmental accountability, the original producer's responsibility for the raw material footprint. It offers highly relevant, current data for everyday background processes like the electricity grid and transportation.

3.4.2 Step-by-Step OpenLCA Execution:

The following step-by-step work-flow, how to execute the impact in openLCA.

Step 1: Software Setup & Method Import: Before building the model, establish your active database and background datasets in openLCA.

- A. Download your selected background 'EcoInvent v3.12' database from openLCA Nexus.
- B. Import the database file by right-clicking the navigation tab and choosing Import database.

Step 2: Define Flows & Parameters: Define the product's operation and units.

- A. Create a new folder under Flows (MLP).
- B. Create a new Product Flow for your reference product (production of MLP of 10,000 units) and set its reference property to Mass.

Step 3: Model Foreground Processes: Build the actual "unit processes" that represent the physical life cycle stages input of inventory data.

- A. Right-click **Processes** in the navigation panel and select Create New process..
- B. Open the **Inputs/Outputs** tab. Add your reference product flow in the Outputs section. Example given in figure 3.5.
- C. In the Inputs section, add raw materials and utility demands.

D. Enter direct elementary emissions in the Outputs tab.

Flow	Category	Amount	Unit	s/Revenues	Uncertainty	Avoided pr	Provider	Data quality	Location	Description
blown film co-extruded...	C:Manufacturing/22...	35.96000	kg		none					
diesel	C:Manufacturing/19...	464.84000	kg		none					
electricity, high vol...	D:Electricity, gas, stea...	2604.680...	kWh		none					
electricity, medium...	D:Electricity, gas, stea...	8523.780...	kWh		none					
hydrogen peroxide...	C:Manufacturing/20...	1.00000	kg		none					
metal working, ave...	C:Manufacturing/25...	30.23300	kg		none					
paper sack	C:Manufacturing/17...	243.27000	kg		none					
transport, freight, c...	H:Transportation and ...	0.00000	t*km		none					

Flow	Category	Amount	Unit	s/Revenues	Uncertainty	Avoided pr	Provider	Data quality	Location	Description
tetra package		10000.0...	Item(s)		none					
aluminium scrap, p...	Recycled content cut...	1.16800	kg		none					
residues from sorti...	E:Water supply; sewer...	1.38000	kg		none					
residues, MSWL w...	E:Water supply; sewer...	9.35400	kg		none					
Water, unspecified ...	J:Resource/in water	3.86955E4	l		none					

Figure 3.5 - Input/output data for production of multilayer packaging

Step 4: Link the Product System: Connect all individual unit processes into a single supply chain network.

- In the General Information tab, click the **Create product system** button.
- Add an impact assessment method (ReCiPe 2016 v1.03, midpoint (H)).
- Name the system, check **Auto-link processes**, and continuous ok click.
- Open the **Model Graph** tab to visually inspect the supply chain. According to figure 3.6.

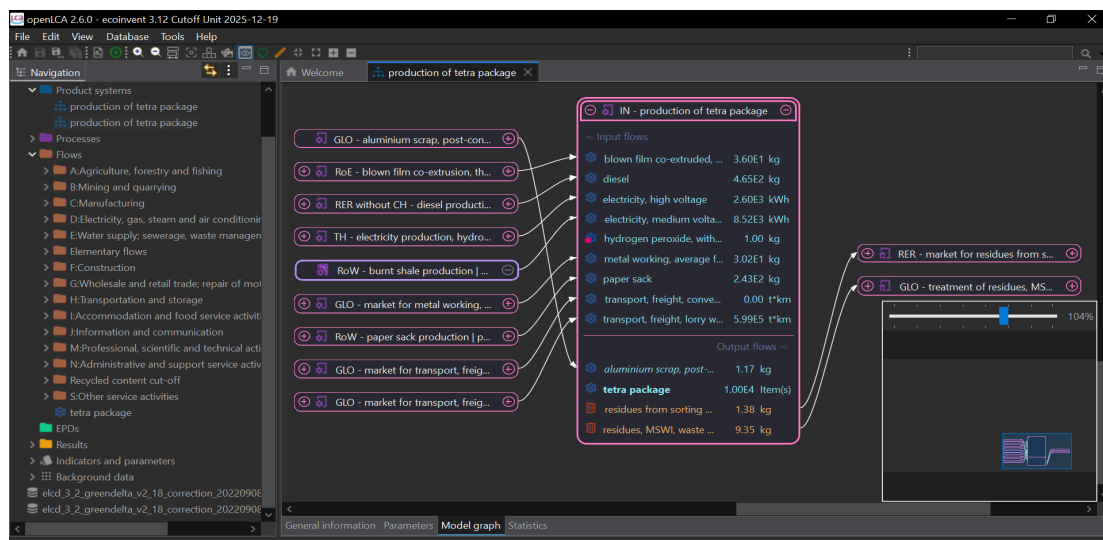


Figure 3.6- OpenLCA Model graph

Step 5: Run Calculations & Impact Assessment

To calculate environmental impact scores(result).

- A. In the General Information tab of your newly created Product System, click Calculate.
- B. Select an **LCIA Method** (ReCiPe 2016 v1.03, midpoint (H)).
- C. Click Start calculation. Once computed, navigate the LCIA Results tab to view the impact category totals.

Step 6: Identify Hotspots & Run Sensitivity Analyses

In the discussion phase to Evaluate the results, explore uncertainties, and test your modeling assumptions. According to finger 3.7:-

- Impact assessment result.
- Inventory result-input.
- Inventory result-output.

