INVESTIGATING THE ENVIRONMENTAL IMPACT OF COMMON COSMETIC PRODUCT PACKAGING FOR IMPROVED SUSTAINABILITY

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Abstract

Investigating the environmental impact of common cosmetic product packaging for improved sustainability

The cosmetic industry is a significant contributor to global plastic waste, largely due to the extensive use of plastic-based packaging materials. In Sri Lanka, a rapid growth in personal care consumption is also evident. This study investigates the life cycle environmental impacts of three widely used cosmetic packaging types in Sri Lanka, namely a plastic bottle with flip cap, a collapsible squeeze tube, and a thick-bottom plastic tub. The life cycle assessment is carried out by using, SimaPro 9.3.0.3, along with the ReCiPe 2016 Endpoint (H) method under the World (2010) H/A scenario.

The study evaluated each packaging under two functional units, packaging required for 100ml of product and packaging based on the original SKU size for clarity purposes. Environmental impacts were assessed with and without the inclusion of filling and sealing energy to determine the sensitivity of energy use in the total life cycle impacts. The findings reveal that packaging material selection significantly outweighs energy consumption in terms of total environmental impacts. Across both functional units, the collapsible squeeze tube made of LDPE showed the highest environmental impacts.

A sustainable packaging design framework was developed based on the LCA results by recommending the use of mono material structures, lightweight packaging, clear recycling labels and right size SKU selection. The framework aims to guide Sri Lankan cosmetic manufacturers in making informed, data driven decisions with a best compromise of the functionality and environmentally friendliness.

In conclusion, the study shows the importance of material selection, design simplification and system compatibility in minimizing the environmental footprint of cosmetic packaging. Future research may further explore consumer behaviour, end of life infrastructure development and comparative assessment involving bio based and refillable packaging alternatives.

Life Cycle Assessment, Cosmetic Packaging, Environmental Impact, SimaPro, Sustainable Packaging in Sri Lanka, Plastic Waste Reduction

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List of Abbreviations

LCA	life cycle assessment
PET	polyethylene terephthalate
HDPE	high-density polyethylene
ISO	international organization for standardization
PLA	polylactic acid
LCI	life cycle inventory
ABS	Acrylonitrile Butadiene Styrene
PP	polypropylene
FU	functional unit
SKU	stock keeping unit
LDPE	low-density polyethylene
DALY	disability-adjusted life years
species.yr	species lost per year
PHA	Polyhydroxyalkanoates

1. INTRODUCTION

1.1.Background

At present, the impacts on the environment by the daily activities of humans are considered to be strongly influenced for the world and at the moment world is continually making an effort to control and avoid those impacts. A strong bond can be seen in between environmental impacts such as environmental pollution, waste landfilling, deforestation, and the burning of fossil fuels in the world with human activities. Excess resource utilization and excess material usage have become a great impact on the environment among all the causes and currently, most researchers and manufacturing companies are researching and developing solutions to overcome these types of issues. Major impact for the environment is the massive collection of plastic wastes in all over the world and when it is analyzed as a numerical value of the waste plastics, annual plastic waste generation of American person is 221 kg, European person 114 kg, Japan and Korean 69 kg etc. as an average from every probable way. Among this plastic waste, it has been illustrated that the highest percentage is from packaging. With evidence for it as in Europe around 40% of the plastic waste is from packaging of the products consumed by people [1].

Packaging performs an extremely significant starring role in a product in many ways and with all it has become the symbol of the product brand or the product identity. Three levels of packaging can be seen in the cosmetic industry as primary packaging level, which is directly contacting the cosmetic, secondary packaging level which acts as a packaging for primary packaging and the tertiary level packaging which is the largest packaging of the bundles of the products with primary and secondary packaging [2]. The very first role of the packaging of a product is principally to be used for the protection of the product which ensures the compliance in numerous ways for a product such as during storage, distribution and showcase in showrooms. With the assistance of the packaging of a product, protection from the environmental factors, physical risks, chemical risks and biological risks can be avoided to a significant level and also can be considered as a duty accomplished by the packaging. Therefore, it can be declared clearly that the packaging of a product is the extremely crucial component of a product and that pave the way for a substantial percentage of collection of waste plastic in the global [3].

Obtaining an appropriate and complementary solution to minimize the plastic waste collection due to the packaging of a product is one of the most important aspects to be encountered by world population in order to save the world. The solution can be obtained in different ways and the main two types are substituting a sustainable packaging material and minimizing the packaging material by changing the packaging method or design in order to utilize the materials effectively. Also, if there is a well systematic way of recycling the collected plastics that would be a solution too but currently only 9% of the waste plastic is successfully recycling in globally. Therefore, in order to avoid the environment impact, a solution is a much-needed aspect for the packaging waste of the world [4].

When considering about the packaging types in all over the world, cosmetic packaging and food packaging are occupying a large percentage from the packaging wastes. In cosmetic packaging container types such as jars, tubes, bottles, dispensers, and sachets are all made by plastics in a high percentage than the other materials which are glass and metal packages in general and in a small-scale extent the packages in paper and ceramic. From recent past, world have keen on addressing a solution for the material of cosmetic packaging by a sustainable material such as biodegradable plastics, bamboo containers etc. but still not much widespread and cost effective to propagate into the market [5]. Therefore, addressing a sustainable solution for the cosmetic packaging is a much needed with the effect to the environment.

1.2. Aim, Objective and Scope

1.2.1. Aim

To investigate the possible intervention for enhancing sustainability using eco-friendly cosmetic packaging with the prevailing methods in Sri Lanka.

1.2.2. Objectives

1. To identify the state of the art and functional requirements of designing cosmetics packaging for a cosmetic type.
2. To conduct a life cycle assessment (LCA) for the prevailing cosmetic packaging types in Sri Lanka.
3. To identify and compile sustainable design aspects and sustainability enhancement design solutions worldwide to provide sustainable packaging design insights for the product and packaging manufacturers in Sri Lanka.

1.2.3. Scope

The scope of the research is to enhance the sustainability in the industry of cosmetic packaging in Sri Lanka, by focusing on the sustainable packaging solutions. Here, recognizing the current practices, identify sustainable alternatives, and develop a design insight to guide the transition towards more environmentally friendly packaging will be focused. The research will be limited to top selling three types of cosmetic packaging in Sri Lanka, with a comparative analysis of global sustainability trends.

2. LITERATURE REVIEW

The environmental effects of conventional cosmetic packaging have garnered significant attention globally, particularly in developing nations such as Sri Lanka. This chapter shows the critical dimensions of cosmetic packaging, emphasizing its design functionality, sustainability enhancements, and life cycle assessment (LCA). Furthermore, it examines the decision frameworks and the strategies to inspire sustainable packaging implementation in Sri Lanka.

The global cosmetics industry is a significant contributor for the environmental degradation due to the large-scale use of non-biodegradable and resource-intensive packaging materials. In Sri Lanka, where cosmetics usage is rising, the environmental impacts of conventional packaging have become increasingly evident.

2.1. Functional Criteria of Cosmetic Packaging

Cosmetic packaging serves multiple purposes: protection, preservation, functionality, and marketing appeal. Several studies have identified the functional attributes essential for designing effective cosmetic packaging.

Packaging must guarantee the product's durability by protecting it from external environmental factors, such as light, oxygen, and moisture. Also, there should not be any reactions to the packaging by the product or environment in the period of the storage and up to the mentioned expired date of the product. Materials such as polyethylene terephthalate (PET) and high-density polyethylene (HDPE) are widely used due to the protective properties [6].

Packaging design should prioritize user convenience and accessibility and also features such as ergonomic shapes, dispensing mechanisms, and reseal ability should be there [7].

Comfort and ease of use of a packaging ensures by the ergonomically designing and accommodating the natural grip and movement for users. Such designs are not only improving functionality but also improve the aesthetic score of the packaging by making it more attractive to users. For example, rounded packaging designs are remarked as friendly and approachable, while sharp angles can convey precision and modernity [8].

Dispensing mechanisms which are designed for effective usage are important for controlling the product usage and minimizing the product waste. Innovations in this particular area which focuses on user-friendly designs that maintain product integrity. For example, incorporating pumps or squeezable tubes can provide consumers with better control of the product dispensing without over usage.

For maintaining the freshness of the product and prevent the contamination, reseal ability of the packaging, which is particularly important for cosmetics which can be used over long extended periods should be processed. Features like snap-on lids or screw caps contribute to the durability and safety of the product, by aligning with user expectations for the quality and the reliability.

Beyond the functionality of the packaging, the visual and physical aspects of packaging significantly influence user insights. The features which are affecting the shape, pattern, material, and surface treatment pave the way for the attractiveness of cosmetic packaging among the young women [9].

Integrating the sustainability into the packaging design is critically important. Users are attracted to the packaging which are not only meets the functional and aesthetic needs but also associates with the environmental values. Using recyclable materials and designing for reusability can enhance the brand image and appeal to eco mindful users [9]. Incorporating above mentioned features into cosmetic packaging design not only improves usability and convenience but also strengthens brand loyalty and meets the evolving expectations of users.

Aesthetic qualities are significantly influence the decisions of user for purchasing. Visual attraction, selection of type of material, and branding elements contribute to the user loyalty [10]. In the Sri Lankan market, colourful and lively designs tend to be fast moving into a wide range of users [11].

Ensuring the adherence of the rules and regulations in cosmetic packaging is more important for the user safety, legal adherence, and maintaining brand integrity. The guidelines for the cosmetic packaging and labelling are established by the International Organization for Standardization (ISO), specially, ISO 22715:2006 states the requirements for the packaging and labelling of all cosmetic products intended for sale or free distribution. This standard outline general principles to ensure consistency and safety in cosmetic packaging across different markets [12]. Not only the ISO standard different regional regulations are established across the different regions with slightly different frameworks to each other. Labelling in accurate and all-inclusive way is a critical component of rules and regulations. Labels must include product identity, net content of the product, ingredient declaration, manufacturer information, usage instructions and warning statements [13].

Other than the labelling, the safety of packaging materials themselves is in a high concern. Packaging material must not adversely interact with the product in it or carry health risks to its users. Evaluating the factors of the packaging such as material composition, potential for chemical migration, and the barrier properties are much essential for maintaining the product's integrity and the safety of the user.

2.2. State of the Art of Sustainable Design Solutions for Cosmetic Packaging

The global packaging industry is increasingly and continuously adopting renewable and biodegradable materials for the packaging like polylactic acid (PLA) and paper-based composites to mitigate the environmental impacts happening with the conventional packaging. PLA, which is derived from renewable resources such as corn, cassava, and sugarcane, is a biodegradable and compostable, breaking down into non-toxic byproducts, which makes it an environmentally friendly alternative to traditional plastics which are using now a days. Its production requires 65% less energy and emits 68% fewer greenhouse gases emission compared to conventional petroleum-based plastics [14]. Additionally, PLA shows mechanical properties which are comparable to traditional plastics, making PLA suitable for various packaging applications [15].

Example for another sustainable alternative is paper-based packaging which is 100% biodegradable and recyclable. Papers are decomposing within two to six weeks and can be recycled up to six times in general before the fibers of it becomes too short for further use [16]. Innovations in the paper packaging area are including the development of a recyclable protective coatings made from lignin, which gives the strength to the paper packaging and the resistance for the liquids or water in this packaging without affecting its recyclability.

However, the implementation of these materials faces challenges in various ways. As an example, while compostable packaging like PLA offers environmental benefits, the lack of adequate composting infrastructure in many regions become an obstruction for its effective disposal and decomposition. Therefore, a holistic approach, which including the development of infrastructure in waste management and user education, is also essential to realize the environmental benefits of renewable and biodegradable packaging materials [17].

Not only the above reasons, but lightweight packaging also minimizes material usage and transportation costs. When the plastic film gets thinner and reduced material thickness can significantly lower the carbon footprint [18].

Refillable packaging types have become increasingly popular among the cosmetic brands in globally directing to reduce the environmental impact and to promote sustainability. For an example, *L'Occitane en Provence* introduced eco-refills in the year 2008 and since they have expanded the offerings to include 16 eco-refill products, with the plans to increase the refillable product type number to 25 by the year 2022. These eco-refills are using up to 90% less plastic material than the standard packaging that are used without refilling option and with this small act it is saving over 214 tonnes of plastic annually [19].

Similarly, the Body Shop has also implemented refill stations across its stores globally. By the early 2023, the refill stations were available in 800 stores worldwide and 50% of them are located in U.S. locations. The company estimates that switching to refillable packaging can collectively save over 1 million plastic bottles by the end of 2023 [20].

The environmental benefits of the refillable packaging are supported by the research which are indicating the significant reductions in the carbon emissions, in energy consumption, and in water usage. According to a study by the LCA Centre, purchasing a refill instead a new product can pave the way for a result of 70% reduction in CO_2 emissions, 65% less energy consumption, and 45% less water usage [21].

For the success of the refillable packaging idea, the acceptance and purchasing of the refill product by user plays a crucial role. The intention to use refills in the cosmetic industry is strongly influenced by the expected ease of use and economic benefits perceived by users [22].

