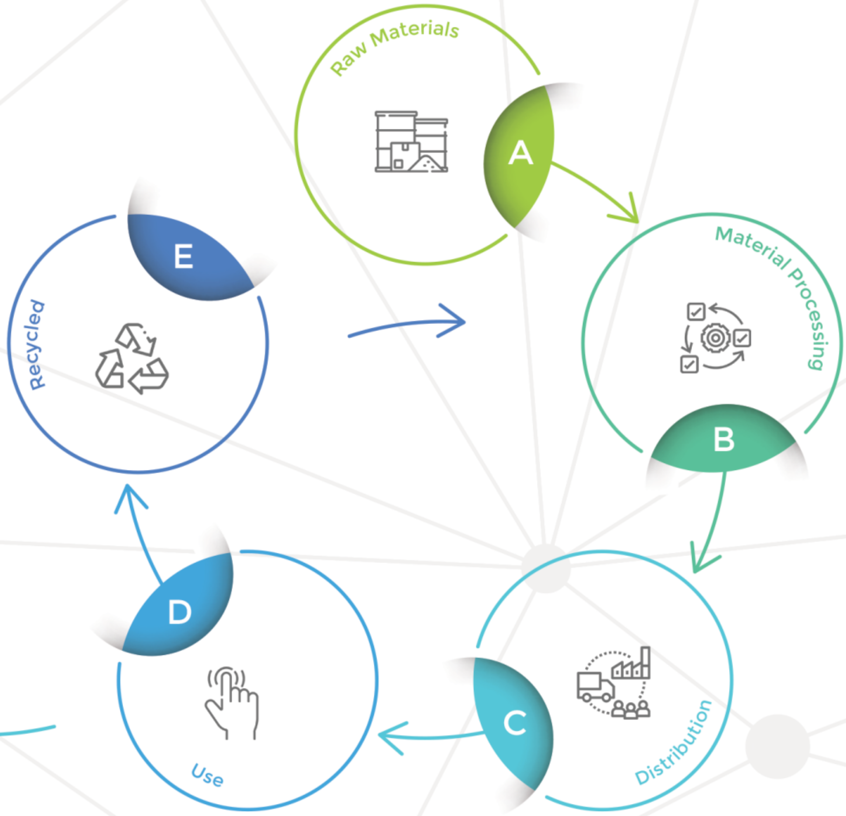

IMPACT OF PACKAGING FILM (MONOLAYER POLYETHYLENE) THICKNESS ON SUSTAINABILITY & CARBON FOOTPRINT

Published by
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Federation House, Tansen Marg, New Delhi, 110001
and
Aspirelabs Accelerator, Noida, Uttar Pradesh

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New Delhi, December 2021

Acknowledgement
We would like to express our gratitude and appreciation to all those who have contributed to this report. We would like to acknowledge all the suggestions from various stakeholders including Petrochemical Industry, Manufacturers, Brands, Recyclers, Not for Profit Organizations and Academia. The development of this report has been possible with the effort of FICCI team and Aspirelabs team with support from IIT Delhi.

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FOREWORD

Plastics constitute a very important segment of the Indian economy and contribute significantly to the growth of various key sectors such as Automotive, Agriculture, Construction, Electronics, Food Processing, FMCG, Healthcare, Textiles and others. They form an integral part of industrial value chains.

Plastic is a highly desirable material and finds wide industrial applications due to its properties such as low cost, light weight, durability and high strength, and contributes to enhancing a product's shelf life. The same properties unfortunately also make its disposal a challenge. This has serious social, environmental and economic implications.

In India, approximately 707 million metric tons/year plastic products are manufactured, and the majority of the plastic material goes to packaging applications, with about 80% of the plastic consumed being used in the packaging sector. Although the per capita consumption of plastic in India is only 11 kg, less than the world average, addressing the challenge of plastic waste is a key global priority for all stakeholders including governments, private sector, civil society and citizens and there is an urgent need to design and implement low carbon footprint packaging systems to bring circularity to the complete value chain of plastic production and use.

Considering the scale and severity of the challenge, the Indian government seeks to eliminate single use plastic and thus has exhorted municipalities, NGOs, and businesses to come up with ways for reducing and safely disposing of waste plastic.

This report produced by FICCI and aided by IIT Delhi and Aspire Labs in partnership with industry members provides a scientific analysis of the impact of higher micron thickness on the environment, economics, and collection efficiency of waste plastic. This study uses empirical evidence to demonstrate the results. FICCI has undertaken this initiative to help provide a direction to policymakers on the basis of a scientifically conducted research output and to aid in the development of a sound and robust policy and regulatory framework that will facilitate the effective implementation of plastic waste management by providing the basis for determination of micron thickness.

We thank IIT Delhi and Aspire Labs for conducting the scientific research and analysis. We would also like to thank our industry members for supporting what we believe is a unique initiative that will boost sound environmental and economic management of plastic waste in the country.

Dr Mukund Govind Rajan
Chair, FICCI Plastics Waste Management Committee

FOREWORD

Aspirelabs Accelerator, through its Startup Accelerator Programs & Consultancy on Plastic Recycling and Life Cycle Analysis, has been assessing technological and economic trends in Circular Economy and Plastic Sustainability Innovation areas. Aspirelabs has been supporting related startups in their entrepreneurial pursuit for more than four years now. The Accelerator programs are focussed on early-stage start-ups. Key supports given to them are i) Quality mentorship ii) Access to Market iii) Fundraising support. Over last four years, Aspirelabs has been able to help more than 50 start-ups in their entrepreneurial pursuit.

Green House Gas (GHG) emission and Life Cycle Assessment (LCA) studies are a first step to scientifically understand the carbon footprint of a product or a service. Over the past years, Aspirelabs has included detailed understanding of GHG and LCA in its value-added offering and engaged with academia and corporates to inculcate concept of carbon neutrality in their product and process design.

From the analysis and Aspirelabs' s broader work done till now in Life cycle assessment area, the evidence suggests that material reduction and recycling, are the two most effective ways to reduce carbon footprint of a product through its life cycle from cradle to cradle.

Reimagine Plastic is one such focussed initiative where Aspirelabs is catalysing and promoting application of Circular Economy concepts in Plastic industry value chain from 'cradle to cradle'.

Interest in Life Cycle Analysis and Greenhouse gas emission calculations are increasingly becoming need of the hour as a selection criterion for responsible producers and consumers. At Aspirelabs we look forward to work with organisations to accelerate this transition.

Ranjit Singh
Founder-Director, Aspirelabs Accelerator

FOREWORD

"Consecutive and interlinked stages of a product or service system, from the extraction of natural resources to the final disposal."
- ISO 14040.2 Draft: Life Cycle Assessment - Principles and Guidelines

Life cycle study, as defined, has been accepted, so as to have complete knowledge about the advantages and the challenges for waste management in due course of life. The essentials of Life Cycle Assessment (LCA) is considered to introduce today's trends towards increased transparency of packaging life cycles and environmental impacts covering basic inputs and outputs of life cycle assessments using standard methods, tools, and datasets. The study undertaken shall be useful in putting forward the best practices in terms of materials selection, micron thickness and recyclability to guide decision-making, set priorities, and accurately communicate product attributes to manufacturers and consumers.

The key to successful packaging is to select the package material and design that best satisfies competing needs with regard to product characteristics, marketing considerations in terms of distribution and consumer needs, environmental and waste management issues, and cost. Significant research work on packaging materials is in progress to develop desired performance properties and applications; many such technology development projects are being translated into commercial products. The common sustainable packaging trends are downsizing the weight/thickness of packaging materials, introducing biomaterials and/or bio-based materials, improved recycling and increasing the use of recycled content.

The ever-increasing concern over the sustainability underlines the need for constantly improving our quantitative sustainability assessment skills. This requires engagement in frontier research and offering high-quality training, courses and post-graduate education in sustainability and LCA related courses using the highest scientific standards. In my opinion, LCA can be used as a means of teaching many key environmental and engineering concepts and introducing students to the uncertainties present in real-world problems.

One of the key learning from LCA in this study is to endorse usage of Post-consumer resin (PCR) as one of the ways to reduce overall carbon foot print of the product. Use of PCR to replace the virgin material as part of the policy is therefore strongly recommended.

Prof. Anup.K.Ghosh
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Indian Institute of Technology Delhi, India

GENESIS

Plastic is a very useful material for packaging from retail to medical to food products, however safe disposal of it remains a big concern globally (Geyer et al. 2017). Sustainability of plastic packaging depends on three factors – 1) type of material 2) quantity per pack 3) safe disposal & recycling efficiency at scale.

There is an urgent need to design and implement low carbon footprint packaging systems to bring circularity to the complete value chain of Plastic. Globally, it has been witnessed that understanding of its recyclability and required technologies and infrastructure are still evolving. Various strategies have been adopted by several policymakers to bring plastic into a circular economy system. Still fundamental understanding of its circularity & science-based views on the same are in elementary stage.

As per Plastic Waste Management (PWM) Rules (2016) it is referred that "plastic sheet or like, which is not an integral part of multi-layered packaging and cover made of plastic sheet used for packaging, wrapping the commodity shall not be less than fifty microns in thickness except where the thickness of such plastic sheets impair the functionality of the product". As film thickness is assumed to be a key reference here, and with above background, this work is an attempt to develop a literature on thickness aspect of film and its role in circularity. The intent is to create a scientific view through life cycle analysis approach to calculate carbon footprints of different thicknesses of Monolayer Polyethylene Film, one of the widely used plastic materials for numerous packaging applications.

Figure 1: Schematic diagram – cradle to cradle

Source- Core team

ACRONMYMS

CO_2	Carbon dioxide
FU	Functional Unit
GWP	Global Warming Potential
GHG	Green House Gases
HDPE	High Density Polyethylene
ISO	International Organization for Standardization
KW	kilo Watt
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LDPE	Low Density Polyethylene
LLDPE	Linear Low-Density Polyethylene
LPB	Liquid Packing Board
MDPE	Medium Density Polyethylene
N_2O	Nitrous oxide
PCR	Post-consumer Resin
PF	Packaging Films
PE	Polyethylene
PP	Polypropylene
PS	Polystyrene
UNFCC	United Nations Framework Convention on Climate Change
WRI	World Resource Institute

EXECUTIVE SUMMARY

Monolayer Polyethylene (PE) film is one of the most common materials used for packaging applications. Over the years, unsafe disposal and mismanagement of post-consumer waste has forced government and policymakers to relook at its usage pattern. One of the policy approaches proposed has been to increase the thickness of packaging material. It is believed that more thickness will provide enhanced financial incentives to rag pickers to pick disposed plastic packaging and hence is more efficient from a recycling perspective. However, this approach comes with trade-offs. The approach adds more plastic into the environment apart from direct enhanced economic costs.

Therefore, it makes sense to consider incentive mechanisms to improve post-consumer plastic packaging. And the key point is to how to balance the incentivizing the collection, sorting activities involved vis a vis resource efficiency of plastic which is ultimately ending up into the environment.

To analyze and understand this better, in this report attempts have been made to present scientific evidence on:

1) Total CO_2 equivalent of PE film packaging released from cradle to cradle[1];
2) Degree of recycling and its correlation with thickness of PE film packaging;
3) Environmental and socio-economic impacts of different micron size thickness (35,50 and 100 micron) of PE monolayer packaging film;
4) The 'optimum environment' friendly plastic packaging thickness in the Indian context.

The scientific evidence to answer these questions will help us make an informed choice with regard to the trade-off between *"benefits of recovery efficiency" vs "increased plastic footprint on the environment"*.

Methodology

We used a combination of primary and secondary research methods for this study. We began by reviewing global literature and best practices around the packaging thickness and compared them to Indian practices. This was followed by lifecycle analysis of monolayer Polyethylene packaging from Crude to Post Consumer processing. We conducted detailed technical analysis of 35-, 50- and 100-micron thickness by using inventory collection and substantiation with the stakeholders. Data inventory received was further validated and analyzed through Life Cycle Analysis software and database.

Findings

Plastic bags in India have significantly less carbon footprint than countries like China and Hong Kong, due to the reuse option. LDPE bags are the most environment friendly when compared to other plastic packaging in the fossil fuel-based category[2]. Single use HDPE bag of 24 microns when recycled for 100 %[3] was found to be the best performing in terms of environmental impact. LDPE carrier bags have the lowest environmental impacts among the environmental indicators

[1] Cradle to cradle can be defined as the design and production of products in such a way that at the end of their life, they can be truly recycled (upcycled), imitating nature's cycle with everything either recycled or returned to the earth, directly or indirectly.

[2] Central Pollution Control Board (CPCB) 2018, Ministry of Environment, Forest & Climate Change, Govt. of India

[3] Russo, V., Stafford, W., & Nahman, A. (2020). Comparing Grocery Carrier Bags in South Africa from an Environmental and Socio-Economic Perspective (Issue April).

The life cycle analysis of 3 thicknesses (35, 50 and 100 microns) was conducted and revealed that when the micron thickness of Virgin Polyethylene is increased from 35 microns to 50 microns, the global warming potential increases by 72-73%. On the other hand, increase in micron thickness from 35 microns to 100 microns increases the global warming potential by 321-323%.

Also, post-consumer recycled granules lead to reduced global warming potential by 28% and 137% for 50 micron and 100 micron respectively w.r.t. 35 micron.

Recommendations

On basis of the analysis, this report recommends the following,

1) For Brand owners: Use monolayer film preferably for packaging keeping in mind appropriate thickness & size of bags based on their functional and transportation requirements. A Minimalist material approach in term of thickness as well as packaging per pack is recommended for a lower GWP.
2) For waste pickers: Waste pickers do not differentiate while collection of film, since the increase of thickness isn't very discerning to the eye. Therefore, thickening of standard packaging film will do more harm to environment by increasing the amount of plastic in the environment, with insignificant improvement in collection rates. Therefore, thicker packaging is not recommended at all.
3) For Recyclers: Appropriate recycling infrastructure needs to be created for PE recycling. Current infrastructure needs both for collection and recycling needs to be scaled up using PPP model to make it self-sustainable.
4) For Manufacturers: Use PCR along with virgin raw material. Also, PCR application to new products and applications should be explored.

