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# **Life Cycle Assessment of Metal Mailbox**

A case study

School of Technology and Innovation  
Master's thesis  
Industrial Management

Vaasa 2023

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**UNIVERSITY OF VAASA****School of Technology and Innovation**

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**Title of the Thesis:** Life Cycle Assessment of Metal Mailbox : A case study  
**Degree:** Master of Science in Economics and Business Administration  
**Programme:** Industrial Management  
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**Year:** 2023 **Pages:** 83

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**ABSTRACT:**

As global concerns about environmental sustainability continue to rise, businesses must assess and improve the ecological footprint of their products. This thesis under-takes a rigorous Life Cycle Assessment (LCA) study, focusing on Bobi Company's Classic and Cargo mailboxes. The primary aim is to discern and quantify the key environmental impacts encompassing the entire lifecycle of these mailbox products.

The summary of findings encapsulates the key discoveries derived from this comprehensive investigation. It showcases how Global Warming Potential (GWP) emerges as the paramount environmental impact category for both Classic and Cargo mailboxes. Additionally, it highlights specific contributors to GWP, such as steel production, transportation, mailbox production, and non-metal materials. The research findings indicate that a significant portion of greenhouse gas emissions in the lifecycle of Classic mailboxes occurs during the upstream stages, such as raw material extraction and transportation. It is noteworthy that the core manufacturing stage exhibits minimal pollution and energy consumption, highlighting effective environmental management within the manufacturing domain. As for Cargo mailboxes, due to the additional transportation required for the core manufacturing stage's painting process, most greenhouse gas emissions occur during this phase. This underscores the critical role of the core manufacturing stage's processes and transportation choices in determining the carbon emissions throughout the product's lifecycle. Corresponding solutions to this issue are proposed in this paper.

From a managerial perspective, this research accentuates the critical role of environmental sustainability in contemporary business practices. It underscores the

importance of proactive measures to mitigate environmental impacts, enhance transparency, and meet the growing demand for eco-conscious products. Ultimately, this study not only lays the foundation for the creation of an Environmental Product Declaration (EPD) report for Bobi Company but also contributes to the broader discourse on sustainable business practices in an increasingly environmentally conscious world, allowing Bobi Company to enhance its strategic planning and showcase brand value more effectively. Moreover, the interpretation of the results and the recommendations offered provide valuable insights for the product development process. Lastly, this thesis makes a valuable contribution to the domain of metal mailbox products, given the limited availability of lifecycle assessment research on such products at present.

Note, this LCA serves as a self-declaration aimed at exploring the environmental aspects of products and has not yet obtained certification from an external third-party organization.

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**KEYWORDS:** Life cycle assessment, environmental products declarations, case study, mailbox, metal sheet product

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## Abbreviations

ADP	Abiotic Depletion Potential
AP	Acidification Potential
BOM	Bill of Materials
EP	Eutrophication Potential
EPD	Environmental Product Declaration
FW	Net Use of Freshwater
GWP	Global warming potential
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NRSF	Non-renewable Secondary Fuels
PCR	Product Category Rules
PENRT	Primary Energy Resources - Non-renewable Total
PERT	Primary Energy Resources – Renewable Total
POCP	Photochemical Oxidant Creation Potential
RSF	Renewable Secondary Fuels
WDP	Water deprivation potential

## 1 Introduction

In the contemporary world, where environmental sustainability has become an increasingly pressing concern, businesses are challenged not only to meet market demands but also to align their practices with eco-conscious values (Curran, 2015). The production of goods, from inception to disposal, has a profound impact on the environment, making it imperative for companies to assess and report the environmental footprint of their products. It is in this context that Life Cycle Assessment (LCA) and Environmental Product Declaration (EPD) analyses find their significance (Hunsager, Bach, & Breuer, 2014).

Life Cycle Assessment (LCA) is a comprehensive methodology that allows companies to evaluate the environmental impacts of their products at every stage of the product lifecycle (Curran, 2015). From raw material extraction to manufacturing, transportation, product use, and eventual disposal, LCA offers a holistic view of how a product affects the environment. It provides quantitative data on a wide range of environmental indicators, such as energy consumption, greenhouse gas emissions, resource depletion, and more. LCA enables businesses to pinpoint areas of high environmental impact within their product lifecycle, guiding them toward more sustainable practices (Curran, 2015).