The challenges are there in the promoting and spreading the use of refillable packaging which reduce waste. Issues such as consumer convenience, standardization of refill systems, and the initial environmental impact of producing durable containers need to be addressed to get the maximum in the sustainability benefits of these initiatives [23].

Designing the cosmetic packaging with mono-materials and clear and informative labelling is essential for enhancing recyclability of the packaging while supporting the circular economy initiatives. Mono-material packaging is composed of a single type of material which can simplify the recycling process by eliminating the need for the material separation which will pave the way for increasing the recycling efficiency and at the end reducing the environmental impact of that packaging [24].

In the cosmetics industry, using a mono-material packaging that align with sustainability goals with the ability for easier recycling processes is considered as a sustainable solution. Also, a sustainable packaging design in the cosmetics sector mainly focuses on the strategies such as reducing material complexity and enhancing material recovery, which are crucial for achieving circularity [25].

Moreover, the clear and informative labelling on packaging plays a crucial role in user participation in recycling programs. Labels that include the instructions for straightforward recycling help the user to dispose the packaging correctly and thereby that is improving recycling rates and material recovery. This approach enhances the brand reputation of the product among eco-friendly users which eventually supports environmental sustainability.

The mono-material designs for the packaging and clear, informative labelling requires the collaboration from all the supply chain which compromised with material suppliers, designers, manufacturers, and policymakers. These collective efforts are very essential to overcome the challenges which are related to material performance, cost implications, and regulatory compliance, which are ultimately contributing for a more sustainable approach to the cosmetic packaging industry.

2.3. Life Cycle Assessment (LCA) for Cosmetic Packaging

LCA is a method that is used to evaluate the environmental impacts of a product, process, or service throughout its entire life cycle in a systematic way. This analysis considers and includes all most all the stages from raw material extraction (cradle), manufacturing of the product, distribution of it, use of the item, and to disposal (grave). By considering all stages, LCA provides a comprehensive view of environmental burdens, aiding in identifying opportunities for improvement and supporting decision-making [26].

The primary benefits of life cycle assessment are, environmental impact identification, informed decision-making which can be described as comparing alternative materials, processes or products ensuring choices that align with the goals of the product, regulatory compliance and certification which is dealing with environmental regulations and can obtain eco-labels and certification and the last benefit is enhancing the brand reputation as today people are bit more focusing on environmental responsibilities as well.

The effectiveness of an LCA largely depends on the software tools and databases employed. Several prominent LCA software tools are utilized in the industry, such as SimaPro, GaBi, OpenLCA. Each of these software tools have differences.

SimaPro software is recognized for its comprehensive analytical tools, that facilitates detailed environmental impact assessments of a product or service. It consists of large number of databases and methods as well supports a variety of databases and impact assessment methods which will enable the users to conduct thorough and transparent LCA studies. SimaPro also offers features like scenario analysis, parameter modelling, and access to up-to-date environmental databases such as ecoinvent and Agri-footprint [27].

GaBi which is developed by Sphera, is esteemed for its extensive modelling capabilities and a vast database tailored for complex LCA studies. It provides a robust platform for modelling life cycles and offers industry-specific data, making it suitable for detailed environmental assessments. GaBi's integration with the Environmental Footprint database allows for comprehensive evaluations aligned with current environmental standards [28].

Open LCA is an open-source and free software, is popular for its flexibility and cost-effectiveness. It is also compatible with various databases of LCA, and it supports a broad range of impact assessment methods by making it available for both academic and professional applications. Transparency and adaptability of OpenLCA have contributed to the widespread of the software in the LCA community.

All of the above-mentioned software tools depend on Life Cycle Inventory (LCI) databases, that provide the primary data which are necessary for assessing environmental impacts. Ecoinvent is the most common database which is used in LCA studies. This database is recognized as one of the most wide-ranging LCI databases and containing over 18,000 datasets covering a wide range of products and processes in the world. It also offers detailed and transparent data which facilitates the consistent and reliable LCA studies. The methodological framework of the database ensures consistency of various datasets by enhancing the reliability of assessments [29].

The GaBi database is designed to use with GaBi software only. These databases offer wide-ranging data personalised to various industries and applications. For complex modelling and detailed analysis of the study, the databases should provide with high quality datasets that align with industry standards and requirements of rules and regulations. Selecting the most appropriate software and the databases should be done on the requirements of the study, limitations in the budget, and the detail needed. It is also crucial to consider the compatibility of the software with relevant databases and the transparency of the data to ensure an accurate and meaningful results.

LCA studies have been instrumental in identifying sustainable practices within the cosmetic packaging industry globally. There is an article which shows that the way of conducting a comprehensive multi-attribute LCA to evaluate the environmental sustainability of plastic cosmetic packaging. This study addresses the growth that need for sustainable practices in the cosmetic industry which is having the impact of consumer demand, legislation, and the global environmental targets. They have used **SimaPro 9.2.0.1** for the modelling with the one of the most popular global databases, **Ecoinvent v3-APOS database**. The impact assessment method applied was **ReCiPe 2016 at the midpoint level**, focusing primarily on **Global Warming Potential** as the key indicator of environmental impact.

A full-factorial **Design of Experiments** approach was used to assess five key factors across multiple materials:

- Dematerialization (up to 70%)
- With 100% recycled content
- With 100% renewable energy during production
- Implementation of energy-saving measures (up to 50%)
- Recycling at the end of life

The above discussed study evaluated five materials, named, Acrylonitrile Butadiene Styrene (ABS), polypropylene (PP), polyethylene terephthalate (PET), polylactic acid

(PLA), and wood–polymer composite, with two million units of a cosmetic compact as the functional unit.

The following shows the key findings of the above-mentioned study.

- **Material Choice**: when compared to ABS, PP emerged as the most environmentally friendly option with a 50% reduction in global warming.
- **Dematerialization:** the most impactful factor which is reducing the global warming by 70% and this shows a linear relationship between packaging weight and environmental impact.
- **Recycled Content**: Including 100% post-consumer recycled materials led to a global warming potential reduction of 42–60%, depending on the material. ABS benefited the most due to its high initial impact.
- **Energy Strategies**: Using renewable energy and energy-saving measures during manufacturing offered modest global warming potential reductions (9–17% and 7–13%, respectively).
- **End-of-Life Recycling**: Global warming potential reductions of up to 16% were observed, with wood–polymer composite benefiting most due to its high landfill impact. However, recycled content was more impactful than recycling at end of life.
- **Combined Effects**: The combination of **dematerialization and recycled content** provided the most significant environmental benefits.

The study strongly recommends that cosmetic companies should focus on the following.

- **Reducing packaging volume** without compromising functionality
- **Substituting of virgin materials** with the recycled content
- **Evaluating the supply chains** for the efficiency of energy and resources.

Even though bio-based materials like PLA are often seen as eco-friendly, fossil-based PP performed better in most environmental categories. To achieve environmental gains, the need for data transparency and the incorporation of multiple sustainability strategies are a must [30].

Another research is there on developing an LCA-based tool to assess the environmental sustainability of cosmetic products. This study shows the importance of material selection, packaging design, and end-of-life management for minimizing the environmental impacts. It provided a framework for companies to evaluate and improve the sustainability of their packaging solutions in a systematic way [31].

These studies show a critical role of LCA in guiding the cosmetic industry toward more sustainable packaging practices. The study suggested the need for comprehensive assessments that consider material choices, production processes, transportation, and disposal methods to effectively reduce environmental impacts.

Research which are focusing on Sri Lankan, LCA of cosmetic packaging in limited. However, following studies provide valuable insights into the environmental impacts of packaging materials within the Sri Lankan context.

A study is there as, "Life Cycle Assessment of Selected Single-Use Plastic Products in Sri Lanka" which evaluated the environmental impacts of various single-use plastic products using LCA techniques to inform policy decisions on plastic waste management. Even though this is not related to cosmetic packaging or packaging it has some parameters that are important in studying the cosmetic packaging as well. They have used ISO 14040 and 14044 standards as the LCA framework, SimaPro 8.3.0.0, Ecoinvent 3.0 as the database, IPCC 2013 (GWP), ReCiPe Midpoint and Endpoint as the impact method. This study was a cradle to grave study which is done on the single-use plastic products such as cutlery, cotton buds, Joss-stick wrappers, cloth wick wrappers, pesticide bottles, grocery bags, straws, and water bottles with an alternative of PLA-based items or reusable options such as steel and aluminum. The findings highlighted significant environmental burdens associated with single-use plastic products and emphasized the need for sustainable alternatives and improved waste management strategies [32].

2.4. Decision Support Tools/ Methods Available for Sustainable Packaging

A decision framework is a structured method designed to guide decision makers through multiple criteria and conflicting objectives. In sustainable packaging, frameworks often integrate life cycle assessments, multi criteria decision making and circular economy principles [33]. A decision framework for sustainable packaging design is vital to guide manufacturers towards environmentally responsible solutions. Life cycle assessment provides environmental data and forms the scientific basis for making such decisions [34].

Several decision-making frameworks are developed to guide the packaging design towards sustainability. These frameworks combine all the factors of environmental, economic, and functional criteria to help the manufacturers to choose the most suitable options of the packaging.

The examples of decision-making frameworks prevailing are listed below.

- **Eco-Indicator 99** – This is a damage-oriented method which analyse the environment impact of the product or process in main three categories as human health, ecosystem quality and resource depletion [35].

- **The packaging impact quick evaluation tool (PIQET)** – This is a LCA tool for packaging that gives assessment criteria and comparison of packaging systems [36].

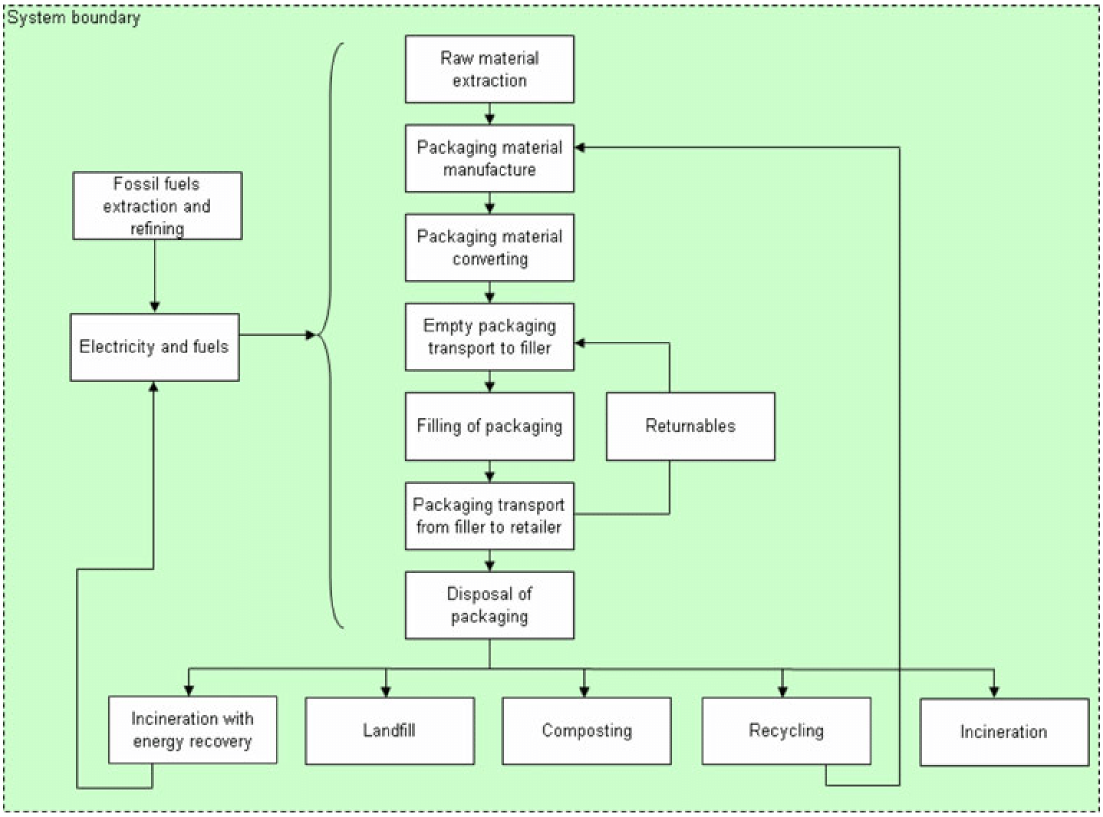

Figure 1. System Boundary of PIQET [36]

- **Sustainable Packaging Coalition's COMPASS Tool –** By considering the material health, energy use and end of life recyclability as the major considerations for the framework. This integrates with the design process with a design metrics [37].
- **Okala Guide** – This shows the guidance for design for environmental by giving impact scores for the material and process. This tool is good for the early design of the product [38].
- **Circular Packaging Design Guidelines (CPDG)** – This tool is based on the circular economy principles. It shows the importance of reuse, recyclability and using recycled materials other than virgin material [39].