Detailed Report

1. INTRODUCTION

1.1 PREAMBLE

Plastic has become an integral part of our daily lives and its production around the world reached 360 million metric tonnes in 2018. It is expected to grow exponentially however the advantages are increasingly subsided by the negative impact due to unsafe disposal post the consumption. Over the years plastic waste has piled up in the landfills, oceans and the pace it gets generated is already in exponential growth. Questions are being raised on the material itself, which scientifically is referred as a wonder material bringing packaging functionality with light weight and has significant advantage when compared to its many substitutes.

With the help of science-based method and tools around Life Cycle Assessment, we are aiming to understand issues as following -

1) The correlation between micron thickness of monolayer packaging and its impact on the environment.
2) The Trade-offs between higher collection efficiency leading to higher recyclability versus lower material resource efficiency & higher carbon footprint.

This study is an attempt to bring clarity to industry personals, product users, policy makers, focused groups, academia etc. as a research work reference and further engage them in science-based approach for a sustainable plastic packaging. Based on consultation with the key stakeholders, the main focus/goals of this study are as following -

1) To identify and evaluate options for measuring the resource reduction and recyclability efficiency of packaging film
2) To recommend an approach to establish requirements for film thickness vis-a-vis recyclability in packaging and
3) To decide how data on the resource and recyclability efficiency of packaging products might most effectively be included in the selection guide.

It has been estimated that about one third of global plastic production is used in single-use plastic products. Single-use plastic is "an umbrella term for different types of products that are typically used once before being thrown away or recycled" (UN Environment Programme, 2018). In 2017-18, India consumed 16.5 million tonnes of plastic around 43% of manufactured plastics were used for packaging purposes. As per the Ministry of Petroleum and Natural Gas (India), it is assessed that the per capita consumption in 2016 was around 12kg and is expected to reach to 20 kg by 2022.

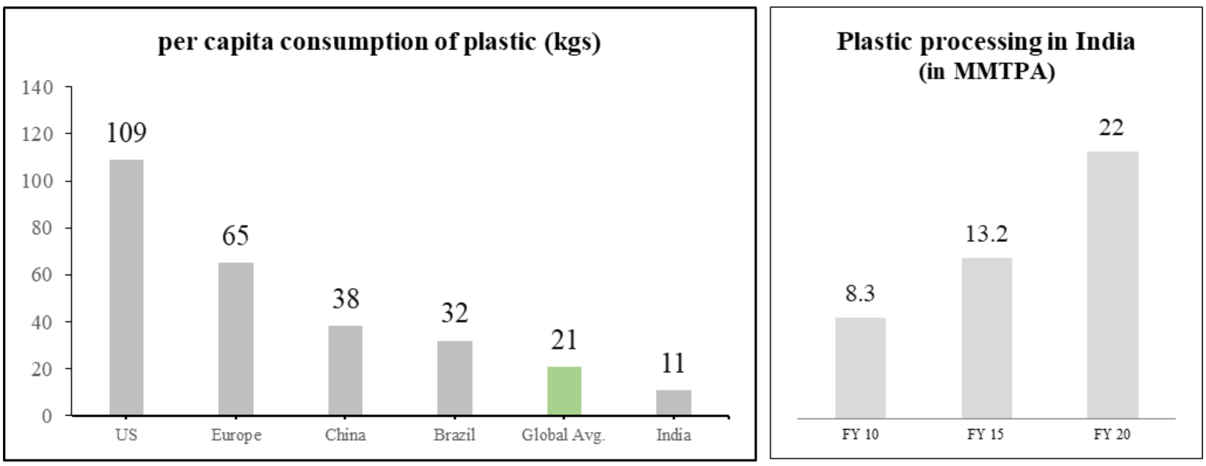


Figure 2: Per capita consumption of plastic & Plastic processing

Source: Source AIPMA and Plastindia report

Packaging is the fifth largest sector in India's economy and is one of the highest growing sectors. According to the Packaging Industry Association of India (PIAI), the plastic sector is growing at 22% to 25% per annum. Further a study on "Plastic Packaging – the sustainable choice" by FICCI in partnership with TATA Strategic management group states that plastic packaging industry in India is estimated around $73 bn in 2020.

Figure 3: Various categories of Polyethylene bags
Source: Core team

While industry is growing fast with increasing demand due to rapid urbanization, emerging middle class, rising living standard and larger workforce, plastic once utilized by a consumer remains unsafely disposed. It has been experienced that post-consumer waste management and infrastructure is in fragile stage and increasingly becoming the challenging task for policy makers and governments. Over last decade this problem has surfaced and reached to alarming level due to its sheer volume and polluting the landfills and oceans. This problem further gets aggravated due to limited options to substitute this material.

Plastic waste management is an issue which is becoming a global challenge. Circular Economy systems are being designed for safe disposal of plastic waste, collection, segregation and recycling. Earlier studies suggest that only 14-15% of the plastic packaging used globally makes its way to recycling plants, and only 9% is actually recycled – while a third is left in fragile ecosystems, and 40% ends up in landfill. According to World Economic Forum, plastic packaging waste represents an $80–$120 billion loss to the global economy every year.

Figure 4: LDPE packaging - for a variety of packaging applications
Source: Core team

While efforts on system designs and infrastructure are taken up in accelerated manner, as per Plastic Waste Management Rules (2016) is it recommended that monolayer films for packaging application needs to be 50 micron an above. The thickness restriction on lower side has been put, in intent to help waste pickers in their efforts to collect loose plastic. However scientific view on thickness of film remains to be understood mode clearly.

Table 1: Material & Thickness of study

Type / Material	Notation	Description
All kind of Products/Hygiene /Confectionary Plastic / Fossil-based	LDPE_35	LDPE; with thickness of 35 micron
	LDPE_50	LDPE; with thickness of 50 micron
	LDPE_100	LDPE; with thickness of 100 micron

Source- Core team

Packaging Material made of plastic has been described as the world's number one item used by consumers and have been considered a symbol of a "throw-away" society (Nipper & Thompson, 2019; UN Environment, 2018). Packaging Material of different micron thickness are preferred for its characteristics (light weight, corrosion resistance, moisture proof, highly versatile) and versatility of applications (Food, Beverage, Healthcare, Cosmetics, Personal Care, and Household Care). There are numerous packaging options (Paper, Plastic, Metal) in the market, but one of the most commonly used packaging materials is polyethylene film (PF). In India, environmental problems related to these packaging materials are attracting more regulatory and public attention. Additionally, packaging standards have become more stringent with introduction of new Indian norms closer to global standards which also drives the manufactures to use substitute materials. Policymakers from around the world have responded to the problem of packaging material by implementing several regulations, such as bans, levies or obligations to provide information about the negative environmental impact of plastic bags.

In order to arrive at which alternative is more sustainable to replace certain micron size packaging material can be quite controversial. Currently, different micron thicknesses of PF are currently being used. It is essential to consider the potential impacts across the full life cycle of a thicker product and its alternatives. Life cycle assessment (LCA) is one of the best suited for carrying out such similar comparisons.

This study was commissioned to review earlier research work, international practices and create scientific view around different thicknesses of monolayer PE film for Indian conditions. We have assessed three thicknesses of monolayer Polyethylene Film (PFs) made varying in terms of their recycled content; degrees of reusability and recyclability.

Table 2: Base case for study and Life cycle analysis

Product	Thickness (micron)	Avg. Area (sq.m)	Avg. wt./bag (g)	Avg. Yield (# of bags/Kg)
Product-1	50	0.22	10.28	199.49

Source: Bulk packaging for products from supermarket

2. GOAL OF THIS STUDY

The aim is to evaluate the environmental impact and footprint of the monolayer polyethylene packaging film of different micron thicknesses which are used for packaging different materials (from retail to health, to hygiene, to confectionary to food packaging etc). And to understand correlation of sustainability & Carbon footprint of it with variation in thickness. This is done with the study of Life cycle analysis, which is a globally accepted scientific method to understand sustainability and carbon footprint of any material.

To understand the impact in totality, the study has been divided in 3 distinct parts as following:

Module-1: Cradle (Crude/Virgin Granules) to Gate 1 (Monolayer PE Film package)
Module-2: Gate-1 (Film Package with Product) to Gate 2 (Post-consumer waste)
Module-3: Gate-2 (Post-consumer waste) to Cradle (PCR Granules)

- 3a: Reutilizing scenario with Reuse 0%; Recycle 80%, Waste 20%
- 3b: Reutilizing scenario with Reuse10%; Recycle 72%, Waste 18%

2.1 SCOPE & METHODOLOGY

The scope of the study is a cradle-to-cradle approach of life cycle assessment (LCA) which begins with the extraction of raw materials used in the packaging bags till the disposal of same after consumer use.
The scope of an LCA study based on ISO 14040 includes the following items:

- The product system to be studied and its functions
- The functional unit
- The system boundary and allocation
- Impact categories selected and methodology of impact assessment
- Data requirements and Assumptions
- Limitations of the study
- Initial data quality requirements
- Type and format of the report required for the study

The functional unit (FU) for this LCA is taken as 1 million bags of 35-micron thickness polyethylene film manufactured in India. In order to understand the life cycle impacts of PE film compared to similarly used materials, this LCA provides a comparative analysis between different product thickness (50 & 100 micron). To compare them, the products must be evaluated based on the same FU to ensure they have the same effective functional use. All analysis conducted is based on the FU, so as to fairly compare the relative inputs and outputs of the life cycle of each product.

We began the study with secondary research (literature review). Then primary research, including inventory collection and substantiation of same with stakeholders was carried out. Data inventory received was further validated and analysed through latest Life Cycle Analysis software and database. Overall the project is conducted through Life Cycle Assessment (LCA) approach. The methodology used is globally recommended to compare carbon footprint of materials. The standard used are as per ISO 14040 and ISO 14044 (ISO 14040 2004; ISO 14044 2006).

The analysis was carried out in 3 modules as follows:

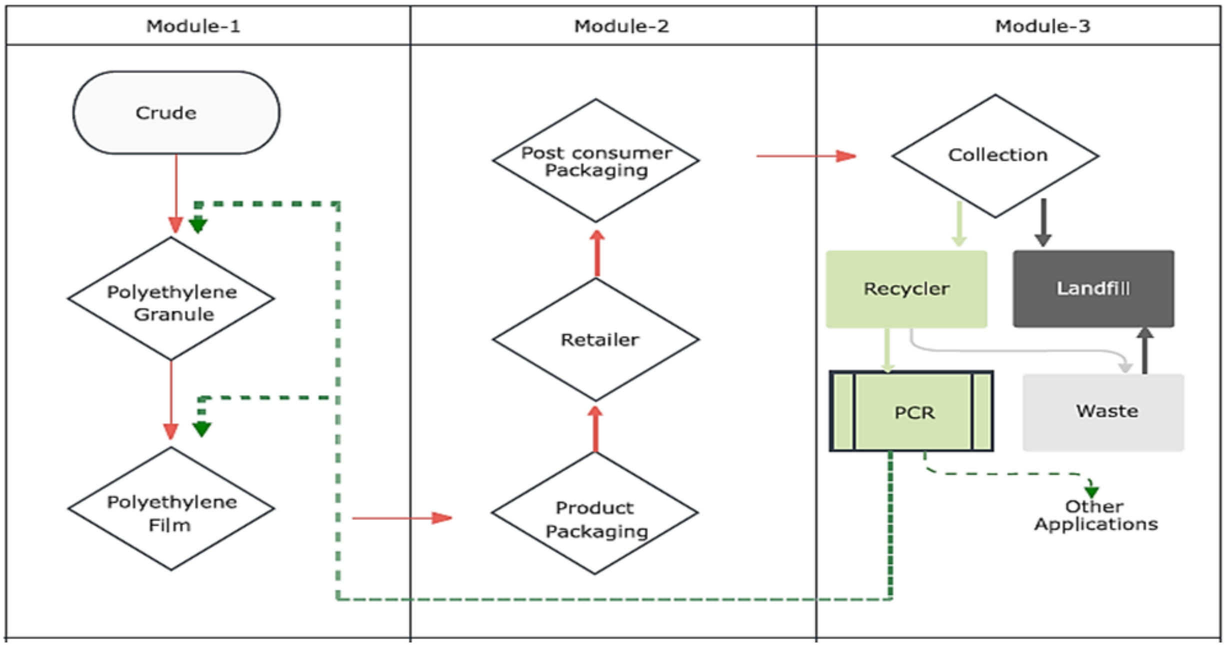


Figure 5: Material flow diagram
Source- Core team

Module-1: Cradle (Crude/Virgin Granules) to Gate 1(Monolayer PE Film package)
Module-2: Gate-1 (Film Package with Product) to Gate 2 (Post-consumer waste of the Film Package)
Module-3: Gate-2 (Post-consumer waste) to Cradle (PCR Granules)
3a: Reutilizing scenario with Reuse 0%; Recycle 80%, Waste 20%
3b: Reutilizing scenario with Reuse10%; Recycle 72%, Waste 18%

3. MATERIAL OF STUDY

3.1 POLYETHYLENE

Polyethylene (PE) is a resin made from petroleum and one of the most common thermoplastics in the world. PE is highly flexible and resistant to steam and moisture, scratches, low-temperature resistant, pressure and radiation resistant, insulator, which gives them the advantage of a very common material for packaging applications. The varieties of polyethylene films include Low Density Polyethylene (LDPE), Medium Density Polyethylene (MDPE), High Density Polyethylene (HDPE), and Linear Low-Density Polyethylene (LLDPE). PE produced by the high-pressure method is called 'LDPE' and produced by the medium or low-pressure method called as 'HDPE'. Polyethylene Film (PF) is used in a variety of applications such as packaging, plastic bags, labels, building construction, landscaping, and electrical fabrication.

Figure 6: Polyethylene Granules
Source- Internet

LDPE was first produced by the high-pressure process in 1930's where ethylene was converted into a white solid by heating it at very high pressure in the presence of trace amount of oxygen. The end product is usually available in the form of small pellets, varying in shape. The process for making PF is called extrusion where pellets are melted until they become molten and pliable. The molten material is then pushed (extruded), through a circular die to form a continuous tube of plastic called the bubble. The bubble is inflated with air to the desired diameter and drawn vertically up a tower giving it time to cool before it is flattened to its lay flat width. The thickness of the film is controlled by the speed at which it is pulled from the die. The width of the film is controlled by the amount of air inserted in the bubble. This film is commonly used for packaging. Due to a wide variety of usage, demand for PE has been increasing exponentially. The Indian plastics industry made a promising beginning in 1957 with the production of Polystyrene (PS). Thereafter, significant progress has been made, and the industry has grown and diversified rapidly. PE is the most largely used plastic raw material by Indian industry. Due to a wide variety of usage, demand for PE has been increasing exponentially and it is the most largely used plastic raw material by Indian industry.