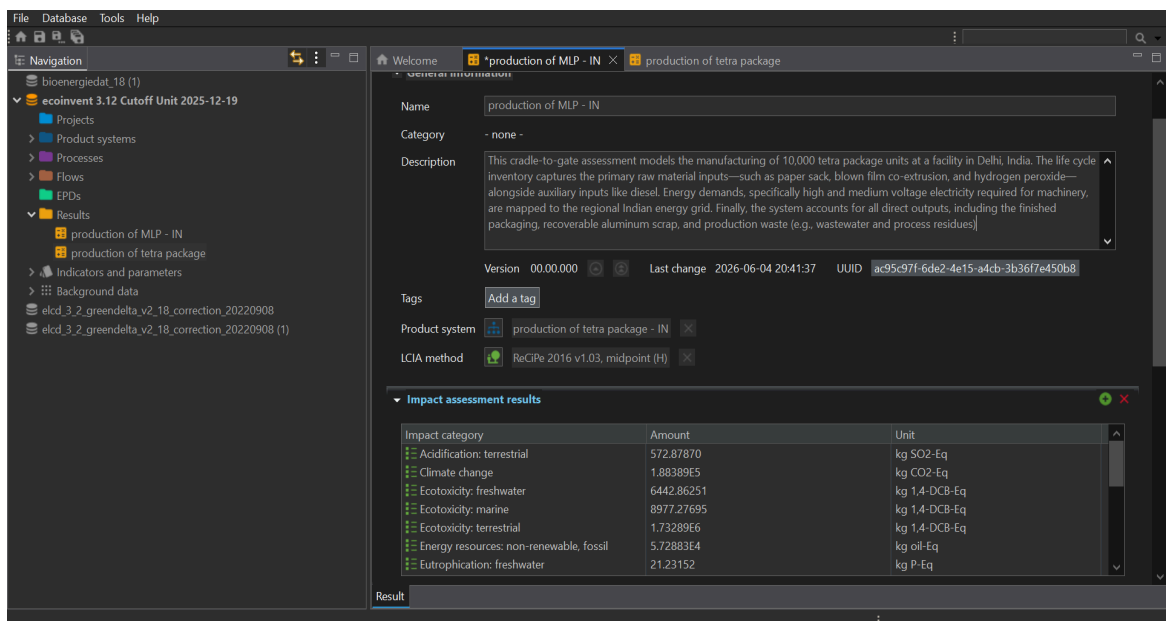


Figure 3.7- Result of impact analysis of production

CHAPTER 4

ANALYSIS

4.1 Material Composition of MLP (Stage-I)

The following step-by-step procedure was used to determine the physical material composition by the weight ratio of the MLP.

STEP 1: Sample preparation and pre-treatment (post-consumed MLP containers were collected and cleaned to remove any small amount of milk.)

STEP 2: Determine initial weight of a container, before using the oven or moisture analyzer to find out moisture content. After drying(without moisture) note the final weight of the Multi-layer packet at temperature 105°C [77, 78]. Moisture analyzers(fig.4.3) work on the thermogravimetric principle (The device measures a sample's initial wet weight, heats it using a halogen or infrared lamp to evaporate the water ,and continuously tracks the weight loss until the mass stabilizer, calculating final moisture content from the difference).

The loss in weight of the sample after heating represents the amount of moisture present in it. It is calculated in percentage as follows:

$$\begin{aligned}\text{Moisture Content \%} &= [(\text{Wet Weight} - \text{Dry Weight})/(\text{Dry Weight})] \times 100 \\ &= [(32.40371\text{g} - 30.0229\text{g})/30.0229\text{g}] \times 100 = 7.93\%\end{aligned}$$

$$\text{Moisture Content \%} = 7.93\%$$

NOTE-

- Sartorius MA37:- A compact, next-generation Moisture Analyzer choice for routine tasks with an updated touch screen user interface.
- Halogen moisture Analyzers:- Utilize a halogen lamp to heat and dry samples quickly. Best suited for rapid, everyday testing machines.

STEP3: Determination of the material composition ratio.

- (a) The total mass of one MLP was determined and the surface area covered by the container.

In Figure 4.3- Determination of total dry weight of MLP of 1-litre capacity, by check use of weight balance, gets a result.

- Total weight MLP = 30.0229g
- Without ink ink = 30.0229g - 0.274g = 29.7489g
- Surface area of open 1-litre MLP pack = 32.2 x 24.4 = 785.68 cm²

(b) Cut the sample into small pieces (approx. 1 cm x 1 cm), According to the given Figure 4.4- Total weight of multilayer pack (1 cm x 1 cm) found.

Total weight (1cm x 1cm) of MLP = 0.0721 g

(c) Manually separated the outer layer of paper fiber (pulp) using water, Fig 4.5 leaving the plastic polymer and aluminum (LDPE + Al) laminate.

Inner double layer of plastic + Aluminium layer = 0.0072g

(d) Treated the remaining (LDPE + Al) layer with a hydrochloric acid (HCl) solvent to remove the plastic films from the aluminum; calculated the weight of the aluminum (Al) and LDPE for the 1 cm² sample and converted it to the total weight by multiplying it by the total surface area.

Fig 4.6 Mean Wt. value of AL (1cm x 1cm) ~ 0.00125 (0.5cm x 0.5cm) x 4 = 0.0050g.

- Wt. of Al (1cm² x 1cm²) = (Inner double layer of LDPE + Aluminium layer) - (double layer of LDPE)
= 0.0072 - 0.0022 = 0.0050 g

Total wt. of Al = 785.68cm² x 0.0050g = **3.9284g**

- Wt. of single layer LDPE = {(Inner double layer of LDPE + Aluminium layer) - Al} / 2
= (0.0072g - 0.0050)/2 = 0.0011g

Four layer LDPE = 0.0011 x 4 = 0.0044g

Total wt. of LDPE = 0.0044g x 785.68 cm² = **3.4569g**

- Total weight of paper = total wt. of MLP without ink wt. - total wt. of LDPE - total wt. of Al.

$$= 29.7489 - 3.457 - 3.9284 = 22.3635 \text{ g}$$



Figure 4.1- Sample Packets.



Figure 4.2- Moisture removal process using a drying oven.

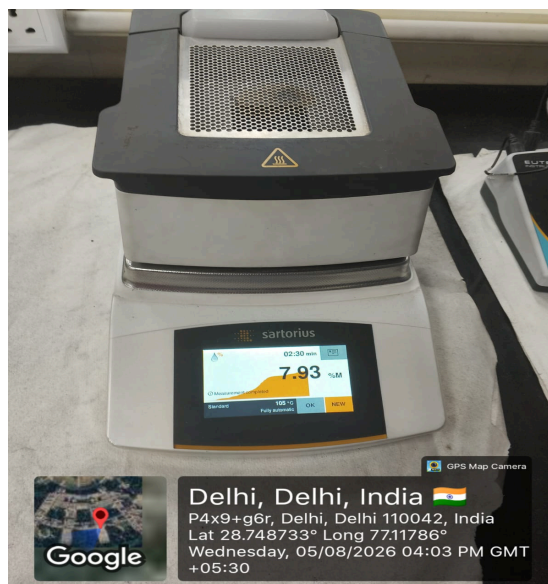


Figure 4.3- Moisture Analyzer (Sartorius MA37).

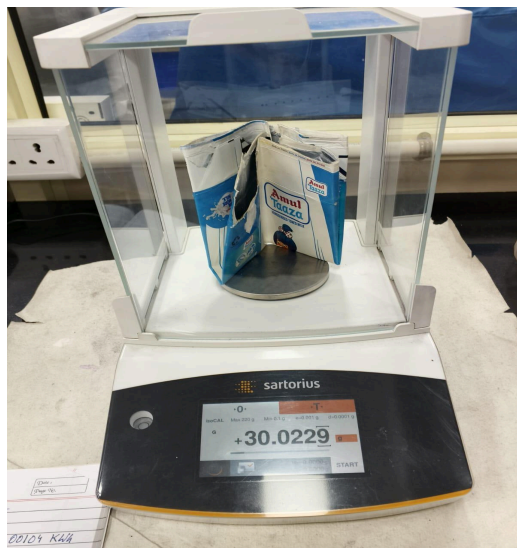


Figure 4.4- Determination of total dry weight of multilayer multilayer pack of 1-litre capacity



Figure 4.5- Total weight of multilayer pack (1 cm x 1 cm)