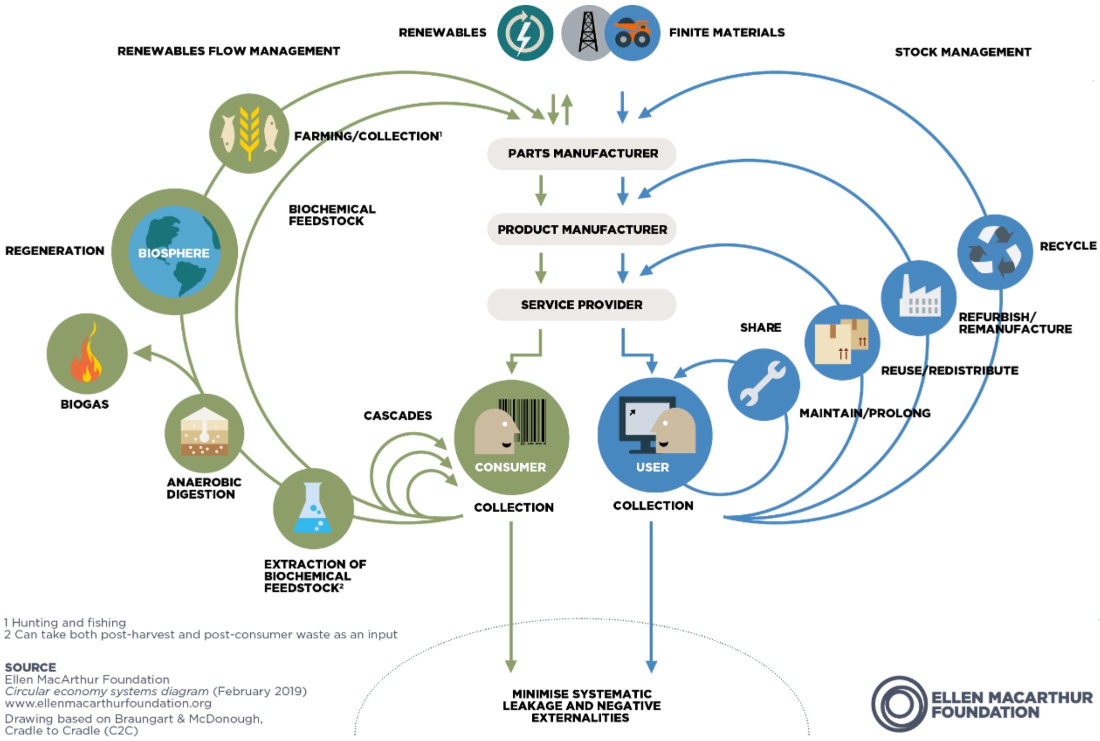

Figure 2. Flow of technical and biological materials through the value circle [39]

Eco design encourages sustainability at the earliest stages of product development, focusing on dematerialization, material substitution, recyclability and disassembly. Other than that, the appropriate material selection, material volume reduction, designing the material with less variety of materials, simplified components and reusability and recyclability are a significant consideration on designing [38].

The limitations of the prevailing frameworks are there, and the main limitation is that the lack of regional customization data or tool for the countries like Sri Lanka. The other limitation is that the restrictions to access for academic purposes of most of the tools and frameworks.

3. METHODOLOGY

This chapter outlines the methodology used to assess and compare the environmental impacts of selected cosmetic packaging types in Sri Lanka. The study employs the Life Cycle Assessment (LCA) framework, aligned with ISO 14040/14044 standards, [34], [40] and utilizes SimaPro 9.3.0.3 software in conjunction with the Ecoinvent 3 database [41]. The analysis focuses exclusively on packaging components of cosmetic products, deliberately excluding cosmetic content and transportation stages in order to maintain consistency and isolate the environmental burden attributable solely to packaging materials and processes.

3.1. Product Selection

Three cosmetic packaging types were selected based on qualitative market research involving interviews with local leading supermarkets. Due to commercial confidentiality, sales data and the product brand names were not documented, but the following products were consistently identified as top sellers in their respective categories.

1. **Product A (100 ml) – Plastic bottle with a flip cap**
2. **Product B (50 ml) – Collapsible laminated squeeze tube**
3. **Product C (20 ml) – Thick-bottom plastic tub**

A B C

Figure 3. Highest moving cosmetic products in Sri Lanka

These products which are shown in above by Figure 1 represent typical packaging formats, plastic bottle with a flip cap, collapsible laminated squeeze tube, thick bottom plastic tub respectively in A, B and C in Sri Lanka's personal care market.

3.2. Goal and Scope Definition

3.2.1. Goal

The goal of this study is to evaluate and compare the environmental performance of common cosmetic packaging types in Sri Lanka and identify opportunities to improve sustainability through material selection and design modifications.

3.2.2. Scope

This study adopts a **cradle-to-grave** LCA approach that includes all processes directly associated with the packaging's life cycle: from raw material extraction to end-of-life disposal. The scope adheres to the ISO 14040 and 14044 standards for conducting LCA [34] [40].

The included life cycle stages are:

- **Raw Material Extraction and Processing**: These processes are significantly contributing for the environmental impacts by considering the energy use and emissions [42].
- **Packaging Manufacturing**: This is the conversion of raw materials into the final packaging format and involves considerable resource and energy input [43].
- **Filling and Sealing**: Energy used during packaging filling operations, although relatively low, varies with packaging design and machinery used; hence, it is included for completeness [44]. In this study the comparison has done with and without the filling energy by considering the uncertainty that will be occurred due to the types of data which are using.
- **End-of-Life Management**: Disposal of the Packaging, such as landfill, incineration, and recycling, plays a critical role in the environmental performance. Sri Lanka faces significant challenges in waste management, and due to that it is vital to include this phase for the life cycle stage [45].

The following stages are excluded from the analysis.

- **Product Content/Formulation**: The focus of this research is exclusively on the environmental impacts of **packaging**, not the cosmetic product itself. Including the product would confound results, as formulation varies widely and is unrelated to packaging sustainability [42].
- **Transportation and Distribution**: All selected products are locally manufactured by the raw materials import from the same destination and distributed under similar supply chain conditions. Transportation impacts are

expected to be similar across all three packaging types and thus excluded to isolate the effects of packaging design [46].

- **Consumer Use Phase**: Consumer behaviour (e.g., frequency of use, disposal practices) is highly variable and difficult to generalize without extensive behavioural studies. Additionally, this phase has limited impact on packaging when compared to other stages [43].

The “ReCiPe 2016 Endpoint (H) v 1.03 / World (2010) H/A” impact assessment method was selected to evaluate environmental impacts across several categories, including global warming potential, water use, resource depletion, and toxicity.

3.3.Functional Unit (FU)

In LCA, the functional unit serves as the reference against which all input and output data are normalized, ensuring comparability among alternatives [40]. For this study, two functional units were selected and analyzed for analysing the sensitivity of the volume of stock keeping unit (SKUs). the selected functional units are “**the packaging required to contain and dispense 100 millilitres of cosmetic product**” and “**the packaging required to contain the selected original market size of the SKU**”.

The reasons for choosing the above functional units for this study are,

- **Equivalency Across Packaging Types**: The selected packaging formats (bottle, tube, and tub) come in varying volumes (100 ml, 50 ml, and 20 ml respectively). Normalizing their environmental impacts to a standard content volume of 100 ml allows for a fair and balanced comparison based on packaging performance rather than commercial size [47]. But when considering about the collection of the waste packaging to the environmental, the fast-moving market size should be considered as the functional unit. Therefore, both functional units have selected for the analysis part.

- **Functional Equivalence**: The packaging systems are required to contain, protect, and dispense cosmetic formulations. Using a content-based functional unit ensures that the comparison aligns with the functional purpose of packaging such as delivering a usable quantity of products to the consumer [48].

- **Alignment with Previous Studies**: Numerous LCA studies on packaging adopt volume-based functional units, such as 1 L of beverage or 100 g of product as they reflect the utility provided by the packaging, rather than the packaging alone [42]. This ensures the consistency with standards in the methodology of LCA, and it improves the comparability of findings with other findings.

- **Avoidance of Packaging Bias**: Weight-based or component-based functional units may be unfair in comparing analysis on certain packaging types due to their differences in material density or the way of construction. A content-volume basis neutralizes this bias by focusing on the service delivered, which is especially important in consumer packaging assessments [49].

Therefore, by defining the above mentioned two FUs the study ensures methodological consistency, functional equivalence, and meaningful sustainability insights for Sri Lankan market conditions. But as a sensitivity analysis the readings were obtained by changing the functional unit to container volume of each container type.

3.4.System Boundary

The system boundary for the LCA is from raw material extraction to end-of-life disposal of the cosmetic packaging. This ensures a complete environmental impact assessment.

The following bullets shows the stages which include the system boundary.

- **Raw Material Extraction**: This covers the extraction and processing of raw materials required to produce packaging such as plastic (high-density polyethylene (HDPE), low-density polyethylene (LDPE), and PP). Further details are discussed in the 3.5 section on life cycle inventory.
- **Packaging Manufacturing**: Covers the manufacturing of the packaging components, including plastic moulding, extrusion etc.
- **Filling & Sealing**: Represents the energy consumption and material inputs required for the filling of the product into its packaging and the sealing process.
- **End-of-Life Disposal**: Includes the disposal or recycling of the packaging post-consumer use. For this study, disposal options are based on Sri Lankan waste management practices, which typically involve landfill, incineration with energy recovery, and limited recycling.

Transportation and product use are excluded from the system boundary.

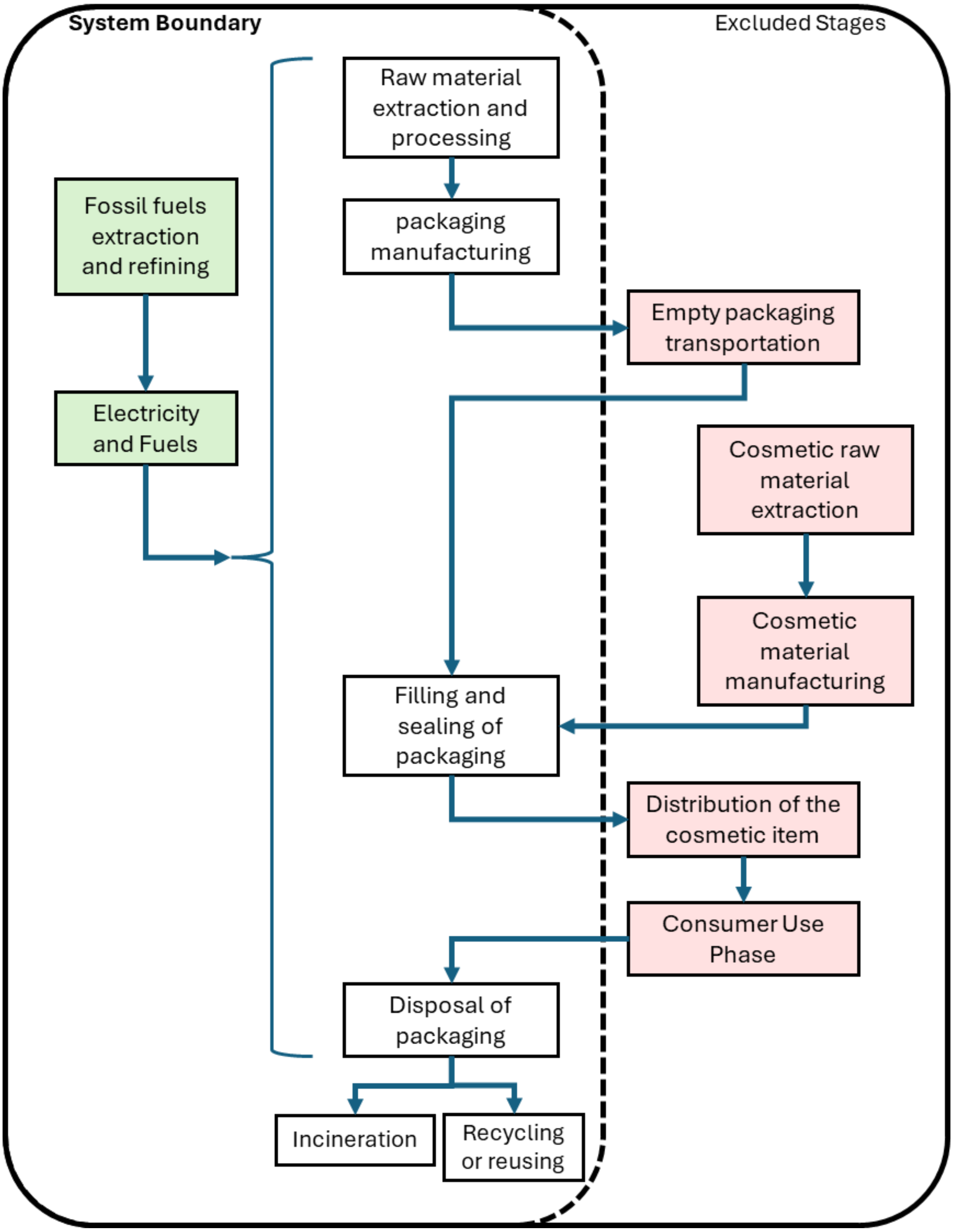

Figure 4. System Boundary Diagram

3.5. Life Cycle Inventory (LCI) and Data Collection

Data for the LCI were gathered from both primary and secondary sources to create a comprehensive and reliable database for the LCA. The data were used to quantify the environmental inputs and outputs associated with each packaging type.