Environmental Product Declaration (EPD) is a standardized document that summarizes the results of an LCA. EPDs are crucial in communicating the environmental performance of a product transparently to consumers, regulators, and stakeholders (Hunsager, Bach, & Breuer, 2014). They provide easily understandable information about a product's environmental attributes, enabling consumers to make informed choices based on environmental considerations. EPDs also facilitate compliance with environmental regulations and support corporate sustainability goals by promoting eco-friendly products (Hunsager, Bach, & Breuer, 2014).

Metal sheet products are widely used in various industries, including construction, automotive, manufacturing, and aerospace (Hagelstein, 2009). These products serve as

fundamental building blocks for many applications, making their lifecycle assessment and analysis crucial for understanding their environmental impacts and identifying opportunities for sustainable practices (Hagelstein, 2009).

The growing concern for climate change, dwindling resources, and the need for responsible corporate practices has driven companies like Bobi to embrace LCA and EPD. These analyses empower businesses with the knowledge to make informed decisions, prioritize sustainability, and reduce their environmental footprint. For Bobi, a company known for its mailbox products, conducting an LCA study and producing EPDs for their Classic and Cargo mailboxes is not merely a matter of compliance; it is a commitment to environmental responsibility.

This thesis will study from the metal mailbox LCA of Bobi Company and analyze the life cycle assessment and analysis of sheet metal products. One method for quantifying and assessing these effects involves the utilization of Lifecycle Assessment (LCA), as outlined by Finkbeiner in 2014. LCA comprehensively scrutinizes all environmental dimensions and potential consequences associated with a product or service across its entire lifecycle. This encompasses activities ranging from the extraction of raw materials, through materials processing and manufacturing. This comprehensive view can provide insights on the sustainability of products, and where improvements can be made.

Performing a comprehensive lifecycle assessment (LCA) and analysis for metal sheet products holds significant importance for various compelling reasons. First and foremost, it allows for a thorough examination of the environmental impact associated with metal sheet production, encompassing stages like raw material extraction, manufacturing, product use, and end-of-life treatment (Cooper, Rossie, & Gutowski, 2017). This understanding of environmental implications is pivotal for pinpointing areas that warrant enhancement and for the implementation of sustainable practices. Furthermore, the assessment enables the evaluation of resource efficiency throughout

the product's lifecycle, shedding light on potential optimization opportunities and avenues for waste reduction.

As environmental concerns and regulations continue to mount, stakeholders such as consumers, investors, and regulatory bodies increasingly demand transparency and sustainability from manufacturers (Lee, Kim, & Kim, 2018). By conducting an LCA, a company showcases its dedication to environmental responsibility, which can positively influence stakeholder perceptions and decisions. Moreover, LCA provides valuable insights into the environmental performance of distinct stages in the metal sheet product's lifecycle, empowering informed decision-making processes. This includes the selection of more sustainable materials, the optimization of manufacturing procedures, and the refinement of product design to minimize environmental impacts.

Through this research, Bobi aims to showcase its dedication to eco-friendly manufacturing and inform consumers about the environmental aspects of their mailbox products. It is only through such analytical tools as LCA and EPD that companies like Bobi can forge a path toward a more sustainable and environmentally conscious future. The insights gained from this study will inform future decision-making processes, inspire eco-friendly innovations, and position Bobi as a responsible steward of the environment.

## **1.1 Background and purpose**

Bobi's mailbox products originate from Vaasa, Finland, and the inception of Bobi Corporation dates to 1991 when the concept of the rounded-head mailbox was conceived. Over the course of just over three decades, Bobi has evolved into a comprehensive product line encompassing various models of mail and parcel boxes, designed to cater to diverse usage scenarios. Bobi has transformed into an internationally recognized brand, garnering popularity not only within Finland but also in numerous countries worldwide. For households across the globe, the concept of home holds paramount importance, and an increasing number of households are identifying with the high-quality, environmentally friendly Finnish-made Bobi products.

Presently, Bobi Corporation is an integral part of the Leinolot Group, with its subsidiary, Leimec, consistently responsible to produce Bobi mailboxes throughout its product history. With a steadfast commitment to advancing environmental sustainability, Bobi Corporation actively encourages both suppliers and customers to participate in the ecosystem of environmental sustainability. In pursuit of this goal, Bobi decides to conduct a Life Cycle Assessment (LCA) analysis of its two flagship mailbox products, Bobi Cargo and Classic.