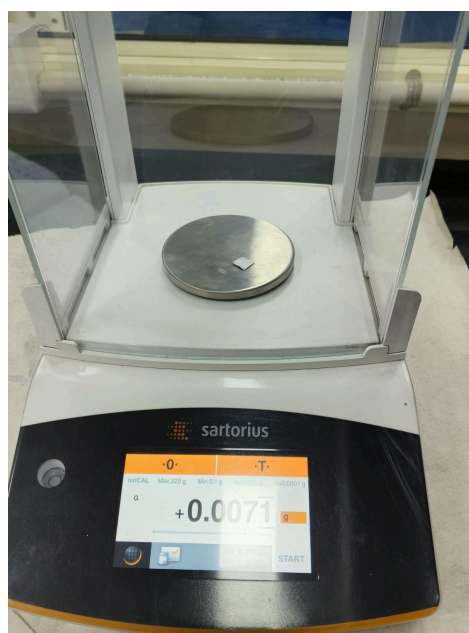


Figure 4.6- Weight of aluminium + LDPE (which cover into both side of aluminium)



Figure 4.7- Weight of aluminium (0.5 cm x 0.5 cm)

Table 4.1: Ratio of material use in production of multilayer pack

Material	Weight	Wt. in %
Paper board	22.3635g	74.488%
LDPE	3.457g	11.5145%
Aluminium	3.9284g	13.0847%
Water-based ink	0.272g	0.906%
Total	30.0229 g	~100%(99.9932%)

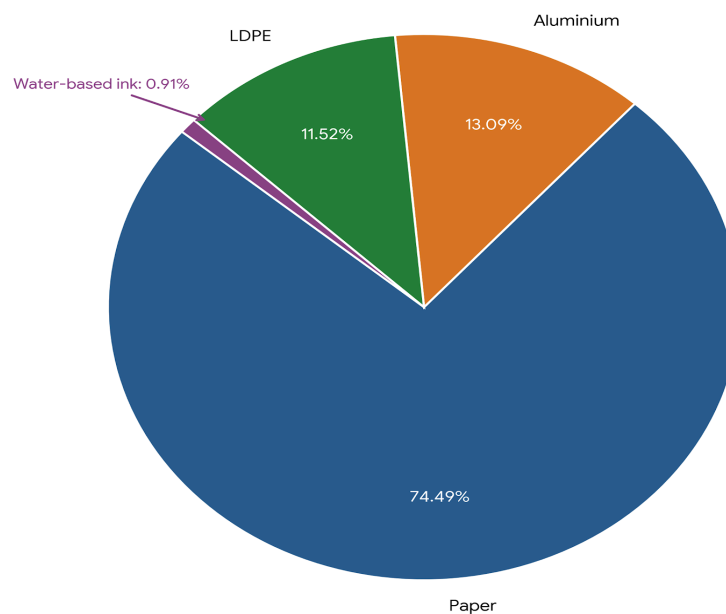


Figure 4.8- Pie-Chart showing composition of multilayer packaging

hence,

- The material composition of paperboard, plastic, and aluminium is 74.488%, 11.5145%, and 13.0847%, respectively.
- Moisture contains MLP = 7.93% from changing weight 32.4037g to 30.0229g after oven dry.
- The mass-to-volume ratio is found to be $30.0229\text{g}/1018.875\text{cm}^3 = 0.02947\text{g}/\text{cm}^3$.
- The area of 1 litre of MLP is 785.68 cm^2 .

4.2 Stage 2- Life Cycle inventory calculation

4.2.1 Extraction phase (Phase-I):

This initial stage involves the energy-heavy conversion of bauxite ore into pure aluminum, the refining of oil into plastic polymers, and the transformation of forestry resources into paperboard pulp. Requirements for this phase included 7.09398 GJ of electricity, 586.8 liters of industrial fuel, and 34,012 liters of water, with consumption driven largely by the high water needs of paper pulping and the energy demands of aluminum electrolysis.

This section establishes the system boundaries with help of table 4.1 for resource extraction, the amount of different material required, according to the 10,000 units + 3% of wasting material of MLP, in table 4.2-

Table 4.2: Amount of material required for doing LCA for 10,000 MLP.

Materials	Paper board	LDPE	Aluminium
weight	230.345 kg	35.6071 kg	40.46252kg

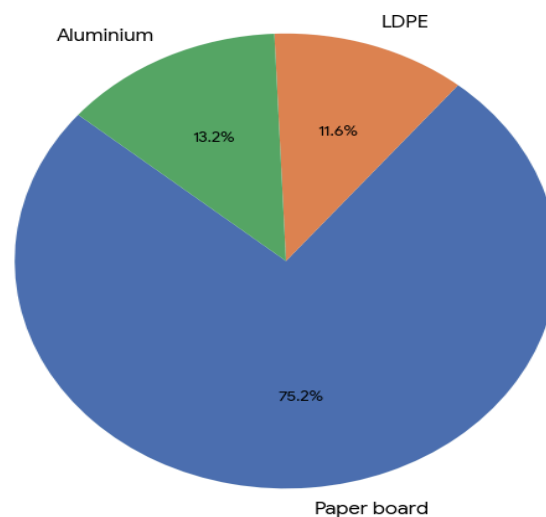


Figure 4.9: Material required for doing LCA.

4.2.2 Packaging Manufacturing(Phase 2):

This phase covers the industrial production where paper rolls are printed and then laminated with plastic and aluminum through a heat press lamination. The process also

includes slitting and trimming the material into distribution-ready in rolls form, consuming a total 0.931176 GJ of electricity and 471.43 liters of fuel to transfer to the dairy industry.

4.2.3 Container Formation, Filling, and Distribution(Phase 3):

This stage simulates the mechanical operations and regional logistics within local dairy facilities, mainly focusing on container formation to contain 10000 liters of milk filling and distribution footprints like those in Bihar or Delhi located retail shops. The recorded resource usage for this phase included 45.44 liters of diesel for transport and 0.29608 GJ of electricity. After discussion and visiting TETRA PAK, Dairy Automation Pvt.Ltd, GsPak and Sudha Dairy's plants. Talk with the working management head to know about what types of emissions and which phase of production has any environmental impact.



Figure 4.10- Sudha Dairy Industry (Bihar)

Figure 4.9 provides visual documentation of the primary fieldwork site for Phase 3, establishing the authenticity of the data collection of the dairy industry internal process of packaging of milk and distribution of dairy products.

4.2.4 Use Phase (Phase 4):

This phase evaluates the energy needed for refrigeration at the retail shops during 12 hours per day for a 3 months storage period. It represented the peak localized energy requirement of my study, consuming 45.5456 GJ of electricity.