1. **Primary Data**: The weights of the packaging components (plastic bottle, tube, and tub) were measured manually for each product by getting the average of three weights of the samples. This data reflects the actual materials used in the packaging systems selected for the study.
2. **Secondary Data**: Background data related to the production of raw materials (e.g., HDPE, LDPE, PP) and the manufacturing processes were sourced from the **Ecoinvent 3** database available in **SimaPro** software**.** These secondary data provided the necessary life cycle information for material production, energy consumption, and waste treatment processes.

Based on the available information, the material information for the packaging types which selected above are mentioned below.

1. **Product A (100 ml)** – Plastic bottle with a flip cap with screw. Material for both parts are HDPE.

2. **Product B (50 ml)** – Collapsible laminated squeeze tube with flip top cap. The tube is assumed to be made by LDPE, and the cap part is made using polypropylene.

3. **Product C (20 ml)** – Thick-bottom PP plastic tub with a screw lid which is also made with PP. The material is an assumption based on other packaging.

The material processing method for each part is listed below.

1. Product A
    - Cap – Injection moulding
    - Bottle – Injection moulding + Blow moulding
2. Product B
    - Cap – Injection moulding
    - Tube – Extrusion
3. Product C
    - Lid – Injection moulding
    - Tub – Injection moulding

For the disposal scenario of these packaging the average value of recycling globally is 9% and remaining 91% is going as incineration and land fill [4]. For the modelling purposes this data is using.

For the filling and sealing energy calculations, we need to get an average on the available machineries for the filling in industry. All these three types of cosmetics are manufacturing in a large scale; the industrial method of filling and sealing can associate with the calculation parameters.

Selected machines and there filling energy is listed below in the Table 1.

Table 1. Filling and sealing energy of machines

Machine Name	Filling type	Power	Filling rate	Ref
Automatic Cream Filling Machine by Lodha International LLP	Servo Based Filling	3 kW	Up to 80 bottles per minute	[50]
Automatic Linear Type Liquid/Cream/Lotion Filling Machine by ZT-Pack	Piston Filling	3 kW – 4 kW	Up to 100 bottles per minute	[51]
Automatic Double Head Cream-Lotion Filling Machine by SB Machines	Piston Filling	2 kW	Up to 80 bottles per minute	[52]
Technic Pharma Equipments' Automatic Tube Filling Machine	servo-based piston system	7.457 kW	Up to 70 tubes per minute	[53]
Venisha Groups' Automatic Aluminum and Lami Tube Filling Machine	Nozzle system	5 kW	Up to 100 tubes per minute	[54]
Abhisara International's Linear Tube Filling Machine	Nozzle system	5.5 kW	Up to 35 tubes per minute	[55]

1. Product A
   When considering the filling method for this product the Automatic Linear Type Liquid/Cream/Lotion Filling Machine by ZT-Pack [51] has used to produce this type of product as stated by the company which manufactured these machines. Servo based filling and piston system is used to produce these types of products.
2. Product B
   For this type of packaging the tube filling machineries are using with the nozzle-based type. The maximum energy per tube can be selected with the above popular types of tube filling machineries.
3. Product C

Filling of this type of tub packaging is also using the same machineries as bottle filling. Therefore, the same data can be used as the plastic bottle with flip cap.

3.6.Impact Assessment Methodology

The impact assessment phase of this study was conducted using the ReCiPe 2016 Endpoint (H) v 1.03 / World (2010) H/A method, implemented through SimaPro 9.3.0.3 software. ReCiPe is one of the most widely accepted life cycle impact assessment methods and is designed to translate life cycle inventory data into indicators reflecting environmental damage. The endpoint version of ReCiPe was selected to provide a higher-level interpretation of environmental impacts by grouping them into areas of protection: human health, ecosystems and resource availability [56].

The study was carried out in endpoint level of impact assessment in order to get the reflection of the final stage of the cause effect chain and to get the damage for the main three key areas. This was selected for the easiness for the understanding of non-technical audiences as this translates the complex environmental impacts into the categories which can easily distinguish. But the endpoint level involves with more assumptions and uncertainty in the software, and it is assumed that these uncertainties and assumptions are not affecting considerably for the conclusions which are taken from these analysis data. This study adopted the Hierarchies (H) perspective, which is a widely used and scientifically supported approach in life cycle impact assessment. It reflects international policy consensus and considers environmental impacts over a 100-year period. The "World (2010) H/A" scenario was selected to represent average global condition and emission factors, making it suitable for evaluating the environmental impacts of cosmetic packaging used and distributed on a global scale as there is not any specific method for Sri Lankan context.

This method evaluates impacts across three main areas of protection:

- Human health, measured in Disability-Adjusted Life Years (DALY)
- Ecosystems, measured in species lost per year (species.yr)
- Resource Scarcity, measured in economic cost (USD 2013)

There are impact categories that were assessed in this study and each associated with one of the three endpoint areas. Each of these categories was evaluated for the three cosmetic packaging types included in this study. The results were used to compare and overall environmental burden of each alternative and identify specific impact hotspots across the product life cycle.

Following figure 5 shows the methodology diagram of the research study.

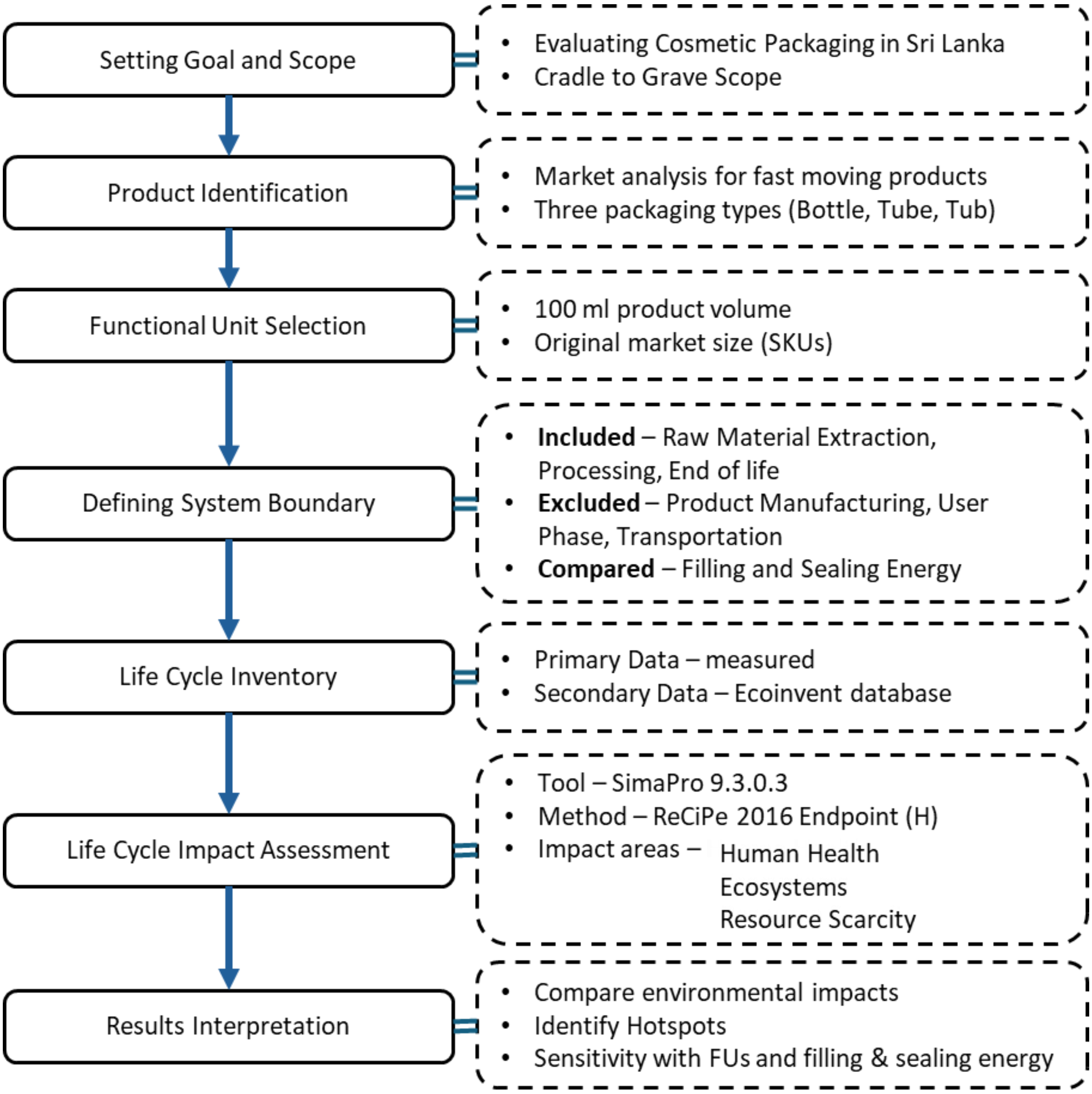

Figure 5. Methodology of the Study

4. RESULTS AND DISCUSSION

This chapter presents the inventory analysis for the LCA and the findings of the LCA comparing the environmental impacts of three cosmetic packaging formats commonly used in Sri Lanka, a plastic bottle with flip cap, a plastic squeeze tube and a thick-bottom plastic tub. These findings are based on characterization results generated using **SimaPro 9.3.0.3** software, applying the **ReCiPe 2016 EndPoint (H)** (Hierarchist) method under the **World (2010) H/A** (Hierarchist/ Individualist) scenario, consistent with ISO 14040 and ISO 14044 standards.

4.1. Inventory Data for the LCA

The filling and sealing energy of the three-product packaging are obtained using the available machineries for filling and sealing in the industry. The assumptions are made that the selected machinery is using for the respective product.

In the plastic bottle with the flip cap, for the modelling purposes the maximum energy per bottle will be selected out of the three machine types which are listed in the table 1, and it will be as the value, 0.00066 kWh.

In the collapsible squeeze tube, the maximum energy per tube can be selected with the popular types of tube filling machineries mentioned in the table 1. The maximum energy value from the table 1 is 0.0026 kWh per tube.

The sample calculations for the above numerical values are as follows.

$$Power\ output\ of\ the\ machine = 4\ kWh$$

$$Filling\ rate = 100\ bottles\ per\ minutes = 6000\ bottle\ per\ hour$$

$$Energy\ per\ bottle = Energy\ used\ per\ hour\ \div Number\ of\ bottles\ per\ hour$$

$$Energy\ per\ bottle = 4\ kWh/6000\ bottles = 0.00066\ kWh$$

Following Table 2 summarizes the estimated inventory values for each packaging types including filling and sealing energy.

Table 2. Inventory data used for the LCA study

Packaging Type	Materials	Manufacturing Method	Weight (kg)	Filling and sealing Energy (kWh)	End of life allocation
Product A – 100 ml	Bottle – HDPE, granulate	Injection moulding Blow moulding	13.5g	0.00066 kWh per bottle	9% recycling 91% incineration & land fill.
	Cap – HDPE, granulate	Injection moulding	5g		

Product B – 50ml	Tube – LDPE, granulate	Extrusion	8.4 g	0.0026 kWh per tube	
	Cap – PP, granulate	Injection moulding	4.4 g		
Product C – 20ml	Tub – PP, granulate	Injection moulding	11.9 g	0.00066 kWh per tub of 100 ml	
	Lid – PP, granulate	Injection moulding	4.9 g		

The results are presented for comparing the above mentioned three packaging products in different functional units, including the original SKU, container that contains 100 ml unit by both including and excluding filling and sealing energy. Multiple impact categories were evaluated to give a comprehensive view of environmental performance across climate, human health, ecosystem quality and resource depletion. Additionally, the chapter includes individual packaging analysis, a comparison of filling energy influence

4.2. Environmental Impact Analysis per 100 ml volume as the FU

The 100ml of delivered product as the FU enables a standardized comparison independent of packaging size. Among the packaging sizes used in Sri Lanka this volume of packaging is the highest visible SKU of cosmetic products. This analysis is done by including the filling energy and excluding the filling energy.

4.2.1. Analysis Including Filling Energy

In the functional unit of 100 ml the highest environmental burden is exhibited from thick-bottom plastic tub except the impact category fossil resource scarcity. In that category the Collapsible squeeze tube has the highest environmental burden. In the second highest environmental burden is showcasing by the collapsible squeeze tube but the difference of it with the plastic bottle with flip cap is not that much high so it can be concluded that the environmental impact is same when comparing the collapsible squeeze tube and plastic bottle with flip cap. The following table 3 depicts all the numerical values for the impact assessment and figure 6 shows the graphical representation of it by getting the percentage of each impact category when compared to the highest value of it among the three products.