This thesis is commissioned by Bobi Corporation in collaboration with the manufacturing company Leimec, with the primary objective of conducting a comprehensive LCA analysis encompassing the entire lifecycle of these two critical mailbox products, each tailored to distinct markets and constructed from different materials. The analysis aims to inform the creation of Environmental Product Declarations (EPDs) based on the findings of the assessment.

## **1.2 Research questions and objectives**

The background and objectives of this paper are clearly defined, with two primary aims: firstly, to conduct a comprehensive Life Cycle Assessment (LCA) study of two mailbox product series (Cargo and Classic) manufactured by Leimec Corporation, and secondly, to formulate Environmental Product Declarations (EPDs) based on the study findings. These objectives serve multiple purposes, including enhancing supply chain transparency by regulating key aspects, from raw material procurement to manufacturing processes, and improving the understanding of environmental impacts associated with these products among both the company and consumers.

In an era marked by an escalating consumer focus on environmental conservation and sustainability, products equipped with LCA and EPD data typically garner increased favorability. This burgeoning trend augments a company's competitive edge within the market and appeals to a broader spectrum of potential customers. Moreover, the

outcomes of LCA and EPD investigations assist suppliers in identifying environmental hotspots within the product lifecycle and optimizing opportunities for improvement. Such insights empower them to refine product designs, enhance manufacturing processes, reduce resource consumption, and minimize waste generation, thereby effectively mitigating the overall environmental footprint of the product.

This research employs a clearly defined set of research questions to guide the investigation. The primary research question seeks to uncover the principal environmental impacts spanning the entire lifecycle of the mailbox product. Complementing this, two secondary research questions are structured. The first secondary question explores the distinct influence of various stages, including raw material extraction and manufacturing, on the mailbox's overall environmental footprint. The second secondary question delves into the specific stages within the mailbox's lifecycle where opportunities arise for enhancing resource efficiency, reducing waste, and minimizing emissions. These meticulously crafted research questions provide a robust framework for the study, ensuring comprehensive exploration of the environmental aspects of the mailbox product.

To realize these objectives, this paper employs a mixed-methods case study approach, adhering to internationally standardized LCA methodologies (ISO 14040 and ISO 14044). The research methodology integrates primary, real-world data provided by the manufacturing company, Leimec, and its suppliers. Additionally, it leverages EPD databases, including Ecoinvent EN15804, and utilizes the OpenLCA software for data integration and analysis. Finally, the study references relevant published literature to complete the comprehensive LCA assessment of the mailbox products.

### **1.3 Scope and Limitations**

This study focuses on the conduct of a Life Cycle Assessment (LCA) for Bobi Corporation's two product lines, namely Cargo and Classic, with the objective of developing an Environmental Product Declaration (EPD) based on the analysis outcomes. Given the

critical importance of adhering to standardized procedures in LCA research, this investigation aligns with the ISO 14040 series of standards (Finkbeiner, 2014) as the foundational framework for conducting the assessment.

Moreover, in consideration of the goal of producing an EPD document as a derivative of this research, the selection of the OpenLCA software tool for LCA analysis becomes particularly pertinent. OpenLCA is characterized by its robust interoperability, facilitating seamless integration with diverse data formats and external databases. This characteristic streamlines the process of assimilating datasets from disparate sources and databases into the LCA analysis seamlessly. Notably, in this study, the Ecoinvent EN15804 EPD database, synergistically integrated with OpenLCA software, will be utilized to augment our LCA analysis and EPD generation.

ISO 14020 stands as the international standard within the ISO 14020 series, setting forth fundamental principles (ISO, 2006a). The comprehensive series encompasses three additional key standards: (1) ISO 14024, focusing on type I environmental labeling; (2) ISO 14021, specifically addressing type II environmental labeling; and (3) ISO 14025, governing type III environmental declarations (International Organization for Standardization, 2016). Due to this Life Cycle Assessment (LCA) serves as a self-declaration aimed at investigating the environmental aspects of products. And this assessment has not undergone certification by an independent third-party organization, making it distinct from LCA processes in compliance with ISO 14025. ISO 14025 primarily pertains to verified declarations by third-party entities, while this work aligns with the principles of ISO 14021, which involve self-declarations without third-party verification (International Organization for Standardization, 2016). ISO 14021, which pertains to Type II environmental labeling, serves as a central standard within this series. It is often associated with self-declared environmental claims. In essence, Type II labels are initiated and provided by the product manufacturer or service provider, typically without third-party validation (International Organization for Standardization, 2016). It's crucial to highlight that this LCA is a rigorous and insightful evaluation, though it remains

a self-declaration, marking a significant step towards understanding the environmental performance of the products under investigation.