Analysis done by the according to methodology steps:-

- Identify Refrigerator Wattage: Find the appliance nameplate (generally outside and front of the fridge) to locate the power rating. According to fig.4.10 use in a shop refrigerator runs approximately 143 watts/hour when the compressor is not an issue.
- Factor in Duty Cycle: A refrigerator does not run at full power 24 hours a day. The compressor cycles on and off to maintain the temperature. On average, a refrigerator compressor runs for about 12 hours per day (50% duty cycle).
- Calculate Daily Energy Consumption: To find the daily consumption in kilowatt-hours (kWh), multiply the power rating by the operational hours and divide by 1,000 to convert watts to kilowatts:

$$\text{Daily Consumption} = (143 \text{ Watts} \times 12 \text{ Hours}) / 1000 = 1.716 \text{ kWh}$$

- Project for 90 Days (according to Food Safety and Standards Regulation-2010, FSSAI for UHT treatment of milk for 90 self-life). Multiply the daily energy consumption by 90 days of continuous usage:

$$\text{Total energy for 90 days} = 1.716 \text{ kWh/days} \times 90 = 154.44 \text{ kWh}$$

- Number of refrigerators required (capacity: 421 liters), has net gross 180 litres capacity (approx.).

$$\text{No. of refrigerator} = \text{total quantity of packet/capacity of refrigerator} = 10000/180 = 55.5 \sim 56.$$

- Total amount required to fulfill the energy demand-

$$\text{No. of refrigerator} \times \text{one refrigerator energy consume} = 56 \times 154.44 \text{ kWh} = 8648.64 \text{ kWh}$$

- Conversion to gigajoules (GJ) = $8648.64 \times 0.0036 = 31.135104 \text{ GJ}$

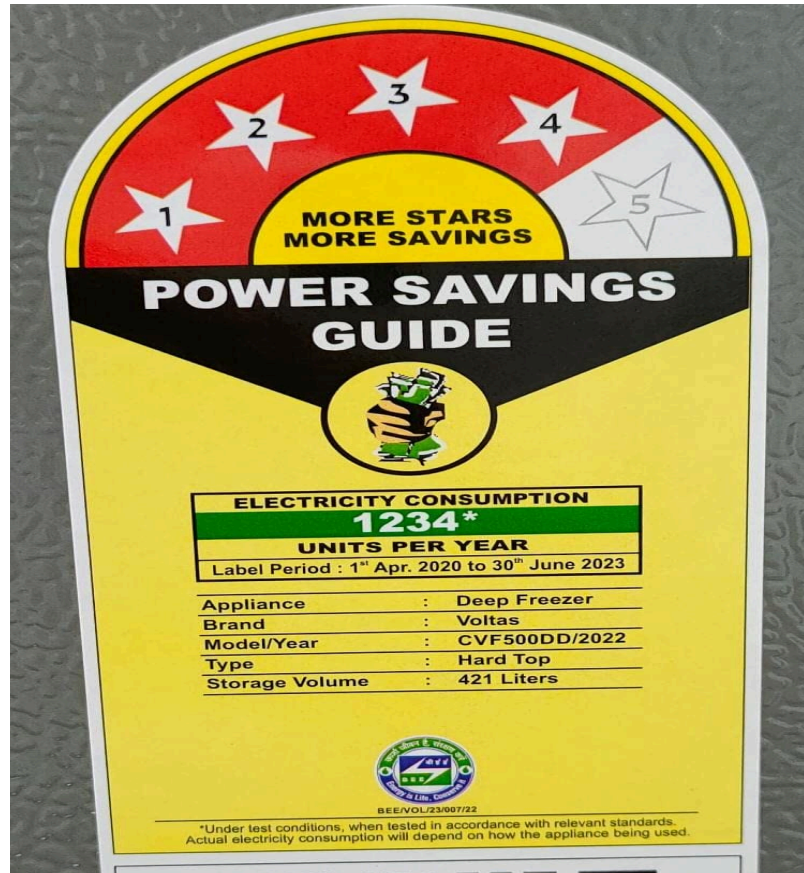


Figure 4.11: Image of voltas deep freezer model label.

Source of figure: Google image

4.2.4 End of Life and Waste Treatment (Phase 5):

This phase evaluates the final disposal of materials through various waste management systems. Standard municipal landfilling requires 30 liters of fuel for collection from household waste to transport at landfill area and 0.5364 GJ of electricity. On the other side, secondary closed-loop mechanical recycling necessitates 3.8358 GJ of electricity and 4,688.57 liters of process water to separate the paperboard and remain LDPE and AL foil melting into reusable table and chair products. Another option, thermal incineration is capable of recovering a maximum of 20.76 GJ of energy when operating at peak facility efficiency of 95 percent. All data combined explain in table 4.3, which are collected data from ground level conditions in Shalimar Bagh- Delhi location, local SWM collection and treatment area.

Table 4.3: Solid waste management metrics for recycling, incineration, and landfills.

Phase 5: End of life.					
Steps	Process	Electricity (GJ)	Fuel (L)	Water (L)	Energy recovery (GJ)
<i>Mechanical Recycling</i>	Material separation and recovery	3.836	23.00	4688.57	0
<i>Incineration (95% Eff.)</i>	Thermal treatment & energy capture	0	34.00	0	20.760*
<i>Incineration (80% Eff.)</i>	Thermal treatment & energy capture	0	34.00	0	16.980*
<i>Landfill Disposal</i>	Municipal collection and dumping	0.536	30.00	0.000	0

* change according to the types of industry and different power plant data.

4.3 Limitation according to LCA phase of MLP:-

Extraction phase (Phase-I):

If you go on site, they are not allowed to see for many reasons, such as it is not a safe area, and the company has its own reasons for not sharing data on resource raw material collection and how much energy/fuel is required for it. Main issue production of multilayer pack it's made of three goods (paper, LDPE, Aluminium), there paper analysis is more easy than other two which petroleum and aluminum, so that reasons they make dependent on the secondary data of other study which are done on the different life cycle assessment study and combine it in one place according of its amount of quantity needs. Resource and budget constraints limited the extent of on-site data collection.

Production of MLP (Phase-II):

- Around 3% of waste is generated from cutting the multilayer packaging during production, which is the lowest among other industries, so they are not interested in any sustainable activity (3Rs).
- These are not proper standards for measuring the weight and thickness of paper according to GSM (grams per square meter), which varies across companies. They do not properly explain or share the data, showing that we can use laboratory tests to determine the weight ratio relative to the total weight of the MLP.
- There is a limitation of studying ink LCA, as the company redesigns from time to time, and it is not easy to calculate their weight and emissions. These are dependent on secondary data.

Container formation, filling (Phase-III):

LCA of ink: limited data on ink production due to limited coverage of system boundaries; measurement errors in energy use, distance covered, and social health are neglected; the environmental impact is not clearly defined for where ink is produced and disposed; generally, it is determined by the market. Limited data shared by dairy companies: companies allow limited time for industry visits, show the production process properly, but lack the expertise to explain how much electricity machines consume and do not share electricity/fuel bill data.

4.4 EMISSION HOTSPOT IDENTIFICATION :-

Extraction phase (Phase-I):-

- Raw material extraction process and pollution in the area:- heavy tree cutting in the forest to get paper, extraction of earth under resources, which impacts upper natural resources(water, upper fertile land, resulting in loss of forest area, which affects humans and animals to find new places and increases the distribution between humans and animals.
- Transportation types:- Transport is main emission list in every research but in resource extraction main issue to select types of transport use with different fuels

uses, in our topic of MLP paper board and aluminum transfer by truck and train because of present of resources in our country in plastic which is byproduct of petroleum product these are imported from gulf countries which transport by heavy petroleum fuel consumption ship.