Table 3. Impact Assessment Results -100 ml FU

Impact category	Unit	Thick-Bottom Plastic Tub	Plastic Bottle with Flip Cap	Collapsible Laminated Squeeze Tube
Global warming, Human health	DALY	3.66×10^{-7}	9.86×10^{-8}	1.29×10^{-7}
Global warming, Terrestrial ecosystems	species.yr	1.1×10^{-9}	2.97×10^{-10}	3.9×10^{-10}
Global warming, Freshwater ecosystems	species.yr	3.01×10^{-14}	8.12×10^{-15}	1.07×10^{-14}
Stratospheric ozone depletion	DALY	3.89×10^{-11}	1.26×10^{-11}	5.74×10^{-12}
Ionizing radiation	DALY	1.44×10^{-10}	5.56×10^{-11}	2.08×10^{-11}
Ozone formation, Human health	DALY	3.33×10^{-10}	1.1×10^{-10}	1.46×10^{-10}
Fine particulate matter formation	DALY	1.97×10^{-7}	6.79×10^{-8}	5.57×10^{-8}
Ozone formation, Terrestrial ecosystems	species.yr	4.83×10^{-11}	1.59×10^{-11}	2.22×10^{-11}
Terrestrial acidification	species.yr	1.13×10^{-10}	3.9×10^{-11}	4.87×10^{-11}
Freshwater eutrophication	species.yr	4.52×10^{-11}	1.64×10^{-11}	7.2×10^{-12}
Marine eutrophication	species.yr	1.93×10^{-14}	5.51×10^{-15}	1.52×10^{-15}
Terrestrial ecotoxicity	species.yr	3.54×10^{-12}	9.54×10^{-13}	4.37×10^{-13}
Freshwater ecotoxicity	species.yr	8.54×10^{-12}	2.13×10^{-12}	1.46×10^{-12}
Marine ecotoxicity	species.yr	1.79×10^{-12}	4.45×10^{-13}	3.09×10^{-13}
Human carcinogenic toxicity	DALY	2.37×10^{-8}	7.42×10^{-9}	7.17×10^{-9}
Human non-carcinogenic toxicity	DALY	4.26×10^{-8}	1.15×10^{-8}	4.41×10^{-9}
Land use	species.yr	4.68×10^{-11}	3.2×10^{-11}	1.12×10^{-11}
Mineral resource scarcity	USD2013	4.91×10^{-5}	1.19×10^{-5}	4.71×10^{-6}
Fossil resource scarcity	USD2013	0.012854	0.003915	0.016284
Water consumption, Human health	DALY	2.16×10^{-9}	7.32×10^{-10}	1.37×10^{-9}
Water consumption, Terrestrial ecosystem	species.yr	1.33×10^{-11}	4.49×10^{-12}	8.36×10^{-12}
Water consumption, Aquatic ecosystems	species.yr	8.31×10^{-16}	2.83×10^{-16}	4.01×10^{-16}

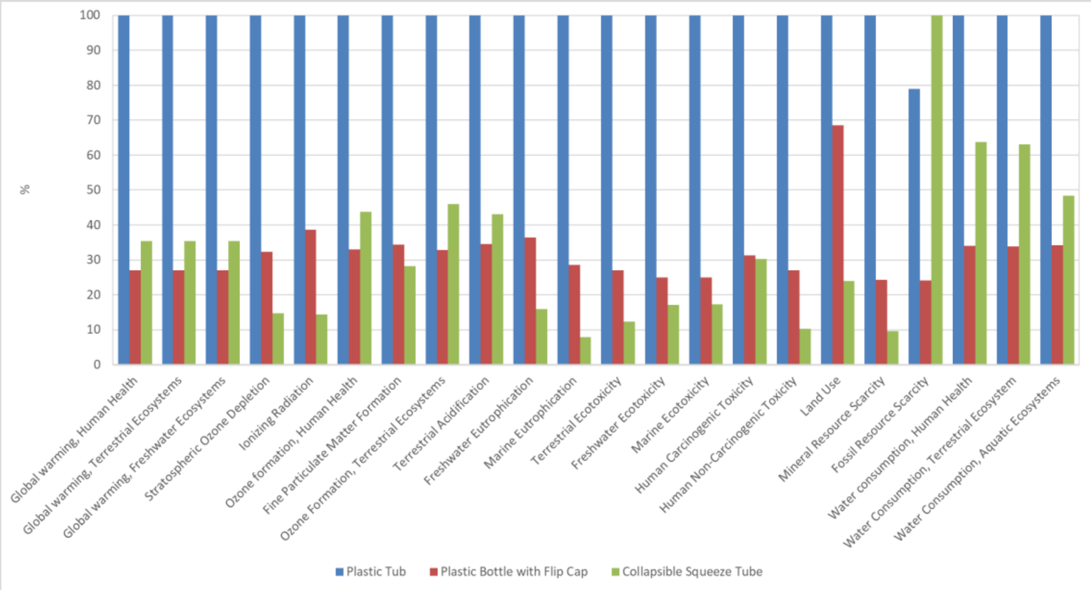

Figure 6.Impact Assessment Results - 100ml FU comparing all three products

The following table 4 shows the damage assessment according to its main category and the figure 7 shows the percentage value of them when compared to the highest value of it among the three products. In the calculation part of converting impact assessment results to damage assessment results, the impact categories under human health are added together to get the damage assessment under human health and same for the other two damage categories. This is done in order to get the clarity of the impacts cocategories and how high the impact for the environment.

Table 4. Damage Assessment Results- 100 ml FU

Damage category	**Unit**	**Thick-Bottom Plastic Tub**	**Plastic Bottle with Flip Cap**	**Collapsible Laminated Squeeze Tube**
Human health	DALY	6.32×10^{-7}	1.86×10^{-7}	1.98×10^{-7}
Ecosystems	species.yr	1.38×10^{-9}	4.09×10^{-10}	4.9×10^{-10}
Resources	USD2013	0.012903	0.003927	0.016289

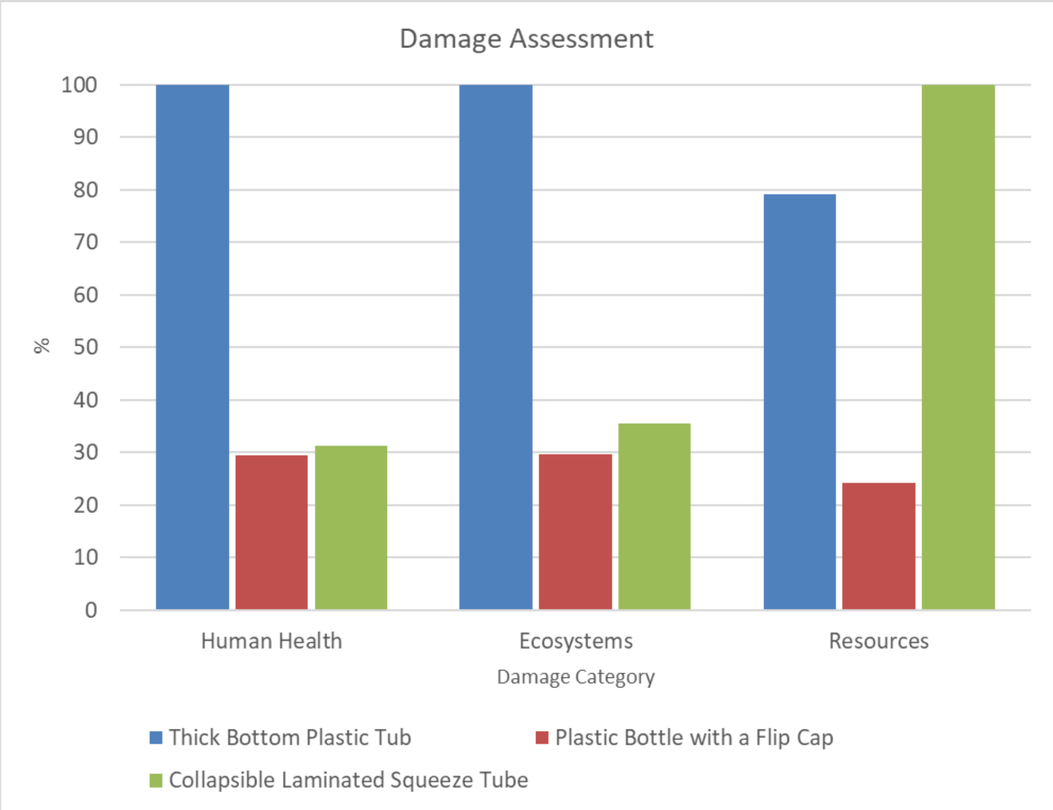

Figure 7. Damage Assessment Results - 100 ml FU

A single score bar graph is generated using the conversion of all the impacts into the common unit of endpoint damage score. Single score is generated as a way of simplifying the results of the impact assessment into one numerical value under single unit. All the units, DALY, species.yr, USD2013 will convert to the Pt (point) or mPt (milli points) which is denoted 1 Pt as one thousands of annual environmental load caused by an average European citizen. Also this graph and the single score method helps to compare all the impacts assessments between products by the cumulative value of all the assessments. When considering the single score bar graph, it clearly shows that the Thick-Bottom Plastic Tub has created major damage to the environment. The single score bar graph is shown in figure 8 below.

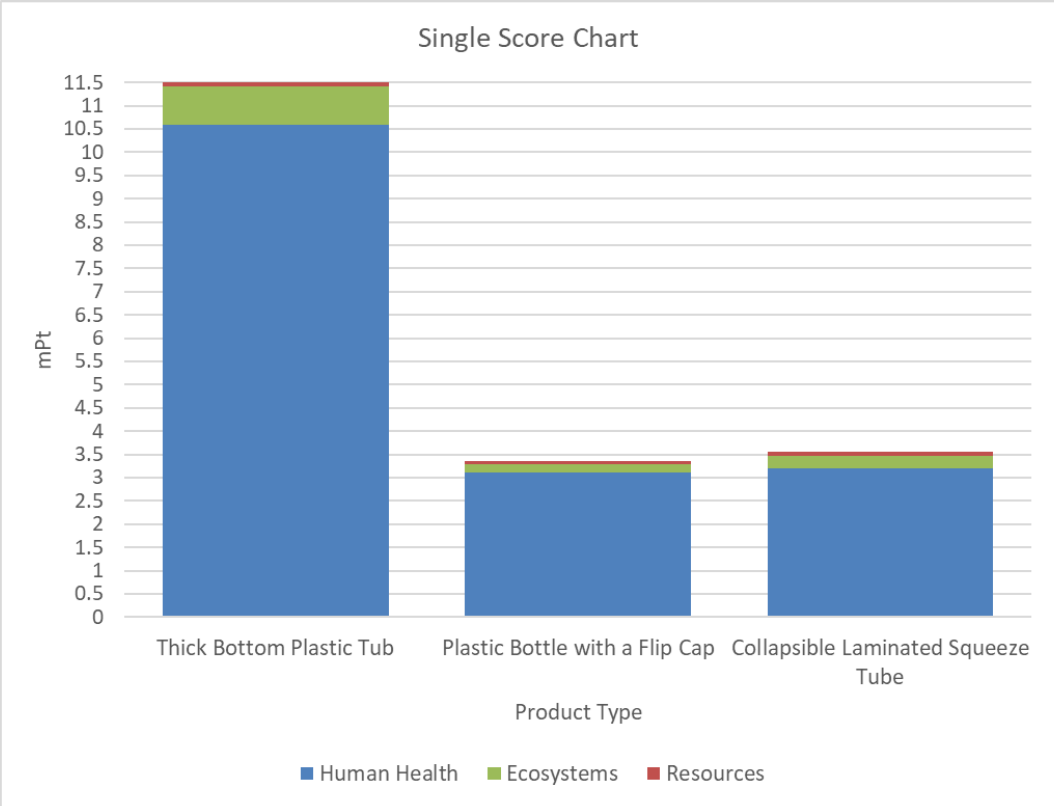

Figure 8. Single Score Graph - 100 ml FU

4.2.2. Analysis Excluding Filling Energy

Excluding filling energy caused minor improvements in total impact values for all packaging types. However, the comparative results remained consistent, indicating that packaging material and design are the primary environmental drivers.

The following table 5 shows the damage assessment excluding filling energy according to its main category and figure 9 shows the percentage value of them when compared to the highest value of it among the three products.