In summary, this research methodologically aligns with the ISO 14040, ISO14020 standards and leverages the OpenLCA software tool, integrated with the Ecoinvent EN15804 EPD database, to ensure the scientific rigor, standardization, and operational feasibility of the study. This approach seeks to comprehensively assess the life cycles of the Cargo and Classic products and ultimately generate EPD documents that conform to established standards.

#### **1.4 Research structure**

Chapter 1 initiates the study by providing an initial overview. It elucidates the research's overarching purpose, objectives, and the fundamental inquiries it endeavors to address. In Chapter 2, the study engages with the body of relevant literature, critically examining key concepts, research methodologies, and recent advancements in the field of Life Cycle Assessment (LCA) and environmental impact evaluation. Chapter 3 offers a comprehensive exposition of the research methodology. It encompasses a detailed description of data collection procedures, analytical techniques employed, and the rationale underlying the selection of the specific LCA methodology adopted. This chapter 4 furnishes crucial contextual information related to Bobi Company, as well as the Classic and Cargo mailboxes under investigation. It delves into the intricacies of their production processes and provides essential background knowledge. Chapter 5 unfolds the central findings arising from the LCA investigation. This encompasses a comprehensive analysis of material compositions, impact assessments, and contributions to Global Warming Potential (GWP). Additionally, it presents recommendations for mitigating environmental impacts. In the concluding chapter 6, the study synthesizes the research's primary takeaways. It facilitates a reflection on the implications of the findings and embarks on a forward-looking exploration of opportunities for enhancing environmental sustainability.

## **2 Literature Review**

### **2.1 The need for sustainability in operations and supply chains**

Sustainability is increasingly recognized as a critical component of operations and supply chains for organizations across the globe. It represents the commitment to managing economic, social, and environmental impacts in a way that not only ensures business continuity but also aligns with ethical values, regulatory requirements, and societal expectations (Mota, Carvalho, Gomes, & Barbosa-Póvoa, 2017).

#### **2.1.1 The benefits of integrating sustainability into operations and supply Chains**

##### **2.1.1.1 Resource efficiency**

Resource efficiency is at the core of sustainable operations and supply chains. It involves minimizing resource consumption, reducing waste generation, and optimizing the use of energy and materials. LCA plays a pivotal role in measuring and improving resource efficiency. It provides a comprehensive view of the resource consumption and emissions associated with a product or process throughout its lifecycle (Mota, Carvalho, Gomes, & Barbosa-Póvoa, 2017).

Implementing resource efficiency practices offers numerous advantages, ranging from cost savings to environmental impact reduction and fostering innovation. Particularly in industries where resource costs constitute a significant portion of expenses, such as those highlighted by Mota, Carvalho, Gomes, and Barbosa-Póvoa (2017), reducing waste and utilizing resources more efficiently can lead to substantial cost savings. Moreover, optimizing resource use also contributes to a lower environmental impact by decreasing energy consumption and emissions, thereby aligning with environmental objectives and regulatory requirements. Embracing resource efficiency often serves as a catalyst for innovation in areas like product design, manufacturing processes, and supply chain operations, nurturing creativity and driving the development of sustainable alternatives (Mota, Carvalho, Gomes, & Barbosa-Póvoa, 2017).

### **2.1.1.2 Competitive advantage**

Consumers, especially those with eco-conscious values, are more likely to choose products or services from businesses with a commitment to sustainability. LCA provides data to substantiate sustainability claims, helping companies differentiate themselves in the market. Consumers can make more informed choices based on verified LCA data. Sustainability efforts can lead to increased customer loyalty. When customers perceive a company as ethical and environmentally responsible, they tend to remain loyal and even become brand advocates (Mota, Carvalho, Gomes, & Barbosa-Póvoa, 2017).