- Ore processing and its mechanical tools:- there are regular changes of technology to more effectively collect resources in the deepest layer of earth to extract, and geological surveys are not as effective as fast to collect data of that place. At the point of emission, heavy machines consume fuel at a high rate, with low average work per litre, and electricity is generated from coal to operate mines.

Production of MLP (Phase-II):-

- waste of extra cutting part of the multilayer pack roll.
- transportation of the MLP roll from the production plant to dairy companies.
- Due to limited data on ink production and limited coverage of system boundaries, data on measurement errors in energy use, distance covered, and social health are neglected. The environmental impact is not clearly defined; where not clear information about ink is produced and disposed of is generally determined by the market.

Container formation, filling (Phase-III):-

Transport in Delhi and Muzaffarpur-like cities, which use mostly non-refreeze trucks, but in the openLCA database take refreeze lorry, with 3 to 4.5 ton capacity, but different per litre diesel fuel consumption of 3.5L/km. Which has a greater environmental impact from fuel emissions and the distance covered around the city to collect milk from farmers, transfer it to companies to process, and sell it to city-area retail shops, which is around 168 km.

End-of-Life Phase (Phase-V):-

In fig4.11 show collection and recycle operations. In recycling facilities, 10kg of paperboard requires 160 liters of water to recycle. In practice, a substantial proportion of MLP waste is disposed of through landfilling due to economic and operational limitations. Other types of data required are vehicle types (diesel truck) to cover how

much distance and incineration process is useful in one site when energy is recovered by burning as a fuel source in industry. But on the other hand in incineration process, it is the more pollution created compared to other processes in a short time.



Figure 4.12: Paperboard collection area

CHAPTER 5

RESULT AND DISCUSSION

5.1 Inventory of LCA Phases (Stage-II)

Table 5.1 details the resource consumption required to process the functional unit of 10,000 liters (requiring 300.22 kg of packaging material).

Table 5.1: Life Cycle Inventory Data for Multilayer Packaging (10,000 units of 1-litre milk pack)

	Multilayer Packaging		
Material Required	306.41462kg		
	Electricity (GJ)	Fuel (L)	Water (L)
Phase1	7.09398	586.8*	34012
Phase2	0.931176	471.43	*
Phase3	0.29608	45.44	*
Phase4	31.135104	0	*
Phase5			
Recycling	3.8358	23	4688.57
Incineration(95%)	20.76(Energy Recovery)*	34	0
(80%)	16.98(Energy Recovery)*	34	0
Landfill	0.5364	30	0

*may vary according to transport types.

To calculation according to resource use in production of MLP in Table 5.1 :-

Energy uses: The highest energy consumption was observed during Phase I (raw material extraction) and Phase IV (refrigeration during use). In phase1 has heavy duty machine use in extraction in mine of aluminium and bauxite ore processing by electrolysis than in pure form of aluminum. In Phase4 refrigerator needs 31.135 GJ.

Transport: In phases 1 (586.8L) and 2 (471.43L), the maximum is due to Plastic feedstock transportation contributes significantly to fuel consumption because the supply

chain involves long-distance transportation from Gulf countries to Indian processing facilities, Gujarat, to the Jamnagar refinery, then to the Pune factory, rather than to Delhi-located dairy industries. Phase 3 (45.44L of diesel) to transfer the product from the factory-packed to the retail shop.

Water consumption: total water consumption (38712 l) is mostly needed for phase 1 due to the pulping of paper industries; in aluminium production, a cooling process is required in ore-to-metal production; and similarly, in petroleum, oil is converted to plastic LDPE.

Energy recovery (16.98 GJ): In incineration processes, generally, the maximum burn is not achieved, so the practical incineration percentage is 85% due to lower moisture content, with the inner side covered by LDPE and aluminium, and the outer side covered by a single LDPE layer .