Table 5. Damage Category - Excluding Filling Energy 100ml FU

Damage category	**Unit**	**Thick-Bottom Plastic Tub**	**Plastic Bottle with Flip Cap**	**Collapsible Laminated Squeeze Tube**
Human health	DALY	6.27×10^{-7}	1.85×10^{-7}	1.9×10^{-7}
Ecosystems	species.yr	1.37×10^{-9}	4.07×10^{-10}	4.74×10^{-10}
Resources	USD2013	0.012742	0.003895	0.016035

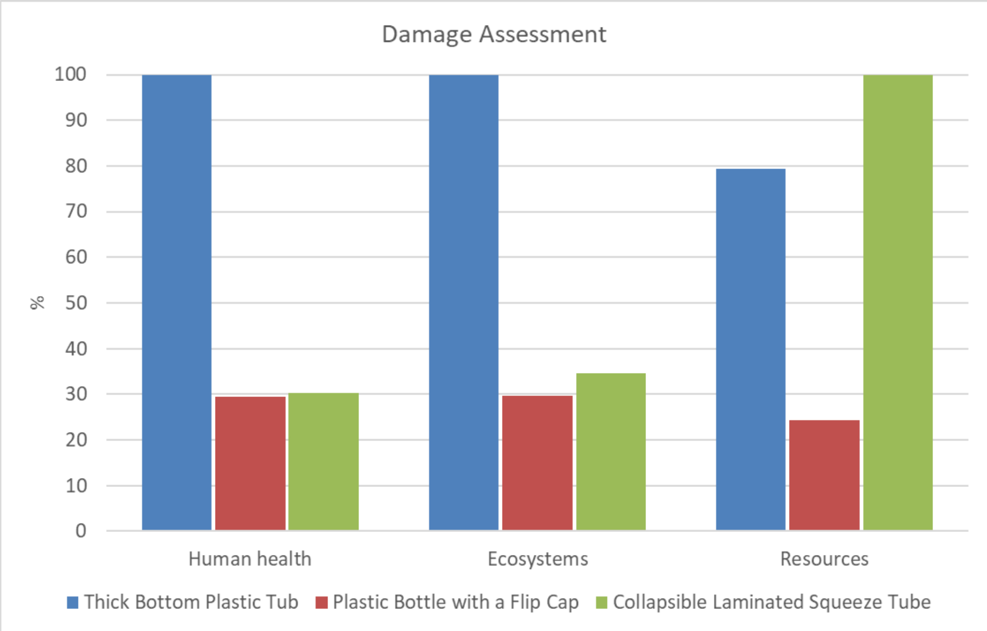

Figure 9. Damage Assessment Results - Excluding Filling Energy 100 ml FU

Normalizing and weighting of the impact assessments components are used to simplify the interpretation of the results. Normalizing eliminates the different units as same as the single score and allow for easier comparison and analysis. Each unit of impact assessment categories have the impact category indicator result and a pre-defined normalization values and with them the normalization results are obtained according to the equation (1). The impact category indicator results and the reference values are in built in the methods in the SimaPro software.

$$Normalized\ Result = \frac{Impact\ Category\ Indicator\ Results}{Reference\ Value} \tag{1}$$

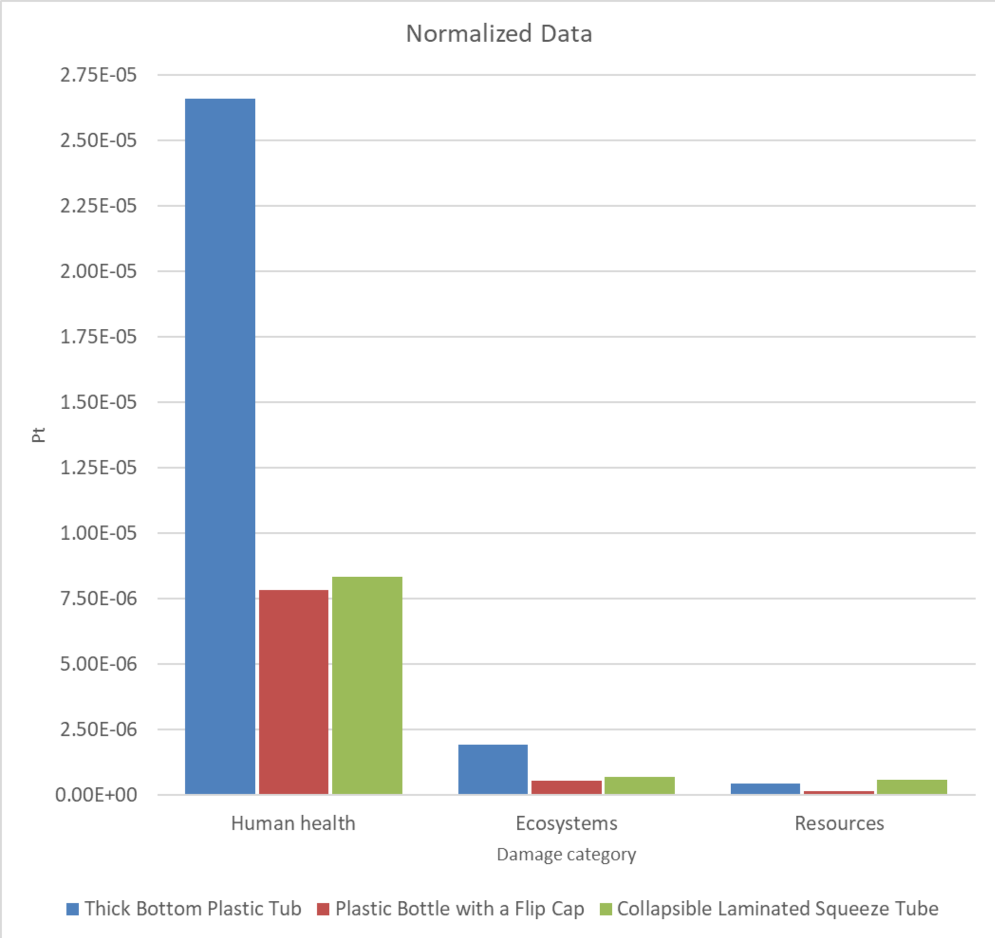

Figure 10. Normalized Chart - Including Filling Energy 100ml FU

When considering the normalized version of both including and excluding filling and sealing energy the human health impact category has subjected to the highest effect from all three-product packaging. It is drastically higher than the other two impact categories. The above figure 10 shows the normalized bar graph including the filling and sealing energy and the following figure 11 shows the normalized bar graph excluding the filling and sealing energy.

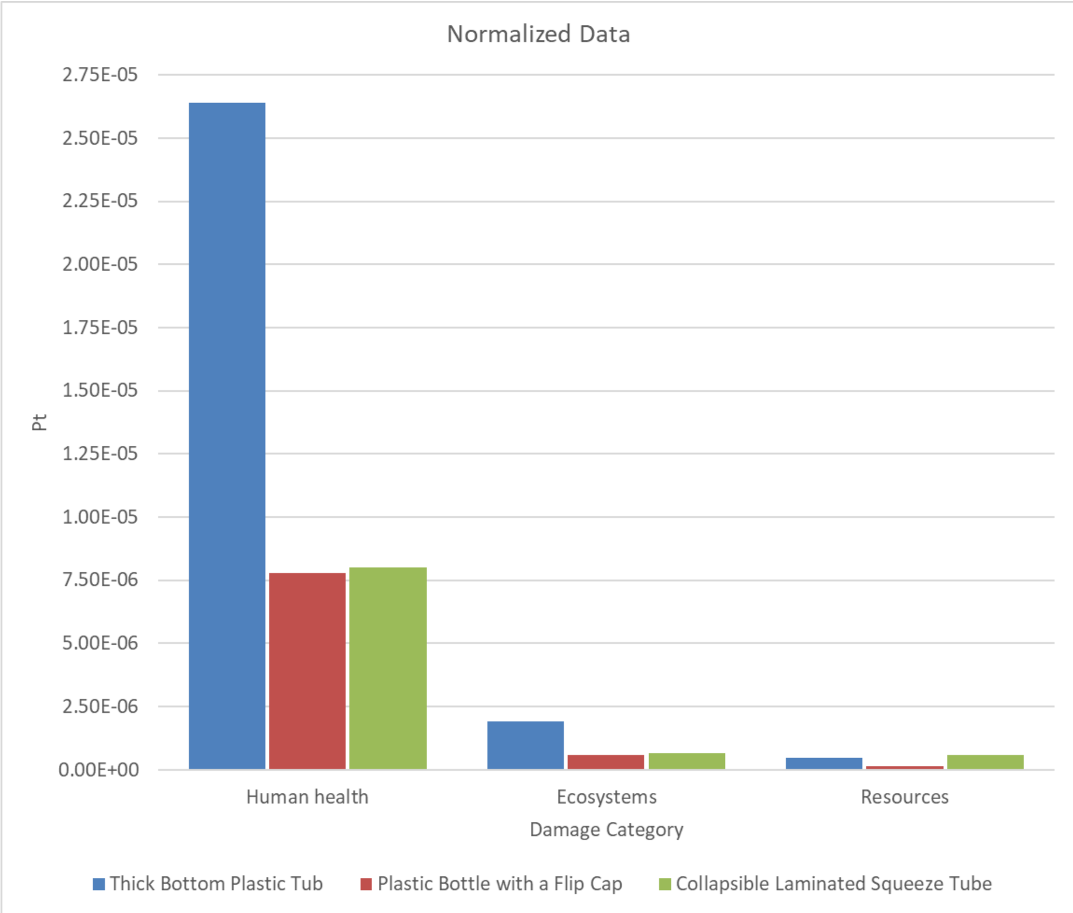

Figure 11. Normalized Chart - Excluding Filling Energy 100ml FU

4.3. Environmental Impact Analysis Comparison Based on Original SKU

When comparing the product packaging the identified functional units have some misalignments because of the fast-moving selected products are moving with the original SKUs and the environment is getting these packaging at the end as the burden. Therefore, the same analysis has done for the original SKU.

4.3.1. Analysis Including Filling and Sealing Energy

When considering the environmental impact of the considered three packaging on the original SKU the plastic bottle with flip cap is having the highest impact on environment except the impact category fossil resource scarcity other than the other two packaging. The next most impactable packaging seems to be thick-bottom plastic tub.

The following table 6 shows the numerical values of the impacts for all the three selected packaging and figure 12 shows the graphical representation of it by getting the percentage of each impact category when compared to the highest value of it among the three products.

Table 6. Impact Assessment - Including filling energy Original SKU

Impact category	Unit	Thick-Bottom Plastic Tub (20 ml)	Plastic Bottle with Flip Cap (100 ml)	Collapsible Laminated Squeeze Tube (50 ml)
Global warming, Human health	DALY	7.31×10^{-8}	9.85×10^{-8}	6.47×10^{-8}
Global warming, Terrestrial ecosystems	species.yr	2.21×10^{-10}	2.97×10^{-10}	1.95×10^{-10}
Global warming, Freshwater ecosystems	species.yr	6.03×10^{-15}	8.12×10^{-15}	5.33×10^{-15}
Stratospheric ozone depletion	DALY	7.78×10^{-12}	1.25×10^{-11}	2.87×10^{-12}
Ionizing radiation	DALY	2.88×10^{-11}	5.56×10^{-11}	1.04×10^{-11}
Ozone formation, Human health	DALY	6.65×10^{-11}	1.09×10^{-10}	7.28×10^{-11}
Fine particulate matter formation	DALY	3.95×10^{-8}	6.78×10^{-8}	2.78×10^{-8}
Ozone formation, Terrestrial ecosystems	species.yr	9.66×10^{-12}	1.58×10^{-11}	1.11×10^{-11}
Terrestrial acidification	species.yr	2.26×10^{-11}	3.9×10^{-11}	2.44×10^{-11}
Freshwater eutrophication	species.yr	9.04×10^{-12}	1.64×10^{-11}	3.6×10^{-12}
Marine eutrophication	species.yr	3.86×10^{-15}	5.51×10^{-15}	7.61×10^{-16}
Terrestrial ecotoxicity	species.yr	7.08×10^{-13}	9.54×10^{-13}	2.19×10^{-13}
Freshwater ecotoxicity	species.yr	1.71×10^{-12}	2.12×10^{-12}	7.28×10^{-13}
Marine ecotoxicity	species.yr	3.57×10^{-13}	4.45×10^{-13}	1.55×10^{-13}
Human carcinogenic toxicity	DALY	4.74×10^{-9}	7.42×10^{-9}	3.58×10^{-9}
Human non-carcinogenic toxicity	DALY	8.52×10^{-9}	1.15×10^{-8}	2.21×10^{-9}
Land use	species.yr	9.35×10^{-12}	3.2×10^{-11}	5.59×10^{-12}
Mineral resource scarcity	USD2013	9.82×10^{-6}	1.18×10^{-5}	2.36×10^{-6}
Fossil resource scarcity	USD2013	0.002571	0.003915292	0.008142
Water consumption, Human health	DALY	4.31×10^{-10}	7.32×10^{-10}	6.87×10^{-10}
Water consumption, Terrestrial ecosystem	species.yr	2.65×10^{-12}	4.48×10^{-12}	4.18×10^{-12}
Water consumption, Aquatic ecosystems	species.yr	1.66×10^{-16}	2.83×10^{-16}	2.01×10^{-16}