3.2 POLYETHYLENE FILM

The first stage is the extrusion process in which low-density polyethylene is transformed into roles from which the plastic bags are made. Color is added to the material at this stage, as well as the desirable characteristics and properties such as the size of the roll, texture etc. The second process, called imprinting, only applies to plastic bags that require it.

At this stage a flexographic machine is used allowing for printing directly from the extrusion stage. While the process may seem simple at first glance, it is very complicated since it requires more precision and monitoring by the operator. Small variations in the amount of ink, drying time or speed may lead to undesirable printing results. The film printing is followed by a sealing step, wherein bags are first cut according to the size, type of bag and pleat size, and other characteristics before sealing the bag seams. Plastic bags are the final product of this stage, which are then sent to storage and later delivered to the customer. In addition, any excess material is sent to the recovery sub-process where it is bonded and pelletized to be used for manufacturing other types of bags.

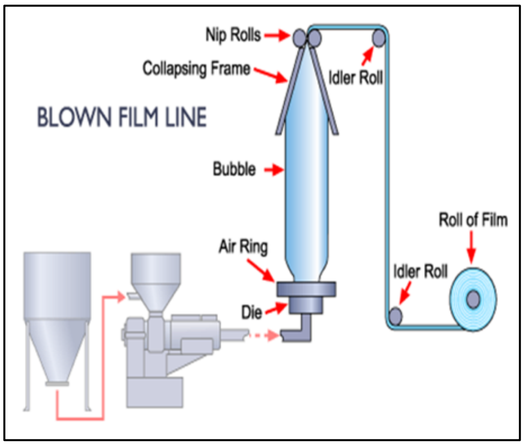


Figure 7: Manufacturing process of Polyethylene

Source - Internet

4. MATERIAL: INDUSTRY RELEVANCE AND CONSUMPTION

According to a study in 2016, the total PE demand in Indian subcontinent is 6% of global demand. The plastic processing industry is estimated to grow to 22 million tonnes (MT) a year by 2020 from 13.4 MT in 2015 and nearly half of this is single-use plastic (according to a Federation of Indian Chambers of Commerce and Industry study). In India, PE and polypropylene (PP) account for more than 62% of polymer usage in the flexible packaging industry.

5. LIFE CYCLE ASSESSMENT (LCA) APPROACH

According to International Standards Organisation (ISO), LCA is defined as compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its lifecycle. Below figure illustrates the life cycle system concept of natural resources and energy entering the system with products, waste and emissions leaving the system.

The LCA method makes objective measurements based on a quantifiable inventory of all inputs and outputs associated with the entire life cycle of a product or service. This includes extraction of raw materials, manufacturing of the product, distribution of the product, and ultimate product disposal. This study followed the procedure detailed in the International Organization for Standardization (ISO) standards to ensure quality results. The particular ISO standards followed are:

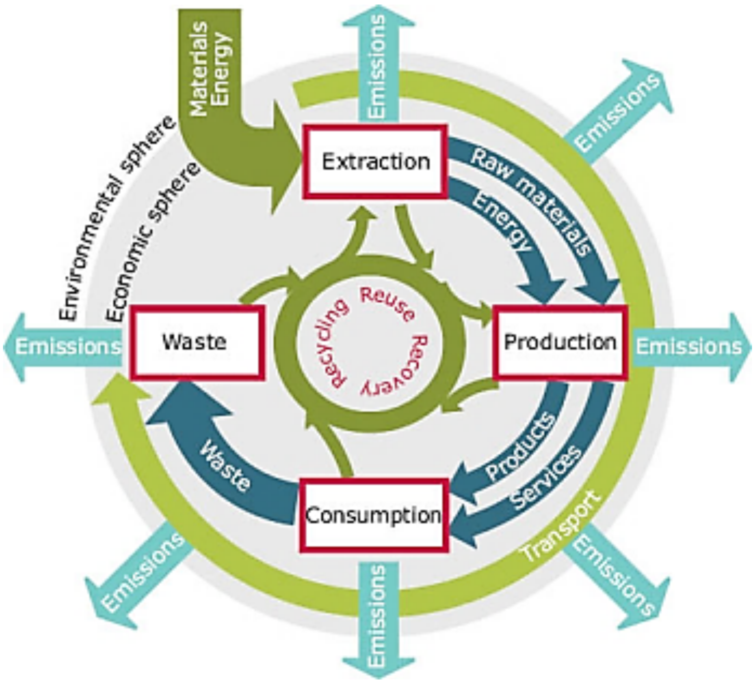


Figure 8 : Life Cycle Assessment, Economic and Environmental spheres
Source- LCA Framework

- ISO 14040: 2006-Environmental Management-Life Cycle Assessment-Principles and Framework
- ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines, is designed for the preparation of, conduct of, and critical review of, life cycle inventory analysis. It also provides guidance on the impact assessment phase of LCA and on the interpretation of LCA results, as well as the nature and quality of the data collected.

Brief schematic representation of LCA is shown as following,

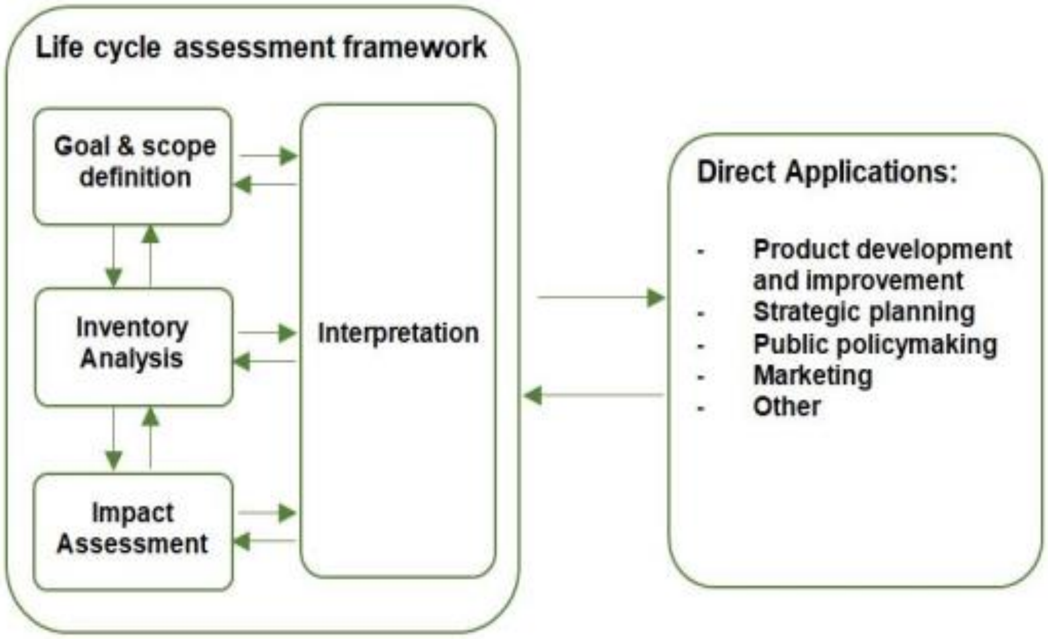


Figure 9: Schematic diagram of Life Cycle Assessment framework
Source: ISO framework

Data collection
For each step from input raw materials (from extraction of crude) to transportation of material to refinery to Manufacturing of PE Film to Conversion of Film to Packaging Film to Transportation and Distribution of finished product to Consumer usage and finally till end-of-life treatment.

Software & Database
The LCA model was created using the GaBi 6 Software system for life cycle engineering, developed by PE International AG. CML 2001 (Nov 2010) method has been selected for evaluation of environmental impacts indicators developed by Institute of Environmental Sciences, Leiden University, Netherlands. These indicators are are widely used and accepted by the international community of LCA practitioners and sustainability experts. All data from the GaBi databases 2011 were created with consistent system boundaries and upstream data.

Detailed database documentation for GaBi datasets can be accessed at

- http://www.gabi-software.com/support/gabi/gabi-6-lci-documentation/
- http://www.gabi-software.com/support/gabi/gabi-lcia-documentation/.

5.1 BACKGROUND LITERATURE & GUIDANCE

Key studies done on LDPE bags and relevant references are as following -

1. CENTRAL POLLUTION CONTROL BOARD(CPCB), MINISTRY OF ENVIRONMENT, FOREST& CLIMATE CHANGE, GOVT. OF INDIA (Central Pollution Control Board 2018)
   - Life Cycle Assessment study of plastic packaging products
   - LDPE bags are the most environment friendly when compared to other plastic packaging in the fossil fuel-based category

- In bio-based packaging category - PLA is an alternate however Landfill contaminants and acidification is much higher than LDPE and still remains a nonviable production due to linked to food chain.

2. DEPARTMENT OF SCIENCE AND INNOVATION, THE WASTE RESEARCH, DEVELOPMENT AND INNOVATION ROADMAP, SOUTH AFRICA (Russo et al. 2020)
    - Study was done on Comparing Grocery Carrier Bags in South Africa from an Environmental and Socio-Economic Perspective
    - Carry bags are recommended to be reused and when is no longer possible, should be reused for a secondary purpose, e.g., as a bin liner
        - HDPE bags are most environment friendly

3. THE DANISH ENVIRONMENTAL PROTECTION AGENCY (Bisinella et al. 2018)
    - Study focused on grocery carrier bags available for purchase in Danish supermarkets in 2017. The study was carried out by DTU Environment in the period October – December 2017
    - Lower thickness and same family film polymer bags show lesser carbon footprint and hence more environment friendly.

5.2 SYSTEM BOUNDARY

System boundary in LCA means the definition of the unit processes included in the system. Unit processes and the level of details of these unit processes have to be decided. The choice of the components in the physical system model depends on the goal and scope definition of the study, the intended application and audience, the assumptions, data and cost constraints, and cut-off criteria.

Figure below represents the general system boundary used for the life cycle of a product label in this LCA. Life cycle material inputs, energy requirements, and emissions to the environment of all unit processes within the individual process stages are included for each product.

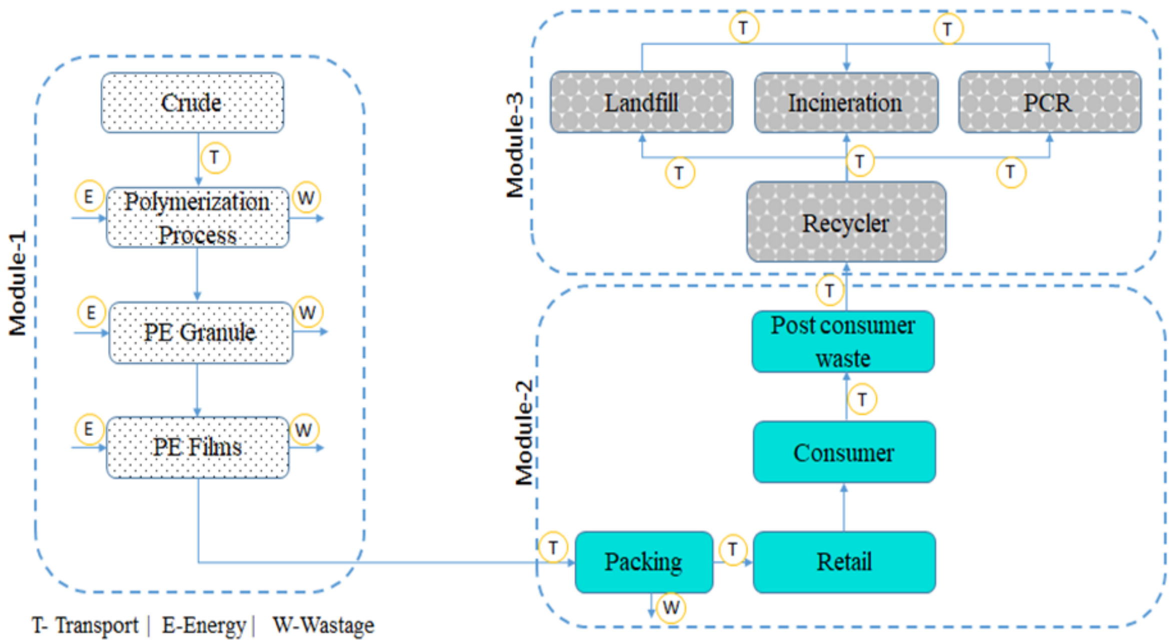


Figure 10: System Boundary Activities and Steps

Source: Core team

It is possible to omit life cycle stages, processes, inputs or outputs but the reasons and the implication of this decision has to be clearly explained. There are several life cycle stages, unit processes and flows to be considered in setting the system boundary in LCA, they are as follows-

5.2.1 RAW MATERIAL ACQUISITION

Starts with the removal of raw materials and energy sources from the earth, as well as the transportation of these materials from acquisition to the processing has to be included

5.2.2 MANUFACTURING

The process of transforming raw materials into a product or a package. This consists of three steps as follow:

1) Materials Manufacture: involving the activities that convert raw materials into a form that can be used to fabricate a finished product.
2) Product Fabrication: Processing of manufactured material into a product ready to be packaged.
3) Packaging/Distribution; finalizing the product and preparation for shipment. This stage accounts for the environmental effects caused by the mode of transportation.

5.2.3 USAGE

Involving consumers' actual use, reuse, and the maintenance of the product. When the consumer doesn't need the product any longer, product will be recycled or disposed.

5.2.4 REUSE/RECYCLE/WASTE MANAGEMENT

This stage includes the energy requirements and environmental wastes associated with disposition of the material.

5.3 INVENTORY ANALYSIS

Life Cycle Inventory (LCI) is a process of quantifying energy and raw materials requirements, atmospheric emissions, wastewater quantities, solid wastes, and other releases for the entire life cycle of a product, process, or activity. LCI is useful for example in helping to organize product or processes comparisons considering environmental factors. LCI Analysis involves the compilation and quantification of inputs and outputs for a product throughout its life cycle. In this phase data shall be collected for each unit process that is included within the system boundary, and these data are utilized to quantify the inputs and outputs of a unit process. The data shall be referenced to the functional unit and the process of conducting an inventory analysis is iterative. There are four steps in conducting an LCI.