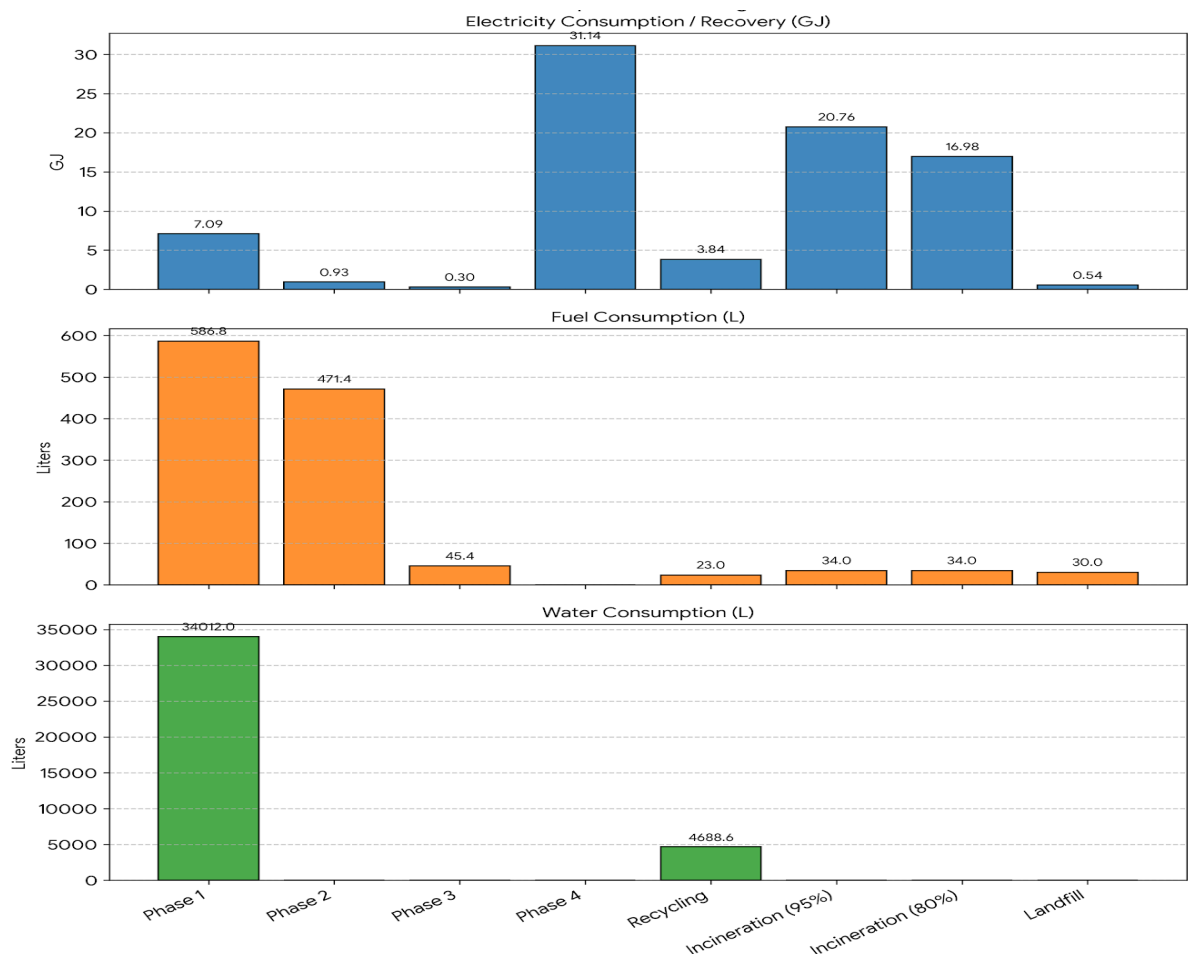


Figure 5.1- Lifecycle inventory data for various phases of the production cycle

5.2 Emission during cradle-to-grave life cycle assessment.

The openLCA software generated an extensive inventory of emissions resulting from the production of the functional unit and a summary of the most critical emissions is provided below.

Table 5.2: Output Emission during 5 PHASE of LCA for 10 thousand units of MLP.

<i>Emission</i>	<i>Unit</i>	<i>Amount</i>
Carbon monoxide	kg	288.887
Carbon dioxide	kg	6988.62
Sulfur dioxide	kg	185.08297
Nitric oxide	kg	1009.87053
Ozone	kg	0.1068
Tetrachloroethylene	kg	7.6622E-5
VOC, volatile organic compounds	kg	4.73362
PM, < 2.5 um	kg	66.69978
PM, > 10 um	kg	138.63747
PM, > 2.5 um and < 10um	kg	32.31372
Tetrafluoromethane	kg	7.66227E-5
Methane	kg	571.7551
HCL	kg	4.3158
1,1,1,2-Tetrafluoroethane	kg	1.26928E-5
Hydrogen	kg	2.48888
Vinyl chloride	kg	6.0605E-4
Ammonium	kg	6.167
BOD5	kg	298.37254
COD	kg	1410.76751

TOC	kg	426.45685
DOC	kg	951.62614
Ethane	kg	0.47278
Ethanol	kg	0.00470
Formic acid	kg	2.43864E-6
1,1,1-Trichloroethane	kg	7.3979E-5
1,1-Difluoroethane	kg	0.00334
1,4-Diethylbenzene	kg	0.00265
2-Nitrobenzoic acid	kg	6.02005E-7
Acetaldehyde	kg	1.504038
Acetic acid	kg	0.02664
Acetone	kg	0.03877
Ammonia	kg	3.30375
Benzene	kg	0.71348
Butane	kg	5.80541
Calcium II	kg	417.51244
Carbon	kg	15.29848
Carbonate	kg	5.12090
Chloride	kg	1239.89195
Copper ion	kg	26.07291
Formaldehyde	kg	2.79172
Iron ion	kg	177.464003
Iron-59	kBq	3.87518

Krypton-85m	kBq	21.34454
Lead-210	kBq	870.45528
Magnesium	kg	27.40734
Nitrate	kg	14.08417
Nitrogen	kg	112.62292
Nitrogen dioxide(surface water)	kg	6.22101E-7
NMVOC	kg	318.8537
Phosphate	kg	49.41569
Polonium-210 (air)	kBq	11.33448
Potassium I (water)	kg	120.82269
Sodium I	kg	924.62850
Sulfate	kg	1070.72038
Sulfur (surface water)	kg	1.66296

The Table 5.2 presents the emissions generated during the five phase of life cycle assessment of Multi-layer milk packets of 10,000 units. These results, derived using the ecoinvent 3.12 database, specifically highlight emission values that meet or exceed a threshold of 10^7 with is relative.

5.3 Impact Assessment Report

The table 4.4 shows the result of inventory data was processed using the ReCiPe 2016 v1.03, midpoint (H) impact assessment method to quantify specific environmental burdens.

Table 5.3: Impact Assessment Results

S.no.	Impact category	Unit	Impact score
1	Acidification	kg SO ₂ -Eq	539.55
2	Climate change	kg CO ₂ -Eq	183207.610
3	Ecotoxicity: freshwater	kg 1,4-DCB-Eq	6484.910
4	Ecotoxicity: marine	kg 1,4-DCB-Eq	8977.289
5	Ecotoxicity: terrestrial	kg 1,4-DCB-Eq	1730625.71
6	Energy resources: non-renewable	MJ	57288.356
7	Eutrophication: freshwater	kg P-Eq	18.405
8	Eutrophication: marine	kg N-Eq	4.293
9	Human toxicity: carcinogenic	kg 1,4-DCB-Eq	10308.95
10	Human toxicity: non-carcinogenic	kg 1,4-DCB-Eq	118974.71
11	Ionising radiation	kBq Co-60-Eq	1670.578
12	Land use	m ² *a crop-Eq	5337.319
13	Material resources: metals/minerals	kg Cu-Eq	4453.929
14	Ozone depletion	kg CFC-11-Eq	0.0286
15	Particulate matter formation	kg PM _{2.5} -Eq	227.530
16	Photochemical oxidant formation: human health	kg NO _x -Eq	1056.783
17	Photochemical oxidant formation: terrestrial ecosystems	kg NO _x -Eq	1093.667
18	Water use	m ³	272.857

The inventory impact assessment result (Table 5.3) highlights the environmental burdens associated with the start of large-scale production and disposal in landfill of 10000 multilayer packet for dairy industry :

Energy & carbon footprint: The environmental impact of multilayer packaging (MLP) in the dairy industry is substantially influenced by its energy and carbon footprint. Both the manufacturing phase and the refrigeration required during the use phase are energy-intensive and mostly depending on a coal-based power grid. The system consumes a total of 57,288.36 MJ of non-renewable energy. This direct dependence on coal contributes to a significant climate change impact score of 1.83×10^5 kg of CO₂ equivalent, establishing the lifecycle of the packaging as a major contributor to greenhouse gas emissions.

Ecotoxicity: The highest overall burden falls under Marine Ecotoxicity (8977.2890 kg 1,4-DCB-Eq), followed by Human Toxicity (12.928 10^4 kg 1,4-DCB-Eq). This points to show chemical or heavy metal releases into water bodies, like stem production from the aluminum extraction from Bauxite mining and polymer LDPE production phases refineries.

Acidification and Eutrophication:Regional impacts like acidification (539.55kg SO₂-Eq) and eutrophication (22.693kg PO₄-Eq) are in table 5.3, to show the paper pulping process and the combustion of fossil fuels across the supply chain by 10 tons capacity of lorry.

Photochemical oxidant: In atmospheric process, where primary pollutants {nitrogen oxides (NO) and volatile organic compounds (VOCs)} reaction in the presence of sunlight to create highly reactively toxic, to converted into secondary pollutants, form as ground-level known as bad-ozone as the most harmful for human health which is 1093.667kg ethylene-Eq from producing by source of transport truck and mining of aluminium.