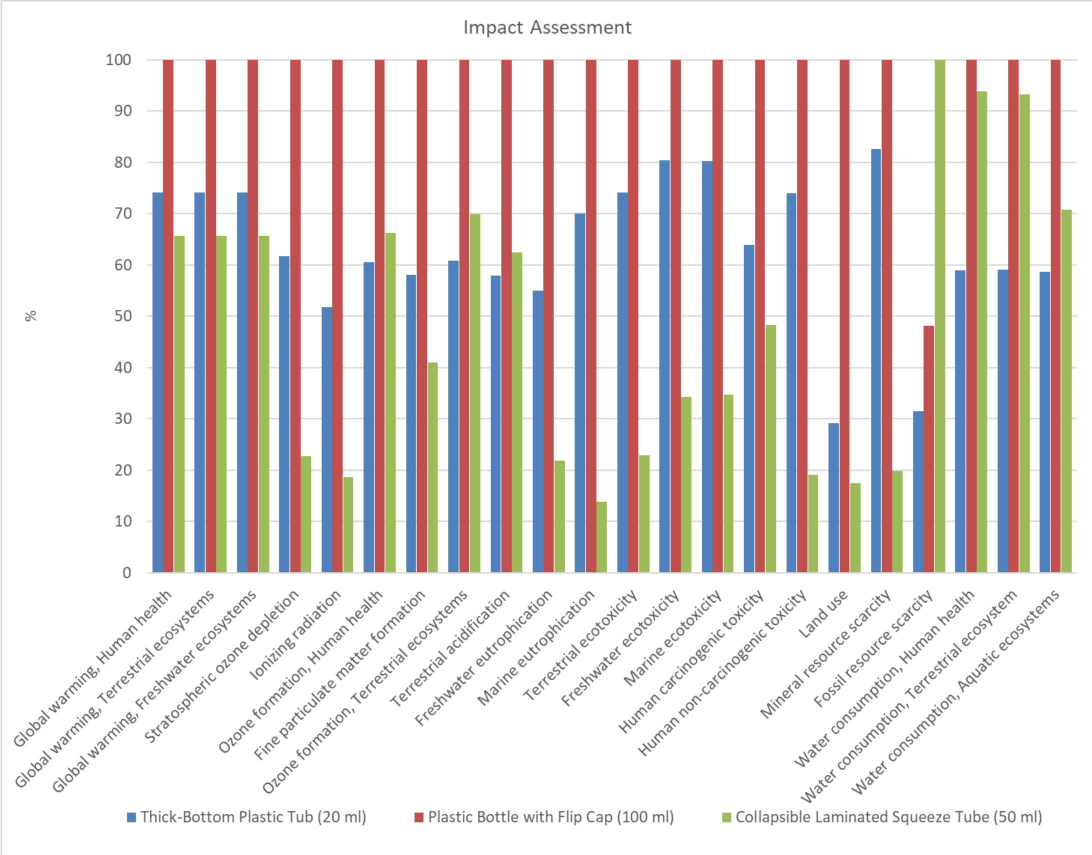

Figure 12. Impact Assessment - Including filling energy Original SKU

While it is expected that modifications to the FU would influence the outcomes of the impact assessment, the original SKU-based FU appears to be appropriate, as it accurately represents the product's contribution to environmental impacts in its actual usage context.

The following Table 7 shows the damage assessment according to its main category and figure 13 shows the percentage value of them when compared to the highest value of it among the three products.

Table 7. Damage Assessment - Including Filling Energy Original SKU

Damage category	**Unit**	**Thick-Bottom Plastic Tub (20 ml)**	**Plastic Bottle with Flip Cap (100 ml)**	**Collapsible Laminated Squeeze Tube (50 ml)**
Human health	DALY	1.26×10^{-7}	1.86×10^{-7}	9.91×10^{-8}
Ecosystems	species.yr	2.78×10^{-10}	4.09×10^{-10}	2.45×10^{-10}
Resources	USD2013	0.002581	0.003927	0.008145

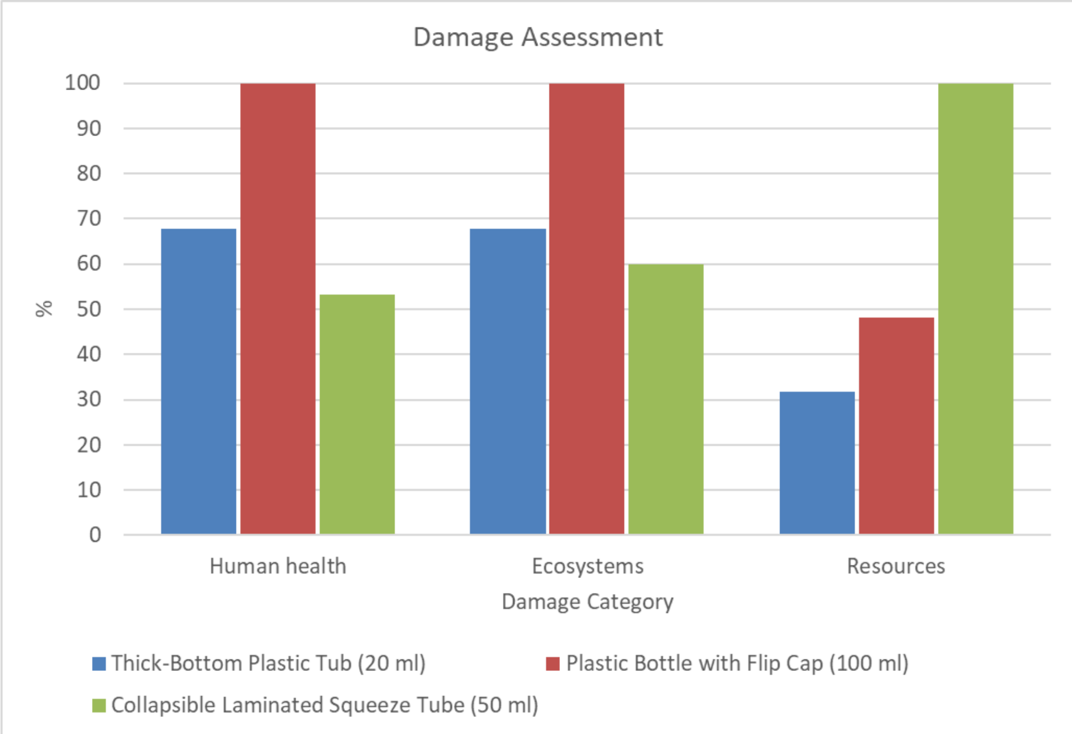

Figure 13. Damage Assessment - Including Filling Energy Original SKU

When considering the single score bar graph denoted by figure 14, it clearly shows that the plastic bottle with flip cap has created major damage to the environment.

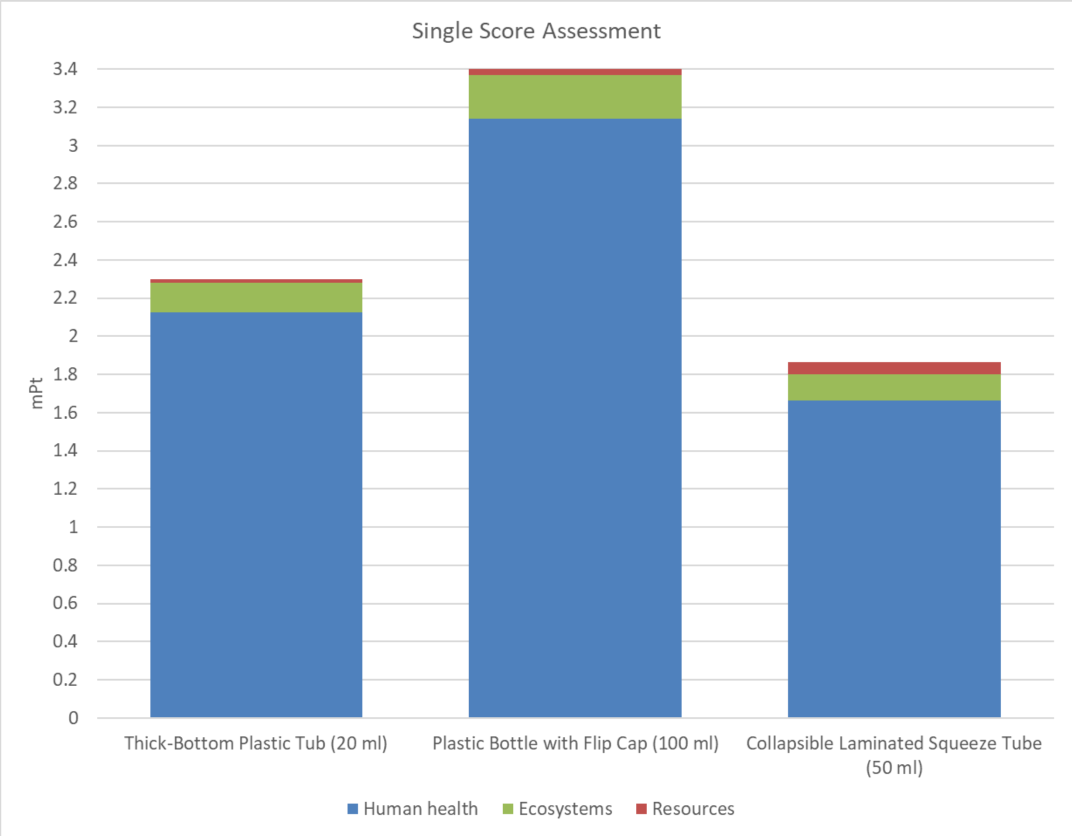

Figure 14. Single Score Assessment - Including Filling Energy Original SKU

4.3.2. Analysis Excluding Filling Energy

Excluding filling energy caused minor improvements in total impact values for all packaging types as same as the 100 ml FU scenario.

The following Table 8 shows the damage assessment excluding filling energy according to its main category and figure 15 shows the percentage value of them when compared to the highest value of it among the three products.

Table 8. Damage Assessment - Excluding Filling Energy Original SKU

Damage Category	**Unit**	**Thick-Bottom Plastic Tub (20 ml)**	**Plastic Bottle with Flip Cap (100 ml)**	**Collapsible Laminated Squeeze Tube (50 ml)**
Human health	DALY	1.25×10^{-7}	1.85×10^{-7}	9.51×10^{-8}
Ecosystems	species.yr	2.75×10^{-10}	4.07×10^{-10}	2.37×10^{-10}
Resources	USD2013	0.002548	0.003895	0.008018

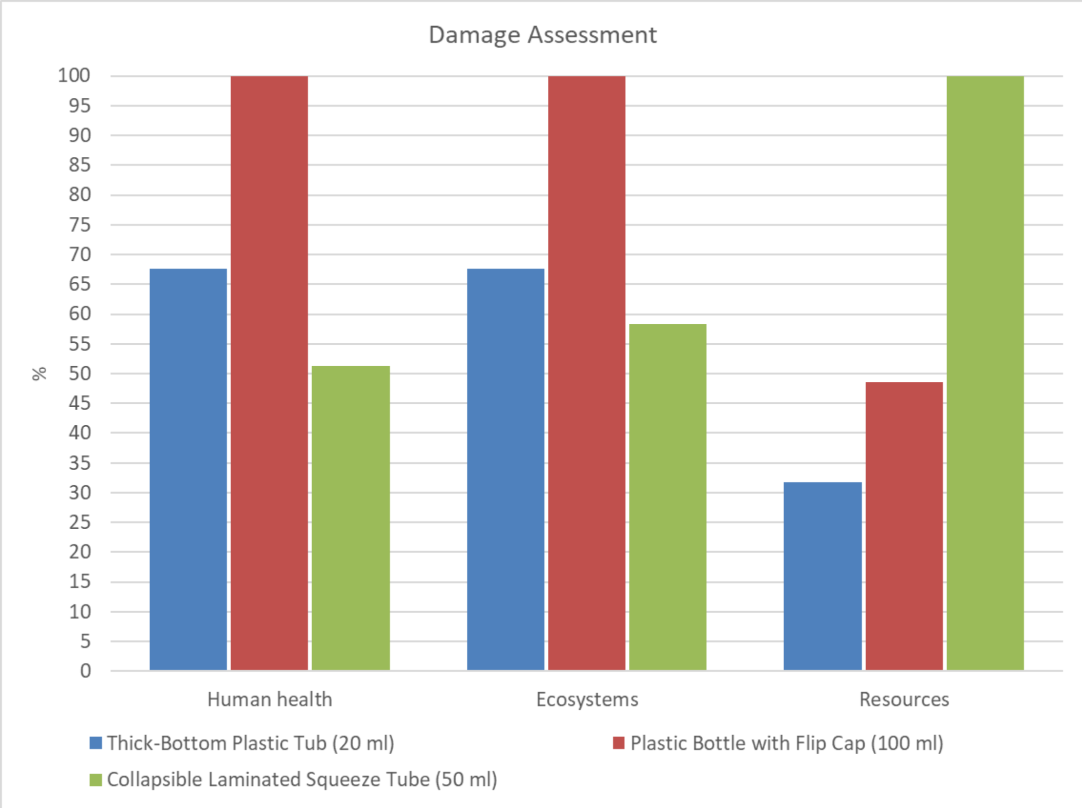

Figure 15. Damage Assessment - Excluding Filling Energy Original SKU

When considering the normalized version of both including and excluding filling and sealing energy the human health impact category has subjected to the highest effect from all three-product packaging despite the change in functional unit. It is drastically higher than the other two impact categories. The following figure 16 shows the normalized bar graph excluding the filling and sealing energy and figure 17 shows the normalized bar graph including the filling and sealing energy.