5.3.1 DEVELOP A FLOW DIAGRAM OF THE PROCESSES

A flow diagram is a tool useful for mapping the inputs and outputs to a process or system. In gathering data, it is appropriate to view the system as an individual step or process as a part of the defined production system. This individual step is called a "subsystem". Each subsystem requires inputs of materials and energy, transportation of product produced, and has outputs of products, co-products, atmospheric emissions, waterborne wastes, solid wastes and possibly other releases. Each subsystem must describe the materials and energy sources used and the types of environmental releases. All transportation from one process location to another is included in the subsystem, quantified in terms of distance and weight transported and identified by the mode of transport used.

5.3.2 DEVELOP LCI DATA COLLECTION PLAN

Key elements of data collection plan are as below:

1) Identifying data sources and types; providing sufficient accuracy and quality of data source aimed to meet the study's goals.
2) Identifying data quality indicators; these are the benchmarks to which the collected data can be measured to determine if data quality requirements have been met.

Life cycle inventory spread-sheet covering most of the decision areas in the performance of an inventory, prepared to guide data collection and validation and to enable construction of a database to store collected data electronically. It is a valuable tool or ensuring completeness, accuracy, and consistency.

5.3.3 DATA COLLECTION

Data collection efforts involve a combination of research, site-visits and direct contacts with experts, which generate large quantities of data. For each unit process within the system boundary, the data can be classified as:

1) Energy inputs, raw material inputs, other inputs
2) Products, co-products, and waste,
3) Emissions to air, discharges to water and soil

5.3.4 ALLOCATION

Allocation is needed when dealing with systems with multiple products and recycling systems. Allocation means —partitioning the input or output flows of a process or a product system between the product system under study and one or more other product system‖ (ISO 14040). An example of allocation procedure application is in reuse and recycling scenario in waste management system. A sensitivity analysis has to be conducted when allocation procedure is applied. Allocation procedure can be applied in process with multi output processes or multi-input processes.

5.4 RESULTS OF LCA

According to ISO 14040, an LCA comprises four major stages: goal and scope definition, life cycle inventory, life cycle impact analysis and interpretation of the results. ISO 14040 series defines the various aspects of assessment protocol to be followed along with various inclusions and assumptions to generate and conduct a standardized study. The ISO 14040 lays the foundation of the study by proposing the principles and framework whereas ISO 14044 deals with the requirements and guidelines to be followed for it.

5.4.1 MODULE WISE SYSTEM BOUNDARIES

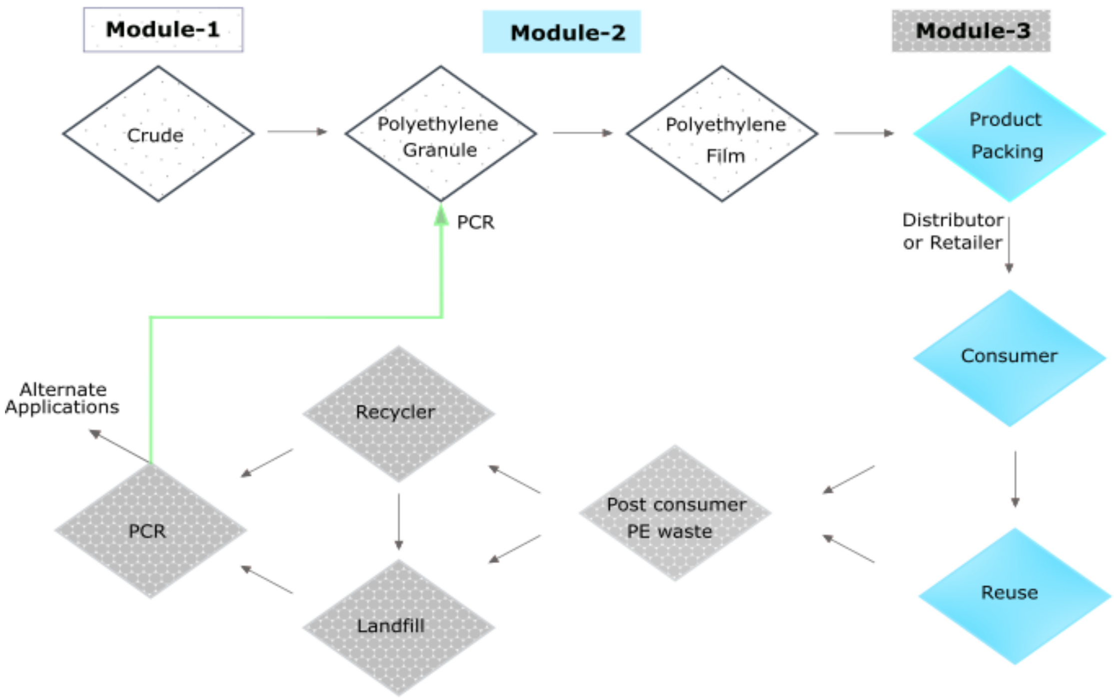


Figure 11: Material Flow Chart

Source: Core team

Module-1: Cradle (Crude/Virgin Granules) to Gate 1(Monolayer PE Film package)

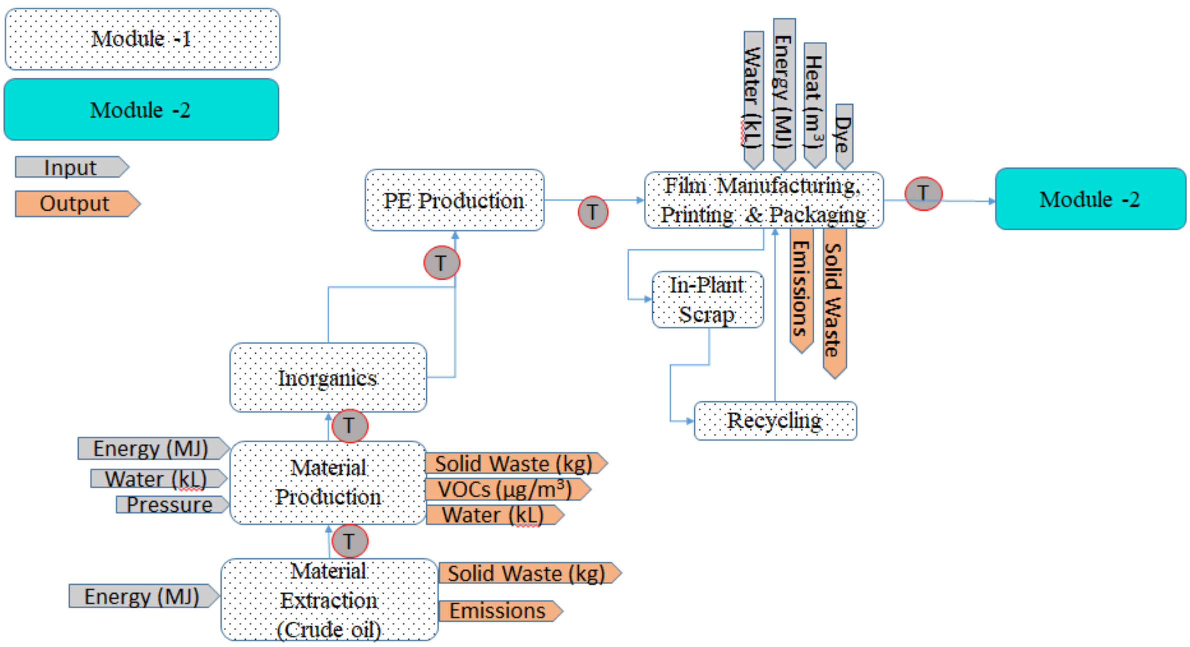


Figure 12: Schematic diagram with boundary and stages for module-1

Source: core team

Module-2: Gate-1 (Film Package with Product) to Gate 2 (Post-consumer waste)

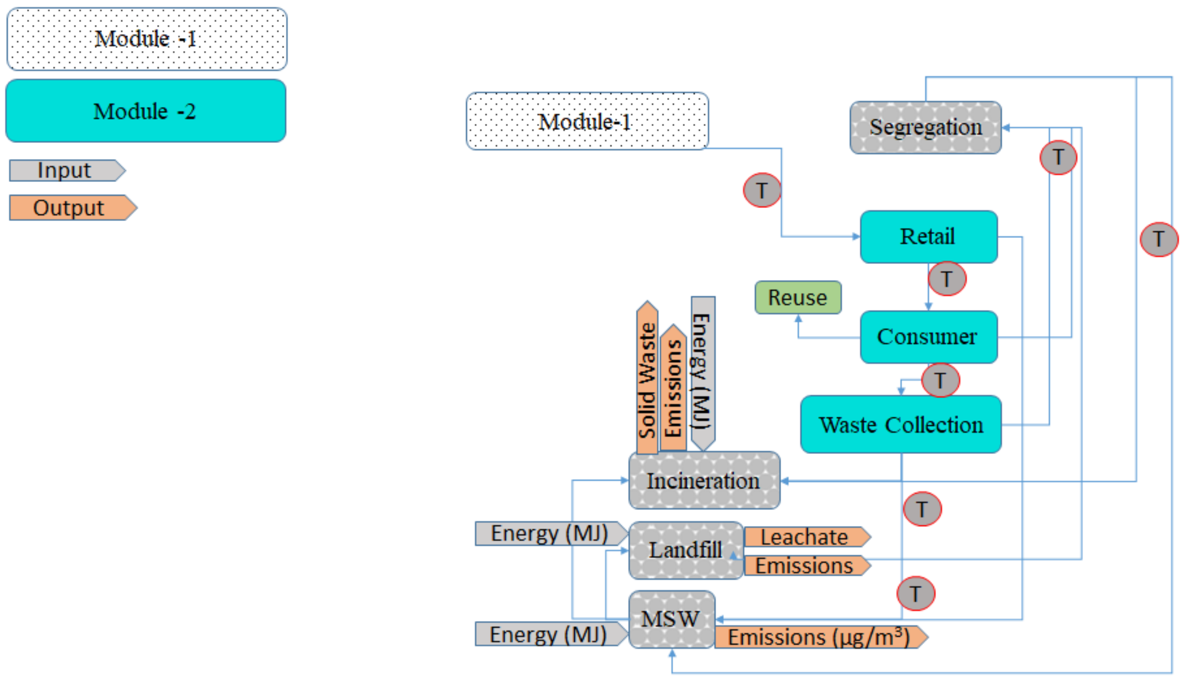


Figure 13: Schematic diagram with boundary and stages for module-2

Source: core team

Module-3: Gate-2 (Post-consumer waste) to Cradle (PCR Granules)

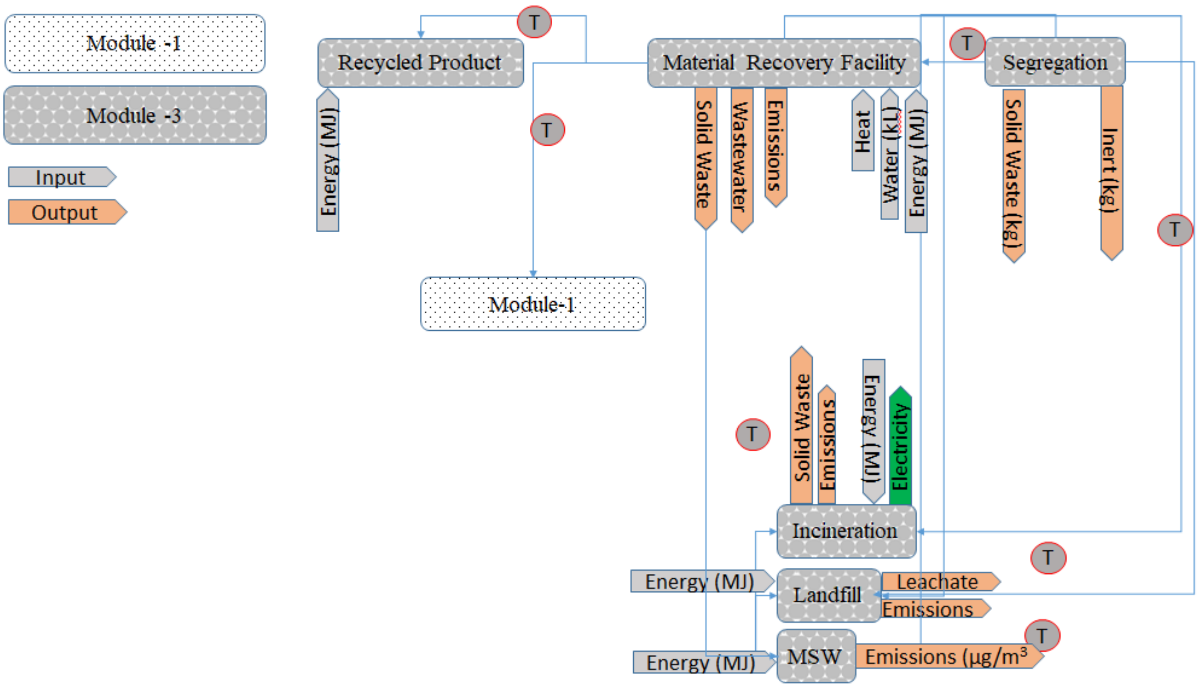


Figure 14: Schematic diagram with boundary and stages for module-3

Source: core team

First modules are straight forward however for module -3 where post-consumer waste collection and recycling is involved; we conducted field surveys with waste picker and also took feedback from recyclers. Based on same the Reuse, Recycling and waste parameters were shortlisted.