### **2.1.1.3 Long-term viability**

By addressing environmental and social risks, businesses become better prepared for future challenges. This includes supply chain disruptions, resource scarcity, and regulatory changes (Mota, Carvalho, Gomes, & Barbosa-Póvoa, 2017). Sustainable companies are more likely to adapt to evolving market conditions. Through continuous LCA monitoring, companies can adapt and innovate, making their products and processes more resilient to future challenges (Mota, Carvalho, Gomes, & Barbosa-Póvoa, 2017).

### **2.1.1.4 Supply chain optimization**

Supply chain optimization aims to enhance efficiency and sustainability. Supplier evaluation, when integrated with LCA, ensures sustainability throughout the supply chain. LCA can evaluate the environmental performance of suppliers, helping companies choose sustainable suppliers who align with their sustainability goals (Mota, Carvalho, Gomes, & Barbosa-Póvoa, 2017).

LCA offers insights for optimizing the supply chain and reducing its environmental footprint. It helps identify "hotspots" in the supply chain with the most significant environmental impact, enabling companies to target these areas for optimization. Optimization can lead to more efficient transportation and reduced carbon emissions

through route optimization, consolidation, and better vehicle selection. Identifying inefficiencies in the supply chain minimizes waste and promotes a circular economy approach (Mota, Carvalho, Gomes, & Barbosa-Póvoa, 2017).

## **2.2 Life cycle assessment (LCA)**

Life Cycle Assessment (LCA) is a rigorous and systematic approach utilized for the examination of the environmental consequences of a product, process, or system throughout its entire life span. This analysis encompasses various phases, starting from the extraction of raw materials, progressing through manufacturing, transportation, usage, and ultimately concluding with disposal or recycling, as detailed by Matthews, Hendrickson, and Matthews in 2014. LCA functions as a robust analytical framework, enabling the quantitative evaluation of a diverse array of environmental factors, which includes but is not limited to energy consumption, greenhouse gas emissions, water usage, and the release of pollutants. Through the meticulous examination of these variables, LCA offers a comprehensive comprehension of the environmental impact linked with a specific entity or activity.

This all-encompassing evaluation provides the means for decision-makers in diverse fields such as industry, engineering, policy formulation, and product development to pinpoint areas with significant environmental impact and make knowledgeable decisions focused on lessening detrimental environmental effects and advancing sustainability objectives. LCA, thus, plays a pivotal role in facilitating environmentally conscious decision-making processes and resource optimization strategies (Matthews, Hendrickson, & Matthews, 2014).

Incorporating LCA into decision-making processes has become increasingly crucial in contemporary contexts marked by heightened environmental concerns and sustainability imperatives. It enables stakeholders to holistically evaluate the environmental performance of different alternatives and make well-informed choices

that align with environmental sustainability goals (Matthews, Hendrickson, & Matthews, 2014).

### **2.2.1 Background and history**

In the 1960s and 1970s, growing awareness of pollution, resource depletion, and the environmental impact of industrial processes led to mounting concerns regarding the sustainability of economic development. This period marked the inception of the modern environmental movement. During this era, researchers and organizations embarked on the development of methodologies aimed at assessing the environmental ramifications of products and processes (Curran, 2015). During the latter part of the 1980s, the fundamental notion of what is now acknowledged as Life Cycle Assessment (LCA) started to assume its contemporary form. Influenced significantly by the academic and organizational endeavors primarily in Sweden and Switzerland, the International Organization for Standardization (ISO) became involved in standardizing LCA methodology. This culminated in the publication of the ISO 14040 series of standards in the 1990s, providing a standardized framework for the conduct of LCA (Curran, 2015). The subsequent decades witnessed the widespread adoption of LCA across diverse sectors, encompassing industries, academia, and governmental entities alike. It emerged as a pivotal tool for decision-making, product design, and policy formulation, particularly within the context of sustainable development and environmental management (Mendes da Luz, de Francisco, Piekarski, & Salvador, 2018).