Figure 5.2 explains the impact categories on the y-axis against a logarithmic scale on the x-axis. The analysis shows that acidification, climate change, and terrestrial ecotoxicity represent the most significant potential environmental impacts. The main sources are the extraction of natural resources including non-renewable energy, metals/minerals, and water/land use exhibits a relatively nominal effect. Results explain, lower impacts were

observed for ozone depletion and marine eutrophication. Regarding social impact metrics, elevated values were recorded for human toxicity (both carcinogenic and non-carcinogenic) and PM formation. both of which mainly influence the air quality from manufacturing factories and raw material extraction areas.

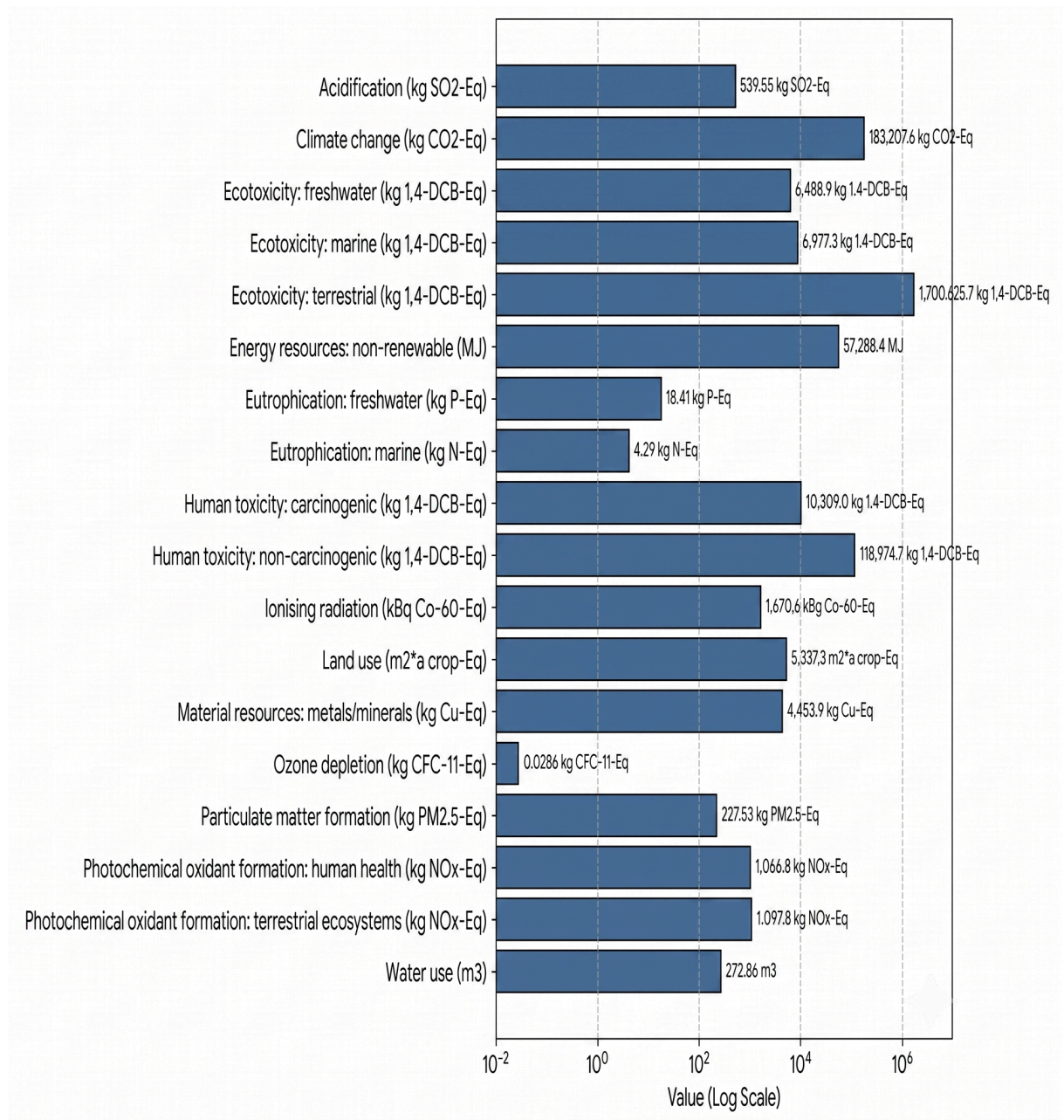


Figure 5.2 - LCA Environmental Impact result.

CHAPTER 6

CONCLUSION

The analysis of MLP reveals a material composition of 74.488% paperboard, 11.5145% LDPE, and 13.0847% aluminum. While the high paperboard part supports recyclability, the bound LDPE and aluminum layers present more challenges to recycling, often making some new conversion into products like furniture a more viable alternative than traditional recycling. Environmental hotspots were identified across the production cycle, with the fourth phase peaking in electricity consumption and the fifth phase requiring high water volumes for paperboard recovery. On the other hand thermal incineration at 95% efficiency can recover 20.76 GJ of energy, it causes heavy atmospheric emissions that compromise environmental quality. In the end recycling is identified as a more sustainable end-of-life procedure than landfilling or incineration, highlighting the role of effective waste management in developing into a circular economy. The study further shows environmental burdens through inventory impact assessments for large-scale production and disposal.

6.1 Environment Impact Assessment:-

The inventory impact assessment result highlights to show environmental burdens associated with the starting of large-scale production and disposal in landfill of 10,000 multilayer Packet for dairy industry:

Climate Change and Energy: Greenhouse gas emissions are found higher, resulting in a climate change impact score of 183207.610 kg CO₂-Eq. The main reason is non-renewable energy from coal base giving us a footprint 2.49763E6 MJ.

Ecotoxicity: The highest overall burden falls under Marine Ecotoxicity (8977.289 kg 1,4-DCB-Eq), followed by Human Toxicity (10308.95 kg 1,4-DCB-Eq). Both points show chemical/heavy metal releases into water bodies, due stem production from the aluminium from Bauxite mining and polymer LDPE production phases refineries.

Acidification and Eutrophication: Regional impacts like acidification (539.55 kg SO₂-Eq) and eutrophication (8977.289 kg PO₄-Eq) are in table, to show the paper pulping process and the combustion of fossil fuels across the supply chain by 3.5 tons capacity of lorry.

4

Photochemical oxidant: In atmospheric process, where primary pollutants {nitrogen oxides (NO) and volatile organic compounds (VOCs)} reaction in the presence of sunlight to create highly reactively toxic, to converted into secondary pollutants, form as ground-level bad-ozone as the most harmful for human health which is 1056.783 kg ethylene-Eq from producing by source of transport truck and mining of aluminium.

6.2. Social Impact and Alignment with SDGs:-

Positive Impacts: Biggest benefit is the ability to maintain food safety and quality without requiring preservatives or refrigeration, which improves energy conservation. This ensures repeated food security in areas with limited milk resources by making use of over-production that might otherwise go to waste. In addition, the packaging offers lower risks during transit; compared to glass, it is lightweight and has a brick-like rectangular shape that optimizes cargo space in logistics trucks.