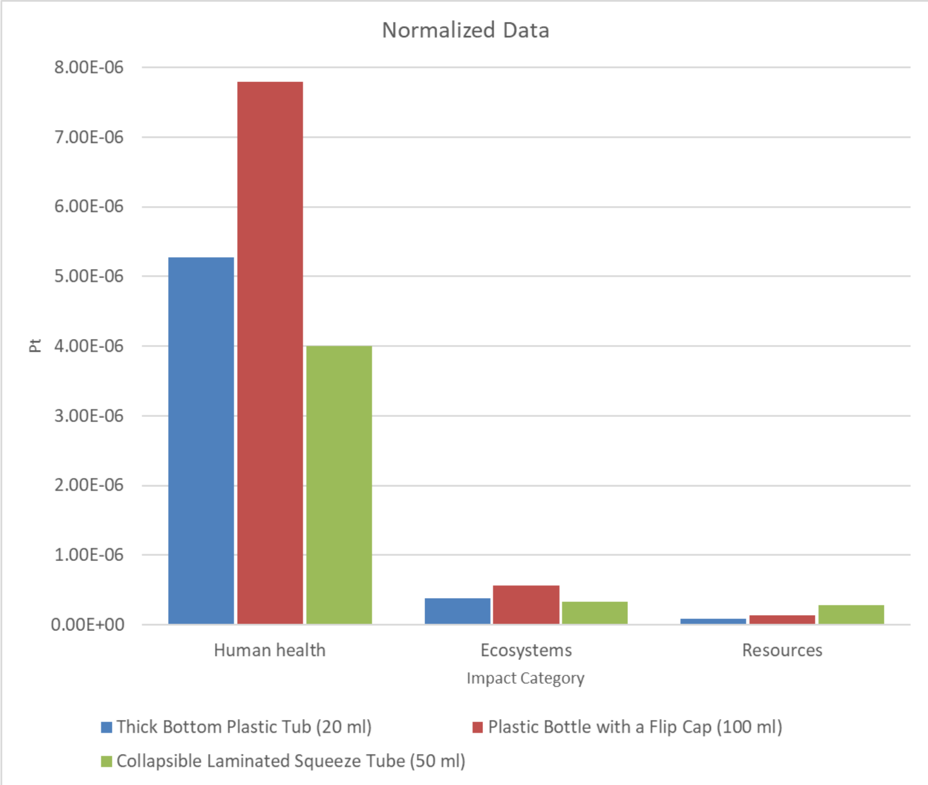

Figure 16. normalized bar graph excluding the filling and sealing energy

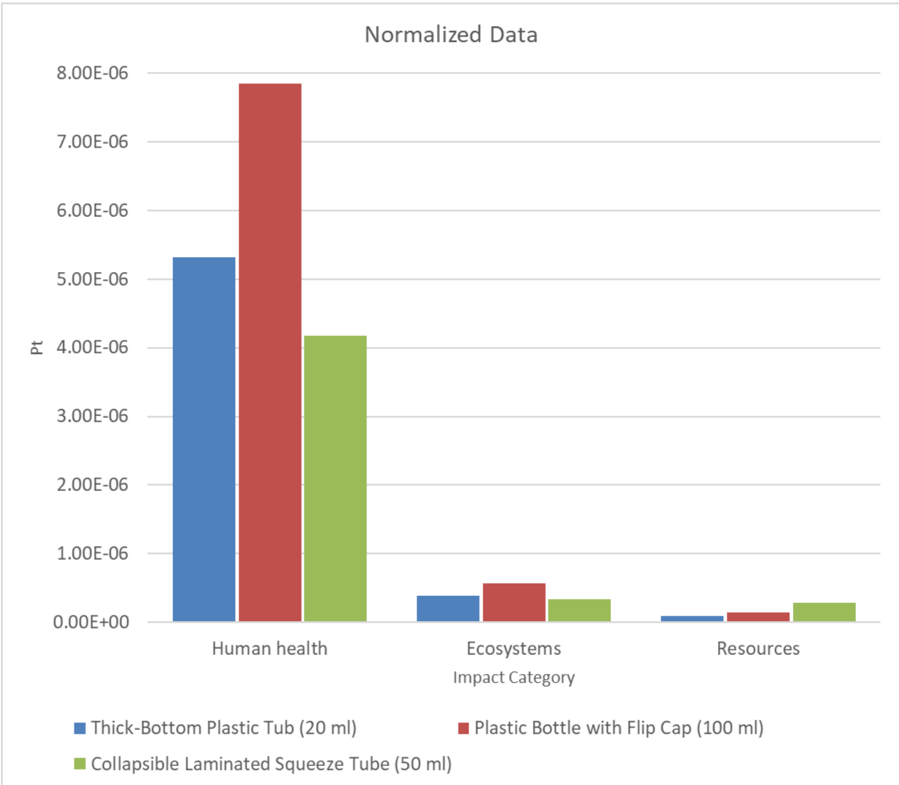

Figure 17. normalized bar graph including the filling and sealing energy

4.4. Sustainable Packaging Design Insight for Manufacturers in Sri Lanka

With the results based on the analysis, a design insight has developed by focussing on minimizing the environmental impacts of cosmetic packaging while supporting recyclability and material efficiency within the local context.

Table 9. Suggested Design Insights

Design Aspects	**Recommended Action**
Material Selection	PP and HDPE have the less impact and quite same impact. But LDPE has high impact comparing the mass of the material. Therefore, prefer for PP and HDPE over LDPE
Material Volume	Reduce the total plastic mass per packaging unit.
Mono Material Design	Use one type of plastic or any other material so that the recycling is easy.
Simplified Components	Minimize caps, closures and inserts as much as possible.
End of Life Compatibility	Match design with existing Sri Lankan recycling infrastructure facilities
Right sizing and Volume efficiency	Maintaining comparatively moderate volume for SKUs and design packaging that closely matches the product volume.

With help of the above framework, which is designed by the research, cosmetic packaging manufacturers in Sri Lanka can make decisions which are informed, data-driven for a significant reduction in the environmental footprint of their products. This design guidance is directly obtained by the findings of the present LCA study, while the transition to sustainable packaging from prevailing packaging requires thoughtful changes in design and material selecting, the proposed strategies offer practical, cost-effective, and locally relevant solutions that are with national sustainability goals and global best practices. Ultimately, this framework serves as a starting point for advancing more responsible packaging systems within the Sri Lankan cosmetic industry.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion on the Research

This research was conducted with the aim of enhancing sustainability in the cosmetic packaging industry in Sri Lanka. It was done through a Life Cycle Assessment (LCA) for three fast moving commonly used packaging types. The study addressed the identified objectives and did an environmental evaluation using internationally accepted methodologies and tools.

The first objective of the research was to identify the functional requirements and design considerations for cosmetic packaging, and this was achieved through an extensive literature review which illustrates the packaging functions and how these functional criteria involved with sustainability by emphasizing the importance of material selection, mono-material structures, clear labelling, and user-centred design.

The second objective focused on conducting an LCA for the prevailing cosmetic packaging types in Sri Lanka. This was thoroughly accomplished using SimaPro 9.3.0.3 software and the ReCiPe 2016 Endpoint (H) method. The analysis consisted of three packaging formats as a plastic bottle with a flip cap (HDPE), a collapsible laminated squeeze tube (LDPE and PP), and a thick-bottom tub (PP). The LCA followed a cradle-to-grave boundary, including raw material extraction, manufacturing, filling and sealing, and end-of-life management. Two functional units were adopted as 100 ml product content and original SKU size to ensure sensitivity analysis. The environmental impacts were obtained across multiple categories given by the software, offering an understanding of the contribution of material type, volume, and design to overall sustainability.

The final objective was successfully achieved by investigating current design innovations such as the use of biodegradable and renewable materials, lightweighting materials, refillable packaging systems, and design for recyclability and by developing a set of sustainable design insights relevant to Sri Lankan manufacturers. This was achieved by proposing a design insight for the manufacturers with the LCA results. The selection of low-impact materials (PP and HDPE), the use of mono-material packaging, minimizing packaging volume, and improving compatibility with existing recycling infrastructure are the findings of them. These insights were obtained directly from the comparison of the environmental impacts and are personalised to support practical decision-making within local industrial contexts.

By bridging literature-based knowledge with experimental LCA findings, the research advances the understanding of sustainable packaging in developing country contexts and offers a credible foundation for further improvements in the Sri Lankan cosmetic sector.

5.2.Conclusion on the Results

This study aimed to evaluate the environmental impact of three commonly and highly used cosmetic packaging types in Sri Lanka through a comprehensive Life Cycle Assessment (LCA). Using SimaPro 9.3.0.3 software and the ReCiPe 2016 Endpoint (H) method under the World (2010) H/A scenario, the analysis focused on three packaging formats, a plastic bottle with flip cap from the material HDPE, a collapsible squeeze tube with the material LDPE and the thick-bottom plastic tub with PP material.

The results clearly revealed the following aspects.

- The most affected aspect of the packaging is the packaging material, the energy for manufacturing, filling and all the other aspects are in the second stage.
- When maintaining large SKUs for a product will be led to less environmental impact.
- The collapsible squeeze tube exhibited the lowest overall environmental impact across all impact categories in the original SKU as the functional unit.
- The LDPE collapsible squeeze tube exhibited the highest environmental impact in the original SKU as the functional unit scenario.
- The HDPE bottle showcased moderate environmental impacts among the three product packaging types.

Additionally, the influence of filling and sealing energy on the overall impact was relatively small compared to the material production, product manufacturing and end-of-life treatments. Therefore, the material selection and recyclability of the packaging emerged as the most significant factors affecting the environmental impacts.

5.3. Recommendations for the Industry from the Study

Based on the findings of the LCA conducted in this study, several key recommendations are proposed to guide the Sri Lankan cosmetic industry towards more environmentally sustainable packaging practices.

For Packaging Designers and Manufacturers

Material selection: Prioritize the use of PP and HDPE over LDPE due to the relatively lower environmental impact, durability and compatibility with existing recycling in Sri Lanka.

Avoid multi-material: avoid from using laminated and composite packaging material or structures that are difficult or impossible to recycle or reuse under the waste management context of Sri Lanka at the moment. Mono material packaging is the best option in this aspect.

Lightweighting packaging: Lightweighting strategies is helpful to minimize material usage without compromising functionality. Even small reduction in material will pave the way for a huge reduction in environmental impact in long time analysis.

Design for simplified mono-material structures: This will lead to easy separation of materials for recycling process and single packaging design will decrease the energy and other resource depletion in manufacturing.

End of Life Management: aligning the packaging design with the local recycling system is a crucial thing.

SKU optimization: Not having multiple volume containers for the same type and reducing packaging to product ratio pave the way for reducing the environmental burden by single unit.

5.4. Future Research

Although this research offers a thorough understanding of the environmental impacts of widely used cosmetic packaging in Sri Lanka, there are still valuable areas that invite further exploration. Future studies could build on this work by broadening its scope and delving deeper into emerging aspects.

5.4.1. Consumer Behaviour and Perception Studies

Understanding the consumer attitudes on the purchasing of cosmetic products and behaviours toward sustainable cosmetic packaging is vital for the successful adoption of eco-friendly alternatives for the packaging. Therefore, future studies can investigate the following key points.

- The willingness of the consumer to pay for sustainable packaging options.
- Preferences of the consumer for refillable, recyclable, or biodegradable packaging types.
- Awareness in society on environmental issues associated with plastic waste in cosmetic packaging.
- The influence of packaging design and labelling of them on disposal practices and recycling practices.

These insights can help to modify the packaging strategies that align with the consumer expectations and can promote responsible end-of-life handling.

5.4.2. End-of-Life Infrastructure Analysis in Sri Lanka

The improper or inadequate waste management system of developing countries such as Sri Lanka has the huge rely on the limitation in implementing sustainable packaging strategies. Further research is needed to do the following.

- Examine and evaluate the capacity and the limitations of recycling and waste controlling infrastructure in Sri Lanka.
- Identify barriers for effective plastic recycling and composting of alternative materials such as biodegradable materials.
- Propose for supporting the processing of mono-material, recyclable, and compostable packaging.

These can provide insights for government and manufacturers to enhance sustainability in the packaging sector.

5.4.3. Comparative Assessments of Emerging Packaging Alternatives

As global trends move towards innovative sustainable materials, it is very important to apply them in local situations. Following discuss the future work in this area.

- LCA comparisons of plastic packaging with biodegradable materials and natural alternatives.
- Evaluation of refillable systems and reusable container models, considering Sri Lankan context.
- Analysis of cost, durability and environmental performance of new packaging types.
- Studies integrating circular economy models to test packaging systems within cosmetic supply chains.

These assessments can inform strategic decisions on material substitution and packaging redesign in Sri Lankan context for the sectors of environmental, economic, and cultural transitions.

5.4.4. Scenario-Based Policy and Industry Impact Modelling

Further research can be conducted into scenario-based modelling to estimate long-term benefits of sustainable packaging.

- Forecasting carbon footprint reductions from replacing conventional material with biodegradable and ecofriendly alternatives.
- Analysing impacts of policy interventions such as plastic banning, motivations for sustainable design, and mandatory labelling for recyclability.
- Simulation of industry-scale implementation of sustainable packaging and their return on investment.

This evidence-based modelling would support national environmental policy formulation and assist companies in developing roadmaps for greener product systems.

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