5.4.2 SCENARIO ANALYSIS

Based on findings from survey, four scenarios are considered for analysing the module 3 (post-consumer waste) and analysis results (for module-3) are as below –

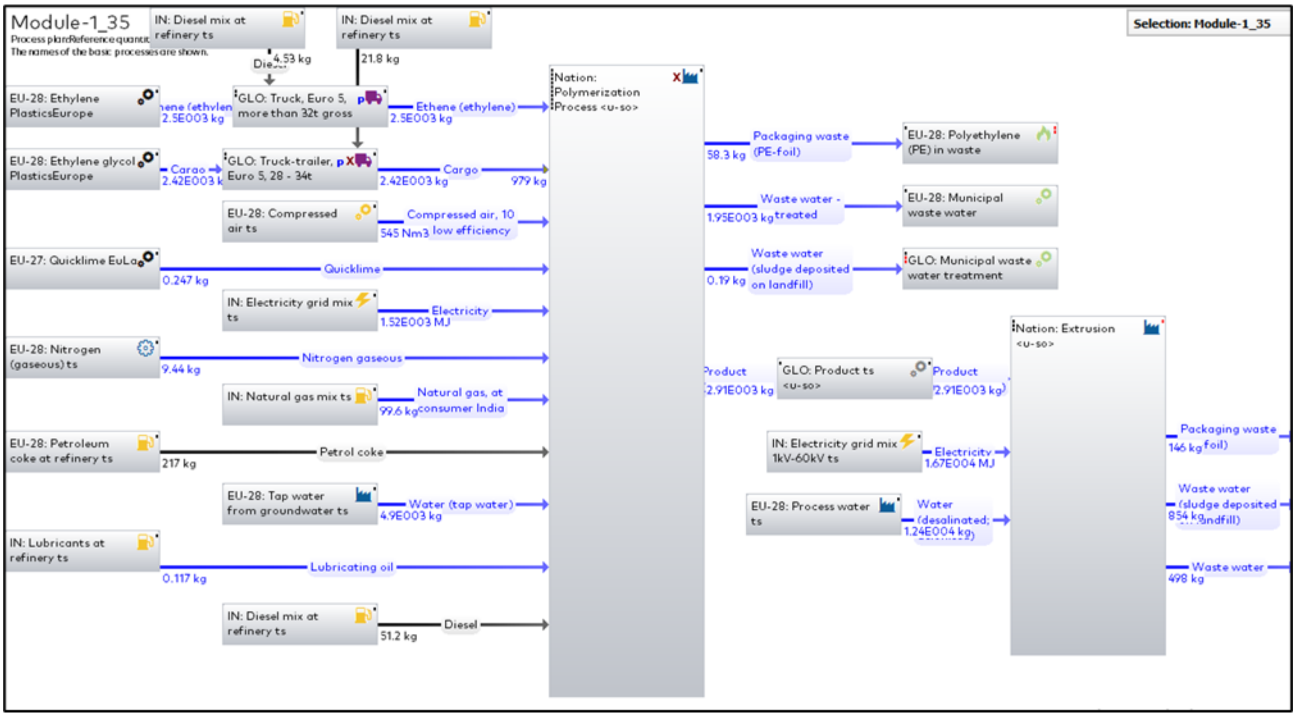
Table 3: Reuse, Recycling and Waste generation scenarios

Scenario	Reuse (%)	Recycle (%)	Waste (%)	35 micron GWP (kg CO_2 Eq)	50 micron GWP (kg CO_2 Eq)	100 micron GWP (kg CO_2 Eq)
1	0	80	20	1620	4915	20372
2	10	72	18	1230	4415	19272
3	0	70	30	1850	6140	23450
4	30	42	28	875	3200	14600

Source- Core team

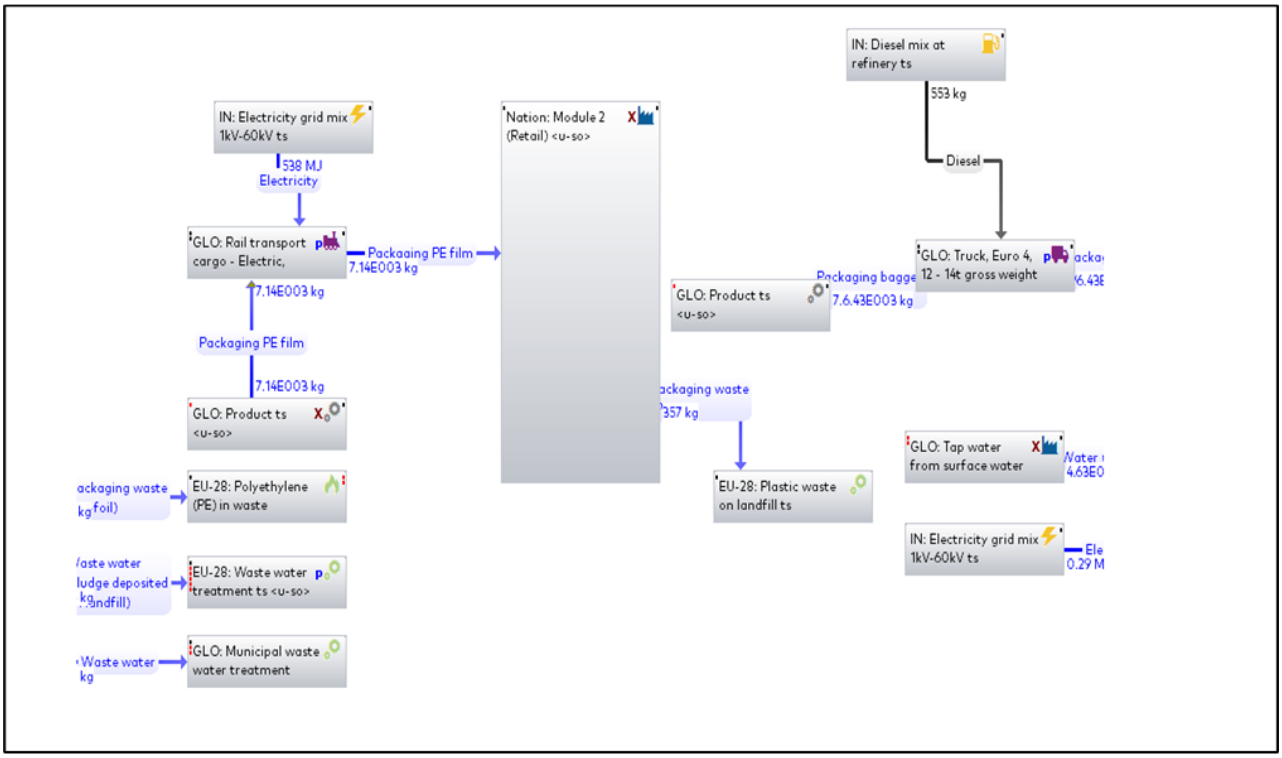
For Gabi software analysis, process plans for the 3 modules (polyethylene-cradle to cradle) were developed. These process plans are shown as below

Gabi Model for module 1 for 35 micron



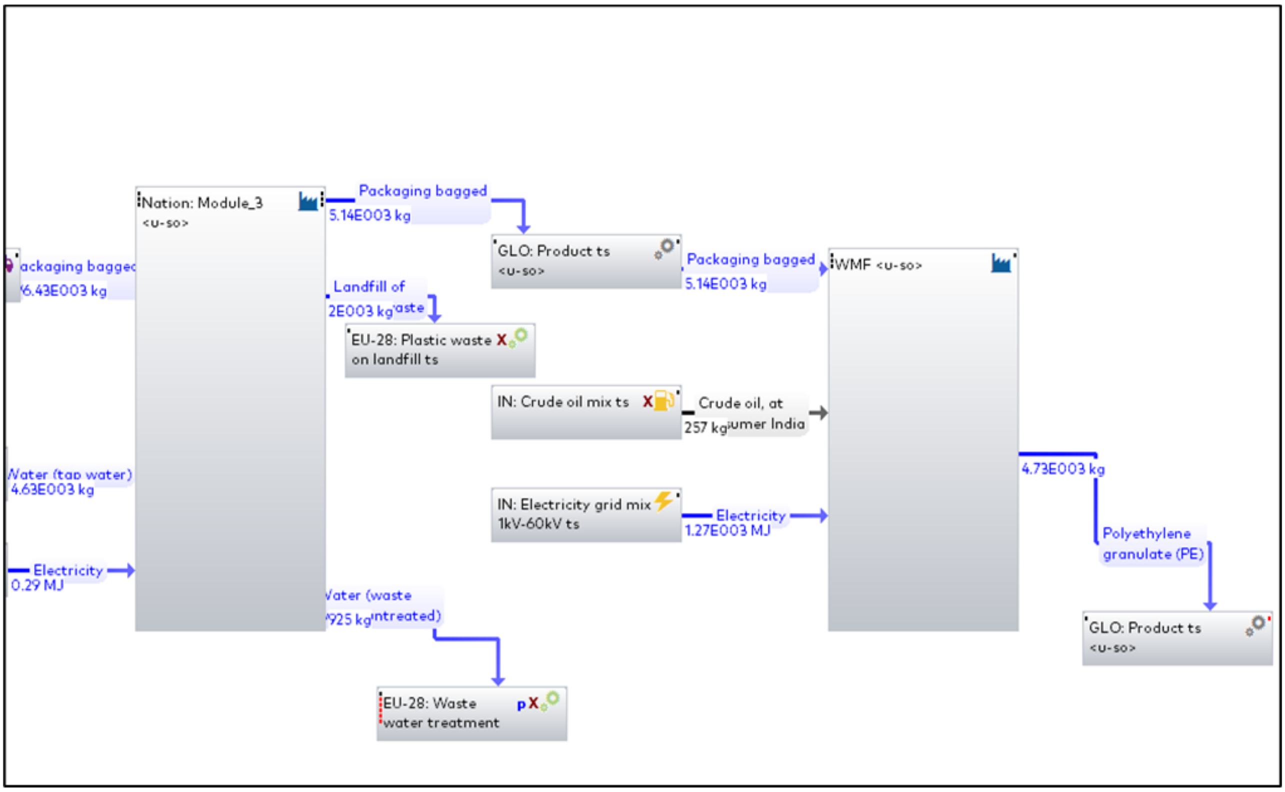
(Figure-15a)

Gabi Model for module 2 for 35 micron



(Figure-15b)

Gabi Model for module 3 for 35 micron



(Figure-15c)

Figure 15 a,b,c: Process Plans for Gabi analysis of monolayer PE film (35 micron)

Source: core team

Further based on recycler's inputs we have further shortlisted 2 scenarios as the most probable as following -

Scenario	Reuse (%)	Recycle (%)	Waste (%)
Scenario-1	0	80	20
Scenario-2	10	72	18

5.4.3 IMPACT PARAMETERS CALCULATION MODULE WISE-

Life Cycle Analysis study helps in finding absolute values of impact parameters for a material. Based on inputs for shortlisted scenarios, and variation of monolayer PE film thickness, Impact parameter values are tabulated hereupon –

EMMISSIONS CONSIDERING REUSE 0% RECYCLE 80% & WASTE 20%

1) For moduel-1

Table 4: Impact parameters at the end of Module-1 (reuse 0%, recycle 80%, waste 20%)

Impact Parameter	UoM	Indicator (CML2001)		
		100micron	50micron	35micron
Global Warming Potential (GWP)	(kg CO2 Eq)	80500	36400	22300
Acidification Potential(AP)	(kg SO2 Eq)	320	108	94.4
Eutrophication Potential (EP)	(kg Phosphate Eq)	68.5	28.2	21.1
Ozone Depletion Potential (ODP)	(kg-R11 Eq)	5.14E-08	1.2E-07	1.90E-08
Abiotic Depletion Fossil (ADP Fossil fuel)	(MJ)	3150000	1100000	527000
Fresh water Aquatic Eco toxicity(FEATP)	(kg-DCB Eq)	3400	1020	785
Human Toxicity Potential (HTP)	(kg-DCB Eq)	32500	5520	5000
Photo Chemical Ozone Creation Potential (POCP)	(kg-Ethane Eq)	30.6	11.3	8.57
Teristic Eco Toxicity Potential (TETP)	(kg-DCB Eq)	153	37	35.5

Source- Core team

2) For Module-2

Table 5: Impact parameters at the end of Module-2 (reuse 0%, recycle 80%, waste 20%)

Impact Parameter	UoM	Indicator (CML2001)		
		100 micron	50 micron	35 micron
Global Warming Potential (GWP)	(kg CO2 Eq)	81000	36800	22410
Acidification Potential(AP)	(kg SO2 Eq)	371	110	97
Eutrophication Potential (EP)	(kg Phosphate Eq)	71.5	29.2	22.6
Ozone Depletion Potential (ODP)	(kg-R11 Eq)	5.15E-08	1.12E-06	1.90E-08
Abiotic Depletion Fossil (ADP Fossil fuel)	(MJ)	3250000	1150000	532000
Fresh water Aquatic Eco toxicity(FEATP)	(kg-DCB Eq)	3540	1040	875
Human Toxicity Potential (HTP)	(kg-DCB Eq)	32500	5600	6000
Photo Chemical Ozone Creation Potential (POCP)	(kg-Ethane Eq)	30.75	11.5	6.93
Teristic Eco Toxicity Potential (TETP)	(kg-DCB Eq)	153	37.8	39.6

Source- Core team

3) For module -3

Table 6: Impact parameters at the end of Module-3 (reuse 0%, recycle 80%, waste 20%)

Impact Parameter	UoM	Indicator (CML2001)		
		100 micron	50 micron	35 micron
Global Warming Potential (GWP)	(kg CO2 Eq)	100400	41225	24100
Acidification Potential(AP)	(kg SO2 Eq)	378	116	108
Eutrophication Potential (EP)	(kg Phosphate Eq)	75.3	30.2	23.6
Ozone Depletion Potential (ODP)	(kg-R11 Eq)	5.18E-08	1.12E-06	1.90E-08
Abiotic Depletion Fossil (ADP Fossil fuel)	(MJ)	3510000	1150000	555000
Fresh water Aquatic Eco toxicity(FEATP)	(kg-DCB Eq)	3870	1050	1230
Human Toxicity Potential (HTP)	(kg-DCB Eq)	32800	6100	9890
Photo Chemical Ozone Creation Potential (POCP)	(kg-Ethane Eq)	32.7	11.4	6.86
Teristic Eco Toxicity Potential (TETP)	(kg-DCB Eq)	157	45.1	44.9

Source- Core team

EMMISIONS CONSIDERING REUSE 10% RECYCLE 72% & WASTE 18%

1) For Module-1

Table 7: Impact parameters at the end of Module-1 (reuse 10%, recycle 72%, waste 18%)