Negative Impacts: Multiple negative impacts persevere, the multilayered structure where materials are tightly bonded, necessitating specialized recycling processes that require additional energy. Furthermore, the recycling process is water-intensive; for every 10,000 multilayer Pack units, 4,800 liters of water are required to separate the paperboard from the aluminum and LDPE layers.

Alignment with SDGs:-

Direct SDG Linkages: Figure 5.1 presents the direct SDG alignment with the outcomes of the project, listed below:

- **SDG 9 (Industry, Innovation, & Infrastructure):** Continuous study of Life cycle analysis (LCA) to research how to improve product time to time analyzing the environmental inputs of resources and outputs of the final product and recycling the cutting waste resources.
- **SDG 12 (Green Jobs):** Instead of just throwing things away, a “circular economy” finds a use for them. Building and running a new collection chain system creates sustainable employment opportunities ("green jobs"). Plus, it fundamentally changes how we consume and produce things, drastically cutting down on the sheer volume of trash we generate.

- **SDG 13 (Greener Cities and Climate Action):** When organic waste rots in a landfill, it releases methane, which is a powerful greenhouse gas. By composting it instead, we instantly cut down on those carbon emissions, making our cities more sustainable and actively fighting climate change.

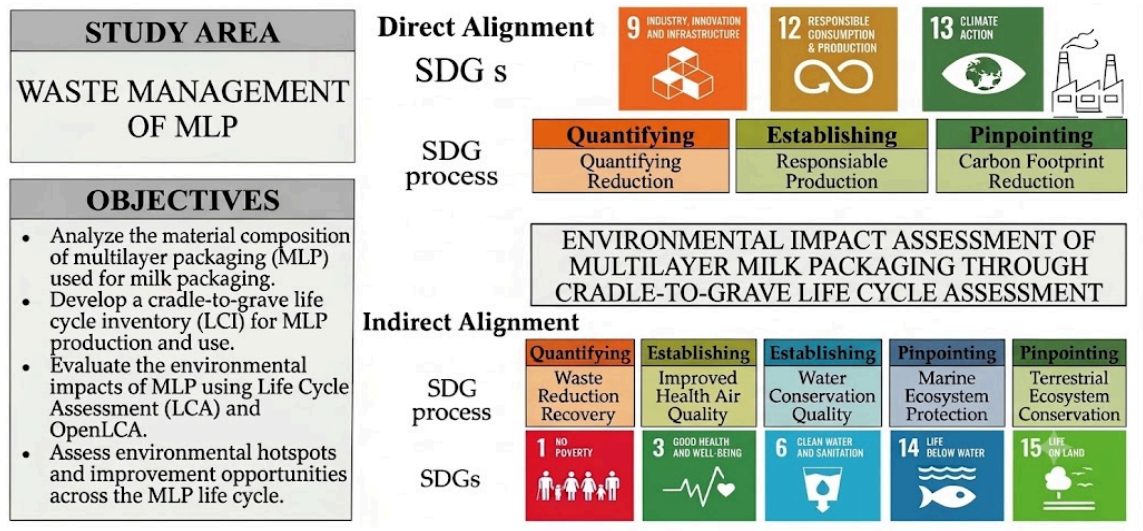


Figure 6.1: SDGs Linkages

- **Indirect SDG Linkages:** Secondary positive effect in SDGs target due to resource or service use during production and waste management of MLP. which effects are job creation (green job), replanting (long time resource present), water treatment (not effect future health of human and land water resource), food nutritive value manage (improve health to save food resources).
- **SDG 1: No Poverty (Economic Resilience & Green Job Creation.):** Low-income communities are historically the most unsafe to industrial pollution, often facing steep medical bills from poor air/water quality of every affected city in India. By improving health outcomes (SDG 3) and innovating industries (SDG 9), we reduce these financial burdens. How to reduce, transitioning to sustainable models creates new “green jobs” in resource recovery, waste management, and clean energy, providing steady income opportunities that help lift communities out of poverty.
- **SDG 3: Good Health & Well-being(Improved Air Quality):** As LCA targets the reduction of harmful industrial emissions and carbon footprint, it indirectly

leads to cleaner air. This decreases the risk of respiratory illnesses and improves overall public health in societies which are nearby industrial areas.

- **SDG 6 & 14 (Cleaner Rivers and Oceans):** Sustainable technology uses less water and reduces harmful chemicals (ink for printing and plastic waste) which leak into ground water and treat before supply to keep drinking water safe.
- **SDG 15 (Healing the Land):** Reducing waste in manufacturing of MLP, preventing pollution in air and water and replanting of paper manufacturing plants(resource recovery). Which helps to protect forests, soil quality, and land-based wildlife from their habitat destruction.

6.3 Future Scope:

The research can be help to industries and future researcher through following are:-

- Refinement of LCA inventories to main high-resource consumption nodes within the extraction and manufacturing phases, enabling industries to implement targeted reductions in electricity and water use.
- Find alternative material options, such as bio-based LDPE or enhanced mono-material laminates, to simplify the complex six-layer structure and improve global recycling efficiency.
- Centralization of localized geographical and infrastructural data to develop different region waste management frameworks for Tier-I, II and III cities in India. Set economical value of MLP waste, to increase collection by rag pickers.
- Building direct, collaborative relationships with these companies. Getting our hands on primary, ground-level extraction data will make our life cycle inventory (LCI) much more accurate and true to actual industrial operations.
- Research and invest in innovative, low-water mechanical or chemical separation technologies to separate paper board, LDPE, and aluminum foil. Which has less economic cost for recycling in future.
- To minimize resource consumption by prioritizing the use of local or nearby raw materials. reduce transport routes within the dairy industry supply chain can lead to significant reductions in fuel consumption and associated greenhouse gas emissions.

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VITAE

Mr. Adarsh Kumar Qualification: M.Tech. (Environmental Engineering); B.tech. (Civil Engineering) Technical Skills: AutoCAD, STAAD Pro, Revit Core Competencies: Project Cost Estimation (Materials, Labour & Overheads), Foundation Design, Sewage System Design Areas of Interest: Environmental Engineering, Wastewater Management, Sustainable Infrastructure Design, Life Cycle Assessment. Estimation and costing. Contact: adarshksuman@gmail.com	
Mr. Anunay A. Gour Designation: Assistant Professor, Department of Environmental Science & Engineering, Delhi Technological University, Delhi Qualifications: Ph.D. (Pursuing), M.E. (Civil–Environmental Engineering), B.E. (Civil Engineering), Diploma in Civil Engineering, AMIE Areas of Research: Environmental Engineering, Solid Waste Management, Waste-to-Energy, Environmental Impact Assessment, Life Cycle Assessment, Water & Wastewater Engineering, Air Pollution, System Simulation & Modeling Contact: anunaygour@dtu.ac.in, anunaygour@gmail.com	