Impact Parameter	UoM	Indicator (CML2001)		
		100 micron	50 micron	35 micron
Global Warming Potential (GWP)	(kg CO2 Eq)	78650	34500	22200
Acidification Potential(AP)	(kg SO2 Eq)	308	103	94.4
Eutrophication Potential (EP)	(kg Phosphate Eq)	65.8	28.2	21.1
Ozone Depletion Potential (ODP)	(kg-R11 Eq)	3.45E-08	1.2E-07	1.90E-08
Abiotic Depletion Fossil (ADP Fossil fuel)	(MJ)	2980000	1100000	527000
Fresh water Aquatic Eco toxicity(FEATP)	(kg-DCB Eq)	3250	1020	785
Human Toxicity Potential (HTP)	(kg-DCB Eq)	30900	5520	5000
Photo Chemical Ozone Creation Potential (POCP)	(kg-Ethane Eq)	30.6	11.3	8.57
Teristic Eco Toxicity Potential (TETP)	(kg-DCB Eq)	154	36.8	34

Source- Core team

2) For Module-2

Table 8: Impact parameters at the end of Module-2 (reuse 10% recycle 72% , waste 18%)

Impact Parameter	UoM	Indicator (CML2001)		
		100 micron	50 micron	35 micron
Global Warming Potential (GWP)	(kg CO2 Eq)	80500	36400	22300
Acidification Potential (AP)	(kg SO2 Eq)	320	108	94.4
Eutrophication Potential (EP)	(kg Phosphate Eq)	68.5	28.2	21.1
Ozone Depletion Potential (ODP)	(kg-R11 Eq)	5.14E-08	1.2E-07	1.90E-08
Abiotic Depletion Fossil (ADP Fossil fuel)	(MJ)	3150000	1100000	527000
Fresh water Aquatic Eco toxicity (FEATP)	(kg-DCB Eq)	3400	1020	785
Human Toxicity Potential (HTP)	(kg-DCB Eq)	32500	5520	5000
Photo Chemical Ozone Creation Potential (POCP)	(kg-Ethane Eq)	30.6	11.3	8.57
Teristic Eco Toxicity Potential (TETP)	(kg-DCB Eq)	153	37	35.5

Source- Core team

3) For Module-3

Table 9: Impact parameters at the end of Module-3 (reuse 10% recycle 72% waste 18%)

Impact Parameter	UoM	Indicator (CML2001)		
		100 micron	50 micron	35 micron
Global Warming Potential (GWP)	(kg CO2 Eq)	99200	40750	23525
Acidification Potential(AP)	(kg SO2 Eq)	326	113	105
Eutrophication Potential (EP)	(kg Phosphate Eq)	72.6	30	23
Ozone Depletion Potential (ODP)	(kg-R11 Eq)	5.18E-08	1.24E-06	1.90E-08
Abiotic Depletion Fossil (ADP Fossil fuel)	(MJ)	3430000	1140000	553000
Fresh water Aquatic Eco toxicity(FEATP)	(kg-DCB Eq)	3810	1050	855
Human Toxicity Potential (HTP)	(kg-DCB Eq)	30900	6000	5800
Photo Chemical Ozone Creation Potential (POCP)	(kg-Ethane Eq)	30.6	11.3	5.79
Teristic Eco Toxicity Potential (TETP)	(kg-DCB Eq)	146	45	38.3

Source- Core team

Here it is to be noted that, recycling of Post-consumer resin is onem ore variation. And therefore for a manufacturer it is an option to use virgin material as 100% input or use recycled Post consumer resin feed together (25%). Same has been analyzed separately and analysis results are as below –

5.4.4 INCREMENTAL EMISSIONS WITH 100% VPE

EMMISSIONS CONSIDERING REUSE 0% RECYCLE 80% & WASTE 20% (100% VPE)

Table 10: Increment in Impact parameters (reuse 0%, recycle 80% waste 20%)

Impact Parameter	UoM	% Increase in Emissions	
		35micron to 50micron	35micron to 100micron
Global Warming Potential (GWP)	kg CO2 Eq * 10^{-4}	72	320
Acidification Potential (AP)	kg SO2 Eq * 10-2	7	250
Eutrophication Potential (EP)	Kg Phosphate Eq * 10-1	28	219
Ozone Depletion Potential (ODP)	kg-R11 Eq * 108	5,795	173
Abiotic Depletion Fossil (ADP Fossil fuel)	MJ* 10-5	107	532
Fresh water Aquatic Eco toxicity (FEATP)	kg-DCB Eq* 10-3	21	344
Human Toxicity Potential (HTP)	kg-DCB Eq* 10-3	2	447
Photo Chemical Ozone Creation Potential (POCP)	kg-Ethane Eq* 10-1	65	375
Teristic Eco Toxicity Potential (TETP)	kg-DCB Eq* 10-1	15	301

Source- Core team

EMMISSIONS CONSIDERING REUSE 10% RECYCLE 72% & WASTE 18%(100% VPE)

Table 11: Increment in Impact parameters (reuse 10%, recycle 72%, waste 18%)

Impact Parameter	UoM	% Increase in Emissions for 35micron to 50micron	% Increase in Emissions for 35micron to 100micron
Global Warming Potential (GWP)	kg CO_2 Eq * 10^{-4}	73	322
Acidification Potential (AP)	kg SO2 Eq * 10-2	8	268
Eutrophication Potential (EP)	Kg Phosphate Eq * 10-1	30	227
Ozone Depletion Potential (ODP)	kg-R11 Eq * 108	6,426	173
Abiotic Depletion Fossil (ADP Fossil fuel)	MJ* 10-5	106	537
Fresh water Aquatic Eco toxicity (FEATP)	kg-DCB Eq* 10-3	23	340
Human Toxicity Potential (HTP)	kg-DCB Eq* 10-3	3	447
Photo Chemical Ozone Creation Potential (POCP)	kg-Ethane Eq* 10-1	95	463
Teristic Eco Toxicity Potential (TETP)	kg-DCB Eq* 10-1	17	297

Source- Core team

5.4.5 INCREMENTAL EMISSIONS WITH 75% VPE AND 25% PCR

EMMISSIONS CONSIDERING REUSE 0% RECYCLE 80% & WASTE 20%(75%VPE)

Table 12: Increment in Impact parameters reuse 0% recycle 80%,waste 20%

Impact Parameter	UoM	% Increase in Emissions	
		35micron to 50micron	35micron to 100micron
Global Warming Potential (GWP)	kg CO_2 Eq * 10^{-4}	44	184
Acidification Potential (AP)	kg SO2 Eq * 10-2	47	357
Eutrophication Potential (EP)	Kg Phosphate Eq * 10-1	227	763
Ozone Depletion Potential (ODP)	kg-R11 Eq * 108	5,548	140
Abiotic Depletion Fossil (ADP Fossil fuel)	MJ* 10-5	29	290
Fresh water Aquatic Eco toxicity (FEATP)	kg-DCB Eq* 10-3	121	687
Human Toxicity Potential (HTP)	kg-DCB Eq* 10-3	5	441
Photo Chemical Ozone Creation Potential (POCP)	kg-Ethane Eq* 10-1	92	452
Teristic Eco Toxicity Potential (TETP)	kg-DCB Eq* 10-1	12	250

Source- Core team

EMMISSIONS CONSIDERING REUSE 10% RECYCLE 72% & WASTE 18%(75% VPE)

Table 13: Increment in Impact parameters reuse 10%, recycle 72%, waste 18%

Impact Parameter	UoM	% Increase in Emissions	
		35micron to 50micron	35micron to 100micron
Global Warming Potential (GWP)	kg CO2 Eq * 10^{-4}	44	191
Acidification Potential (AP)	kg SO2 Eq * 10-2	51	354
Eutrophication Potential (EP)	Kg Phosphate Eq * 10-1	255	834
Ozone Depletion Potential (ODP)	kg-R11 Eq * 108	5,641	140
Abiotic Depletion Fossil (ADP Fossil fuel)	MJ* 10-5	20	292
Fresh water Aquatic Eco toxicity (FEATP)	kg-DCB Eq* 10-3	101	589
Human Toxicity Potential (HTP)	kg-DCB Eq* 10-3	8	454
Photo Chemical Ozone Creation Potential (POCP)	kg-Ethane Eq* 10-1	58	374
Teristic Eco Toxicity Potential (TETP)	kg-DCB Eq* 10-1	8	265

Source- Core team

5.5 OVERALL TAKEAWAYS

1. Literature review

   - India based studies : It has been found that, plastic bags in India have significantly less carbon footprint than countries like China and Hong Kong due to the reuse option (Muthu et al. 2011). LDPE bags are the most environment friendly when compared to other plastic packaging in the fossil fuel-based category (Central Pollution Control Board (CPCB) 2018, Ministry of Environment, Forest & Climate Change, Govt. of India).

   - International studies : Study reported by The Council for Scientific and Industrial Research, South Africa, shows that the single use HDPE bag of 24 microns when recycled for 100 % was found to be the best performing in terms of environmental impact (Russo et al. 2020). The Danish Environmental Agency found that LDPE carrier bags, had the lowest environmental impacts among the environmental indicators (Bisinella et al. 2018).

With the previous trends available in the literature, it can be derived that this study will be of first of its kind on LDPE based packaging to bring out the vital information on bag thickness which is best for the environment not only for the decision makers but also for other stakeholders.

2. Analysis and Life cycle Assessment based view

Life cycle analysis of 3 thicknesses (35, 50 and 100 microns) was conducted and results are as following-

Table 14: GWP with Virgin Polyethylene (VPE_100%)

Module	Reuse* (%)	Recycle** (%)	Waste** (%)	35 micron	50 micron	100 micron	% increase (35 vs 50 mic)	% increase (35 vs 100 mic)
				GWP (kg CO_2 Emission Eq)				
1	--	--	--	22300	36300	80028	63%	259%
2	--	--	--	110	225	700	105%	536%
3a	0	80	20	1620	4915	20371	203%	1157%
3b	10	72	18	1230	4415	19271	259%	1467%
(1+2+3a)	0	80	20	24030	41440	101099	72%	321%
(1+2+3b)	10	72	18	23640	40940	99999	73%	323%

Source: core team

*: based on assumption and internal discussion (reference - Muthu, S. S., Li, Y., Hu, J. Y., and Mok, P. Y. (2011). "Carbon footprint of shopping (grocery) bags in China, Hong Kong and India." Atmospheric Environment, 45(2), 469–475)

**: Data from Waste Plastic Recyclers (2020)

- Key takeaways
  - Material impact in terms of GWP is ~ 72% higher if 50 micron film is used and shoots to 321% if 100 micron is used w.r.t. 35micron base case
  - Magnitude of material carbon footprint is around 77-90% hence impact of material is bound to supersede any possible change in recycling efficiency improvement.

Table 15: GWP with VPE_75% & Recycled Polyethylene (RPE) _25%

Module	Reuse* (%)	Recycle** (%)	Waste** (%)	35 micron	50 micron	100 micron	% increase (35 vs 50 mic)	% increase (35 vs 100 mic)
				GWP (kg CO_2 Emission Eq)				
1	--	--	--	19750	26820	46500	36%	135%
2	--	--	--	110	225	700	105%	536%
3a	0	80	20	1390	3625	13650	161%	882%
3b	10	72	18	690	2640	12750	283%	1748%
(1+2+3a)	0	80	20	21250	30650	60350	44%	184%
(1+2+3b)	10	72	18	20600	29650	59850	44%	191%

Source: Core team

*: based on assumption and internal discussion (reference - Muthu, S. S., Li, Y., Hu, J. Y., and Mok, P. Y. (2011). "Carbon footprint of shopping (grocery) bags in China, Hong Kong and India." Atmospheric Environment, 45(2), 469–475)

**: Data from Waste Plastic Recyclers (2020)

- Key takeaways –
  - Inclusion of PCR (at 25% rate) in the virgin material influences material impact in terms of GWP by reduction of 28% and 137% for 50 micron and 100 micron respectively w.r.t. 35 micron.

- Figuratively outcome is shown as a balance format as below-

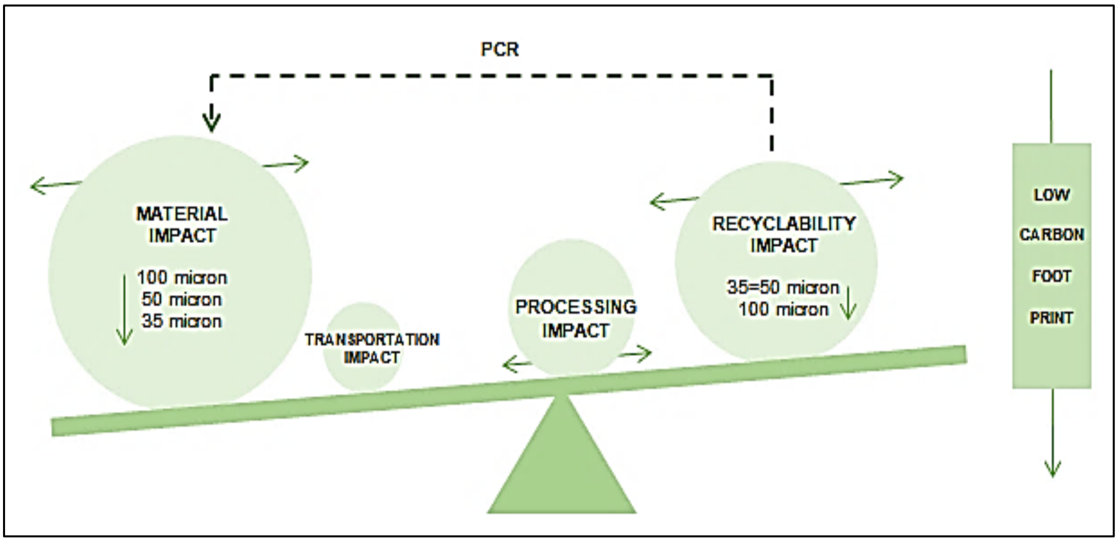


Figure 16: Global Warming Potential balance & Thickness variation
Source: Core team

Overall impact is explained as follows-

i. Material Burden

Scenario	GWP due to 35 micron	GWP due to 50 micron	GWP due to 100 micron
No PCR	X	1.73X	4.23X
With 25% PCR (with 10% reuse case)	.87X	1.24X	2.53X

ii. Cost & Social Aspect

Product cost per pack with 35 micron	Product cost per pack with 50 micron	Product cost per pack with 100 micron
c	1.03c	1.06c

Overall takeaways form the results are as below:

1) Material impact in terms of GWP is ~ 72% higher if 50-micron film is used and shoots to 321% if 100 micron is used w.r.t. 35micron base case.
2) Inclusion of PCR (at 25% rate) in the virgin material influences material impact in terms of GWP by reduction of 28% and 137% for 50 micron and 100 microns respectively w.r.t. 35 micron (base case)
3) Magnitude of material carbon footprint is around 77-90% hence impact of material is bound to supersede any possible change in recycling efficiency improvement.

4) In terms of environmental & socio economical perspective, cost impact would be on the range of 4 to 6% for moving from 35 mic to 100mic.
5) Further it can be depicted as Tripod of thickness impact. Thicker packaging casues higher material usage for the same packaging application and functionality, further overwhelming collection and recovering infrastructure and leading to costlier products.

Therefore, it is recommended that thinner option (35 micron) is most environment friendly than thick packaging alternates (50 and 100 micron).

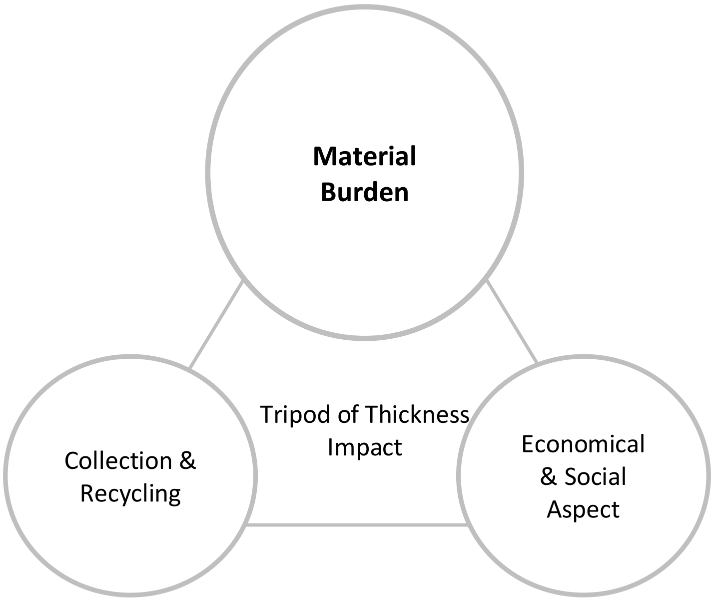


Figure 17: Tripod of thickness impact
Source: Core team

6. CONCLUSION

In this study, the complete lifecycle of monolayer PE packaging film was carried out and a cradle-to-cradle approach was considered. The significant conclusions drawn from this comparative life cycle assessment is that overall carbon footprint of PE films of 35 micron are the lesser of other two thicknesses (50 and 100micron) considered. This stands valid for virgin material as well scenario where prescribed recycling is put in place.

The importance of recycling was also shown in the analysis, where it could be seen that the 10% reuse of the recycled material, lowered the impact on climate change below that of the other thickness material. However, GWP still remains above that of 35-micron.

The results show clearly that the 100- and 50-micron thick PE films have much higher environmental impact than the 35-micron PE film, over the entire life cycles.

Further results from survey and analysis on waste collection and segregation revealed that waste pickers do not see much difference between 50 micron or 35-micron packaging. It clearly came out that small micron thickness (any micron below 50 micron) is not going to make any significant impact. And push for increasing packaging thickness where lower micron could serve the purpose is only going to increase the environmental burden.

This also will have major impact on environment and economy as ultimately customer needs to bear the brunt of additional cost with incremental harm to environment.

Stakeholder wise recommendations are shared in the executive summary section.

7. FURTHER WORK

Considering the holistic view and keen interest of the government, we propose:

1) Practice of using PCR resin in mix with virgin plastic at scale
2) Sustainability Reporting Policy to bring the visibility around packaging products being used.

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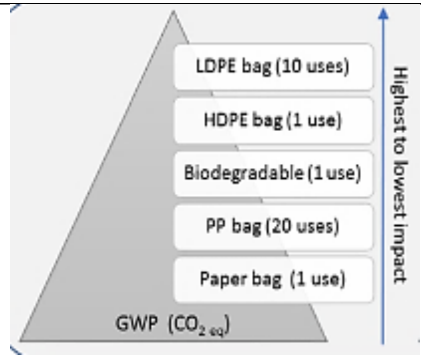
ANNEXURES

ANNEXURE I: LITERATURE SURVEY

SN	Title of Paper / Year / Location of Study	Software	FU/ Approach/ Micron / Material	GWP in kg of CO_2 eq / Remarks
1.	Environmental Impacts of Packaging Materials in Serbian Milk Industry, A Comparative Life Cycle Assessment /2008 / Serbia	SimaPro	1000 litres of milk in containers of 1 litre capacity / Cradle to Grave / PET & LPB (liquid packaging board)	3241 kg
2.	Life Cycle Assessment of consumer packaging for liquid food LCA of Tetra Pak and alternative packaging on the Nordic market / 2009 / Denmark, Finland, Norway, and Sweden	GaBi	Dairy packaging (1000 L) / Cradle to Grave / Tetra Pack, PET, HDPE, and glass bottle	Sweden : 0.09 kg / L (for tetra pack) Denmark : 0.065 kg/L (for tetra pack) Finland : 0.095 kg/L (for tetra pack) Norway : 0.1 kg/L (for tetra pack)
3.	Environmental impacts of milk packaging made from polythene using life cycle assessment / 2010/ China	SimaPro	17.75 kg of PE / Cradle to Grave / N.A.	• Recycle can reduce 75.9% of environmental impacts and over 90.2% of total environmental impacts on stages of raw material, transport and production in its life cycle except treatment stage
4.	Life Cycle Assessment of multilayer polymer film (LDPE/PA) used on food packaging field /2011 / Italy	SimaPro	1 Sq. m) / Cradle to Grave / 70 and 90 micron	70 micron: 362 kg 90 micron: 468 kg
5.	A comparative study on milk packaging using life cycle assessment: from PA-PE-Al laminate and polyethylene in China / 2011 / China	SimaPro	Packaging and distribution of 1000 litres of milk / Cradle to Grave / PA-PE-Al (A Paper, Polyethylene & Aluminum foil Laminate) and Polyethylene	• Composite packaging has slightly higher environmental impact than the plastic one. • Raw material extraction is the highest in all of the life cycle stages except for disposal.
6.	Carbon footprint of shopping (grocery) bags in China, Hong Kong	SimaPro	Number of shopping bags used for grocery shopping per year by an average	India: 60 kg China & Hong Kong: 475 kg

	and India / 2011 / China India & Hong Kong		Chinese/Indian/Hong Kong residents / cradle to grave / plastic, paper, non-woven and woven	
7.	Life Cycle Assessment of Plastic Bag Production / 2012 / Sweden	SimaPro	1000 bags = 23.3 kilogram / Cradle to Grave	538 kg
8.	Life Cycle Assessment of Polyethylene Terephthalate (PET) Beverage Bottles Consumed in the State of California / 2012 / USA	GaBi	Delivery of beverages packaged in single-use bottles made from 1 kg PET resin to California consumers / Cradle to Grave	The majority of environmental impacts in many impact categories, including global warming, acidification, and air pollution come from energy-intensive pre-consumer stages
9.	Life Cycle Assessment of Grocery Bags in Common Use in the United States / 2014 / USA	SimaPro	4 different FU / Cradle to Gate	LDPE bags have about 2 to 3 times the GWP of Paper bags and Plastic Retail Bags and about half the GWP of Paper bags
10.	Life Cycle Assessment of Stone Paper, Polypropylene Film, and Coated Paper for Use as Product Labels /2016 Taiwan	SimaPro	Cradle to Grave	PP Film performed relatively poorly in fossil fuel related impact categories, whereas coated paper performed relatively poorly in land use and water depletion categories. Stone Paper fared relatively poorly in two human and environmental health impact categories.
11.	Life Cycle Assessment A comparative LCA of plastic and paper bags / 2016 / Sweden	SimaPro	Plastic bag equivalents per household and year /Cradle to Gate /	Plastic bags are less harmful to the environment than paper bags, unless the paper bags are reused at least three times
12.	Life cycle assessment of end-of-life treatments for plastic film waste / 2018 USA	SimaPro	One metric ton of either recyclable waste or mixed waste	Considerable advantage of recycling over landfill disposal or incineration
13.	Life cycle assessment of carrier bags and development of a littering indicator / 2019 Spain	GaBi	To facilitate the transportation of purchased food and drinks to an average household for one year, from the point of sale to the place of consumption / HDPE, LDPE, PP, paper and biodegradable plastic bag	

				 *Figure 18: GWP of various plastic bags* *Source: Core team*
14.	When plastic packaging should be preferred: Life cycle analysis of packages for fruit and vegetable distribution in the Spanish peninsular market / 2020 / Spain	GaBi	1000 metric tons of fruits and vegetables in plastic crates or cardboard boxes / Cradle to Grave	When the difference between single-use cardboard boxes and reusable plastic crates is scaled the impact on the most influential impact category, GWP, would imply an annual saving of -785,240 metric tons of CO_2 eq. for the conservative scenario

ANNEXURE II: LIFE CYCLE ASSESSMENT (LCA), INDICATORS & SOFTWARE

Life cycle assessment (LCA) is a standardised method for measuring and comparing the environmental consequences of providing, using and disposing of a product.

The international standard for life cycle assessment, ISO 14040 (ISO 2006), states that "LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)".

The technical framework for LCA consists of four components, goal and scope definition, life cycle inventory, life cycle impact analysis and interpretation of the results each having a very important role in the assessment. The ISO 14040 lays the foundation of the study by proposing the principles and framework whereas ISO 14044 deals with the requirements and guidelines to be followed for it.

Goal and Scope Definition: The goal should clearly state the intended application/purpose of the study, the audience for which the results are intended, the product or function that is to be studied. When defining the scope, consideration of the reference unit, system boundaries and data quality requirements are the issues to be covered.

Inventory Analysis: Inventory analysis is related with the collection, analysis and validation of data that quantifies the appropriate inputs and outputs of a product system.

Impact Assessment: The primary aim of an impact assessment is to identify and establish a link between the product's life cycle and the potential environmental impacts associated with it. There are two ways in modelling LCIA, Midpoint and Endpoint. Midpoint impact category, also known as problem-oriented approach, translates environmental impacts into environmental themes such as climate change, acidification, human toxicity, etc. Endpoint impact category is a damage-oriented approach and it translate environmental impacts into issues of concern such as human health, natural environment, and natural resources. Less assumptions are used in midpoint modelling, but endpoint modelling is easier to understand.

Interpretation: This interpretation provides the conclusions of the environmental profile of the product or system under investigation, and recommendations on how to improve it. There are two objectives of life cycle interpretation:

a) Analyze results, reach conclusions, explain limitations, provide recommendations based on the findings of the preceding phases of the LCA and to report the results in a transparent manner.
b) Provide a readily understandable, complete, and consistent presentation of the result of an LCA study in accordance with the goal and scope of the study

SOFTWARE

LCA tools have been around since 1990s. With sustainability, climate change and circular economy becoming concerningly relevant and more publicly debated, the LCA tools and calculation methods have also refined and matured to help experts conduct the analysis granularly. Commonly available LCA software tools are one Click LCA and open LCA out of which most established and recommended by experts are two brands GaBi and SimaPro. Both of there are product system modelling and assessment software. Gabi is promoted by PE International, a German company & SimaPro is promoted by Pre-Consultants, based out of the Netherlands.
In this study we have used "GaBi Professional 2020" software and its latest database.

DATABASES

1. PTA-EU-28
2. Ethylene Glycol – EU-28
3. Tap water-EU-28
4. Nitrogen Gas-EU-28
5. Lubricant oil- IN-Refinery Mix
6. Natural gas-IN Natural Gas Mix
7. Diesel-IN diesel Mix refinery

ANNEXURE III: PROCESS FLOWCHART

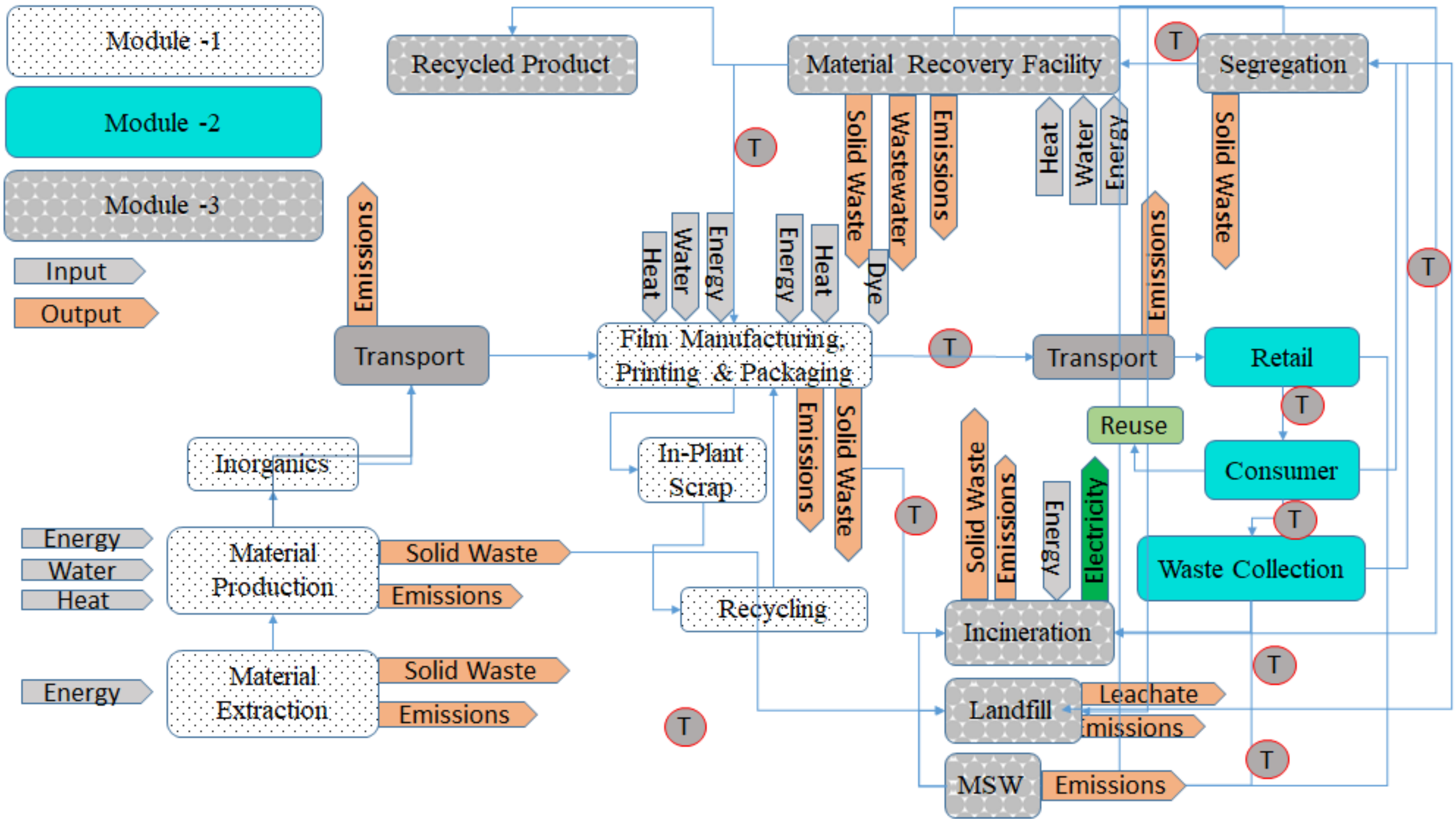


Figure 19: Polyethylene material process chart
Source: Core team

ANNEXURE IV: QUESTIONNAIRE WITH WASTE RECYCLER FOR PROCESS DATA

Questionnaire Survey for a Waste Management Facility
Note: Kindly mention the respective quantities with the desired unit wherever needed.

Primary Questions (Necessary)

1. What is the quantity of Multi-layered Plastic (MLP), Non-metallized (of same family), Non metallized, Non MLP received per month at your Waste Management Facility (WMF) and mention the % of different Polymers from the total MLP received?

Packaging	%	Quantity out of Total
Rigid		
Packaging		

2. What is the quantity, source of water used for cleaning process and mention the quantity of wastewater being recycled back into the process?
3. What is the process flow chart that the material undergoes once it reaches the WMF?
4. Mention the amount of power consumed at the facility (per month) and the source of electricity? Is there any back up for power available at the plant? If so, mention the details (Frequency, Duration and Type of fuel used)
5. Of the total waste received, what is the % of pellets that's get converted into.
6. What is the Minimum and Maximum distance does the waste takes it to reach the WMF? Mention the Mode, Frequency and Type of Fuel used for transporting.
7. After the waste is converted to various forms (ex. Pellets), how far does it get transported. Mention the Mode, Frequency and Type of Fuel used for transporting.
8. List out the quantity of waste generation and gaseous emissions that is let out from WMF and mention the % of waste that gets recycled within the plant.

Secondary Questions (Optional)

1. Do you segregate the Polyethylene (PE) of thickness less than 100 microns? If so, what is the quantity that gets generated per month out of total quantity received?
2. How big is your storage yard (or volume that can be stored in order to have a smooth plant process)?
3. Mention the capacity of Wastewater Treatment plant, chemicals used and the waste that gets generated by operating the plant?
4. How are materials transported from the storage yard to the Plant? Mention the details (average duration, frequency and fuel) of vehicles used.
5. How does the WMF deal with the waste that gets generated from the process?
6. What are the other types of products that gets manufactured at the WMF? Mention the characteristics of each product (Ex. Thickness, Weight, Dimensions)
7. Mention the name, quantity of colorants, dye (printing) used for the new product.

ANNEXURE V: QUESTIONNAIRE WITH PE FILM MANUFACTURER FOR PROCESS DATA

Questionnaire survey for film production & waste generation-
Note:

- Questions are prepared w.r.t to the production of 1 ton of PE Film (thickness 35 µ).
- Kindly mention the respective quantities with the desired unit wherever needed.
- The system boundary that has been kept for Production of PE Film includes Polymerization Process + Extrusion Process + Printing on the PE film

Film Production

1. State the type of extrusion process used in the manufacturing of PE Film
2. The PE film produced is monolayer or bilayer. If so where what are the difference in their composition of raw materials.
3. What are the i) additives ii) colorants iii) slip promoters and iv) anti-static agents used in the process? How are they transported to reach the plant?
4. Is compressed air used in any of the process and what is their quantity
5. What is the operating temperature and used in the Extrusion Process?
6. How much power is consumed for the extrusion process and mention the source of electricity?
7. What is the source of water used in the production of PE film and mention their quantity?
8. Is there any back up for power available at the plant? If so, mention the details (Frequency, Duration and Type of fuel used)
9. What is the means of transportation of goods within the plant? Mention the details of vehicles are used. Also mention the duration and frequency and fuel consumed.
10. Does the produced PE film is stored in a go down? If so, is it located within the plant. If not what is the distance travelled.
11. What is the material that is used for packing the PE film? How far it is transported to the plant.

Waste Generation

1. List out the waste generated (along with their quantities) during the production of PE film.
2. Does the waste get recycled? If so, in which process and mention the %.
3. Apart from solid waste, what are the other types of waste that gets generated from the three processes?
4. Is the waste generated managed within the plant or outside the plant?
5. Mention the gaseous emissions that are let out from the Plant premises.
6. Does steam is used in process. If so, mention the quantity.

ANNEXURE VI: ASSUMPTIONS

(Cradle to Gate-1)

1. 5 % of Waste from Extrusion Process (Siracusa et al. 2014) + (UFlex Questionnaire)
2. Electricity is taken from Indian National Grid
3. 2% of Waste from polymerization process
4. One Ton of PE film the Power consumed is 450KWH (UFlex Questionnaire)
5. 500 Km is considered for transportation of raw materials (PTA & EG) to the industry
6. American plastic film manufacturers required energy in the range of 5.87 to 6.51 MJ for manufacturing one kilogram of plastic films (PE Americas (2008), Life Cycle Services (2007)
7. However, Indian plastic film processing consumes 11.4 to 31.42 MJ of energy for processing same plastic films (Nayak and Swain (2002), Ghosh (2004))
8. Forklift of (capacity 3-6 ton; 4.86 lit of diesel per hour) has used to move the raw materials inside the industry
9. Truck chosen for cargo- Euro-5 (12-14t gross weight/ 9.3t payload)
10. The scrap from the output of extrusion process would be transported to local recycling plants for production of garbage bags.
11. It's necessary to add tap water of 1200 lit per ton of PE film (Horodytska et al. 2020).
12. Transportation of PE granulate to the extrusion plant is 735 kg.km per for 700 km distance (Siracusa et al. 2014)
13. The output Weight of dyes and inks are ignored due to their total weight is nearly equal to 1.4 % of total weight of input ink/dye (Affeldt et al. 2016)
14. The waste coming out from the extrusion process is recycled within the system and reused for the same purpose with 97% efficiency.

(Gate -1 to Gate -2)

1) 2% waste from extrusion to retail (damaging of PE roll or sheets)
2) PE packaging films are transported by rail (Energy-Electricity) and truck (Euro-5 ; 12-14t gross weight/ 9.3t payload & Energy-diesel).

(Gate -2 to Cradle)

WMF (Recycling center-Per Metric ton of PE waste)

- 80 % of the waste is being recycled at WMF and the rest 20 % is sent to landfill without gas collection.
- Only 920 kg of PE granulates are collected for every 1000 kg of PE waste after recycling process.
- 0.7 Liters of diesel and 0.045 kWh electricity are required for operating one metric ton of plastic waste at Waste management facility.
- For operating landfill with plastic waste, 3 L of diesel is required per one metric ton of plastic waste (Khandelwal et al. 2019)
- Waste collection point to WMF center is 30 km (Nearest) and 2500 km (Farthest)
- Fuel required for transportation of 1 ton of PE waste is 7.2 L of diesel (Aryan et al. 2019)

ANNEXURE-VII: INPUTS FROM RECYCLER (SHAKTI PLASTIC INDUSTRIES)

Questionnaire Survey for a Waste Management Facility

PRIMARY QUESTIONS

1. Quantity of Plastic Waste at the WMF (in MT)

Type of Plastic	Qty. received per month at the WMF	Qty. of metallized plastic received per month	Qty. of non- metallized plastic received	% out of Total Plastic received at the WMF
MLP	8000	2000	6000	25%
Non-MLP	20000	-	20000	-

2. Water at the WMF:
   a) Quantity of water used per month on cleaning plastic waste at the WMF: 1 Lakh Litre per month
   b) Source of water used for cleaning process: Ground water/Tanker
   c) Quantity of wastewater being recycled back into the WMF: 80%
3. Process flow chart that the material undergoes once it reaches the WMF:

MLP Recycling at SPI

STAGE 1: SEGREGATION

When plastic are taken to our facility it is first segregated density wise and gradewide. And further processed.

STAGE 2: SHREDDING AND WASHING

Segregated plastic waste is further shredded into smaller pieces for easier handling and processed for washing

STAGE 3: DRY SEPERATOIN

After sorting and cutting, the plastic pieces can be washed to remove traces of dirt and contaminants, which vary from paper and glue, to sand and grit, and mixed plastic types that can be separated in water

STAGE 5: EXTRUSION

The final step in most plastics recycling processes is compounding, which involves converting plastic regrinds into pellets, and often the incorporation of elements to transform the reclaimed plastics into high- quality, reusable materials. In pellet form, plastic is more easily distributed and remanufactured

STAGE 4: AGGLOMERATION

Agglomeration helps to maintain quality standards of recycled plastics such as bulk density, particle size, ash content

4. Power Consumption:
    a) Amount of power consumed at the WMF per month: 1,75,000 units
    b) Source(s) of Power: MSEB
    c) Is there any back up for power available at the plant? DG Set
    d) If so, mention the details (frequency, duration & type of fuel used): Diesel very occasional
5. % of total plastic waste converted into pellets out of the total plastic received at the WMF: 80%
6. Distance of waste collection points from WMF:
    a) Closest point of waste collection from WMF: 30 km from WMF
    b) Furthest point of waste collection from WMF: 2500 km from WMF
7. Transportation of post-consumer/ industrial waste to the WMF:
    a) Mode of transportation: By Road
    b) Frequency: Regular
    c) Type of Fuel used for transporting: Diesel
8. Transportation of pellets/ recycled plastic products from the WMF to the client:
    a) Mode of transportation: By Road
    b) Frequency: Regular
    c) Type of Fuel used for transporting: Diesel
9. Process waste:
    a) Quantity of waste generated through the recycling process at the WMF: Nil (invisible loss 2%)
    b) Quantity of gaseous emissions: Nil
    c) % of waste from the process re-recycled within the WMF: Nil

SECONDARY QUESTIONS

1. Is Polyethylene (PE) of thickness less than 100 microns segregated separately at the WMF? No
2. If so, what is the quantity (%) of PE of thickness less than 100 microns generated per month out of total quantity received: NA
3. Size of storage yard/space at the WMF: 40k sq. ft.
4. Mention the capacity of Wastewater Treatment plant, chemicals used and the waste that gets generated by operating the plant? 1 Lakh Litre. No chemicals used except Alum.
5. Other types of products manufactured at the WMF: Sheets/ Profiles

ANNEXURE-VIII: WASTE PICKER SURVEY

Figure 20: Rag picker Interviews

Source: Core team

Interviews were recorded and can be accessed here – Drive Link
https://drive.google.com/drive/folders/1R5dWjU7P-Nx7JVzXa5l3nIRlgBdlvFFs?usp=sharing

ANNEXURE-IX: IMPACT CATEGORIES

Parameter	Unit	Definition
Global Warming Potential (GWP)	kg CO2 Eq	The measure of alteration of global temperature levels due to the release of greenhouse gas emissions into the environment. The impact of these GHGs, such as CO_2, CH_4, NO_2, and water vapor, releases emissions, leads to an increase in surface temperatures, and finally causes impacts to the environment and humans.
Acidification Potential(AP)	kg SO2 Eq	The measure of the increase of H^+ ion concentration in water results in the drop of pH (pH<3). The occurrence of acid rains is due to the rise in water acidification when it reacts with NO_2, SO_2, and HF, which deteriorates the monuments.
Eutrophication Potential (EP)	Kg Phosphate Eq	The measure of accumulation of nutrients such as phosphates and nitrates from agricultural fertilizers in the water bodies causes excess growth of algal blooms and rapid development of aquatic plants. This acts as a barrier to sunlight's penetration into aquatic bodies, which ultimately affects marine animals.
Ozone Depletion Potential (ODP)	kg-R11 Eq	The thickness shrunk of the stratospheric ozone layer due to the excess release of chlorofluorocarbons emissions (CFCs), which ultimately allows the penetration of UV-B radiation onto the earth's surface. This causes skin cancer for humans as well as animals.
Abiotic Depletion Fossil (ADP Fossil fuel)	MJ	The decrease in nonrenewable resources due to the enormous consumption of resources in various sectors such as construction and mining leads to the scarcity of resources. It may cause a collapse of the ecosystem.
Freshwater Aquatic Eco toxicity (FEATP)	kg-DCB Eq	Toxic/Ill effects on the aquatic ecosystem are due to the release of hazardous effluents from chemical and metallurgical industries, consisting of harmful chemicals. These chemical effluents mix with fresh surface water that leads to the contamination of fresh surface water bodies.
Human Toxicity Potential(HTP)	kg-DCB Eq	Toxic/Ill effects on humans due to the direct exposure to hazardous chemicals released into the atmosphere from various chemical and metallurgical industries.
Photo Chemical Ozone Creation Potential (POCP)	kg-Ethane Eq	The measure of smog created from the reaction of non-methyl volatile organic compounds and oxides of nitrogen in the presence of sunlight/heat (Also called ground-level ozone)
Teristic Eco Toxicity Potential (TETP)	kg-DCB Eq	Toxic/Ill effects on the ecosystem due to the release of hazardous chemicals from various chemical and metallurgical industries into the ecosystem.

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