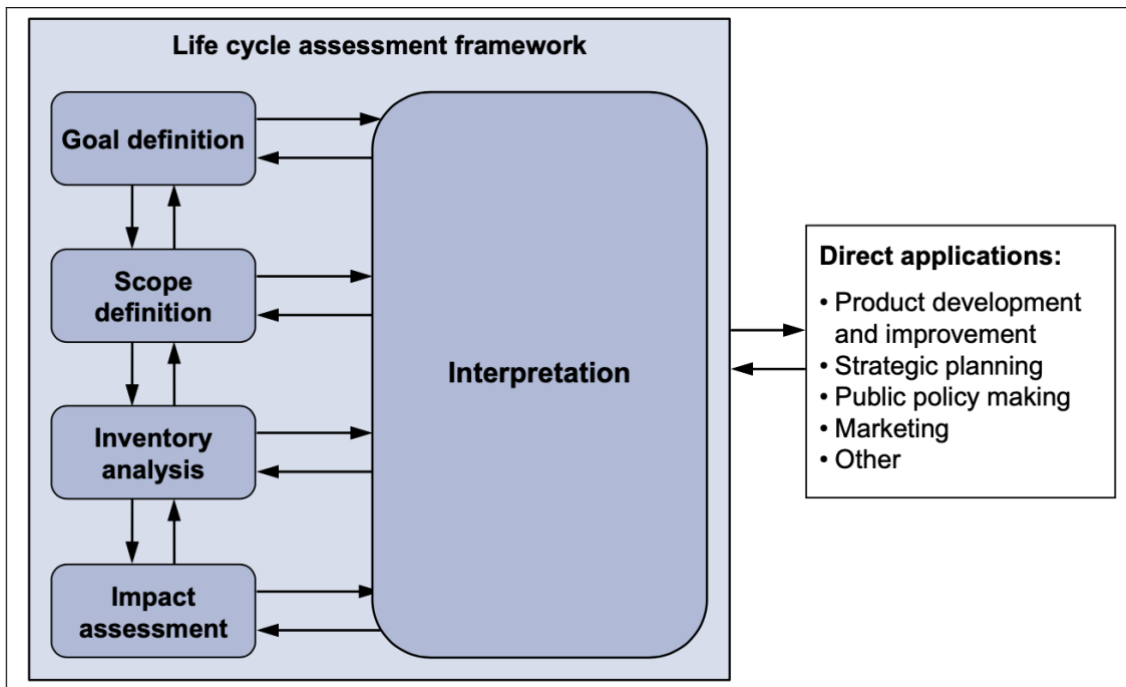
Today, LCA finds extensive utility across various industries, ranging from manufacturing and construction to food production and energy. Its significance lies in its ability to furnish a holistic perspective on the environmental dimensions of products and processes. Furthermore, it has evolved to encompass not only environmental aspects but also social and economic dimensions, giving rise to the concept of Life Cycle Sustainability Assessment (LCSA). This broader approach acknowledges and integrates the triad of environmental, social, and economic considerations, thereby facilitating

informed practices, product development, and policy decisions aligned with the principles of sustainability (Mendes da Luz, de Francisco, Piekarski, & Salvador, 2018).

### 2.2.2 Theoretical Framework and guidelines

In the realm of Life Cycle Assessment (LCA), the ISO 14040 and ISO 14044 standards serve as indispensable cornerstones. The framework for conducting a Life Cycle Assessment is itself predicated on these two fundamental standards (Curran, 2015; Wolf et al., 2010).

Figure 1 provides a high-level overview of the comprehensive LCA framework.



**Figure 1. Framework for life cycle assessment (from ISO 14040-2006)**

From Figure 1, it is evident that the LCA framework comprises four pivotal stages: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation. Each of these stages contributes significantly to gaining a holistic understanding of the environmental impacts associated with a product or process. Subsequently, the insights garnered from LCA are utilized in product development, improvement, or the formulation of strategic plans, marketing strategies, and even public policy development

with the overarching goal of promoting environmental friendliness throughout the product's lifecycle, thereby facilitating environmental sustainability. Following each iteration of improvement, a fresh round of analysis is conducted to evaluate the efficacy of new decisions in the real-life product lifecycle, scrutinizing the emergence of novel areas for enhancement.

In essence, the LCA framework, anchored in ISO standards, represents a dynamic and iterative process for assessing and enhancing environmental sustainability in a systematic manner. It not only provides a structured approach to comprehending the ecological footprint but also offers a roadmap for steering products and processes towards greater environmental harmony, contributing to the overarching goal of sustainable development.

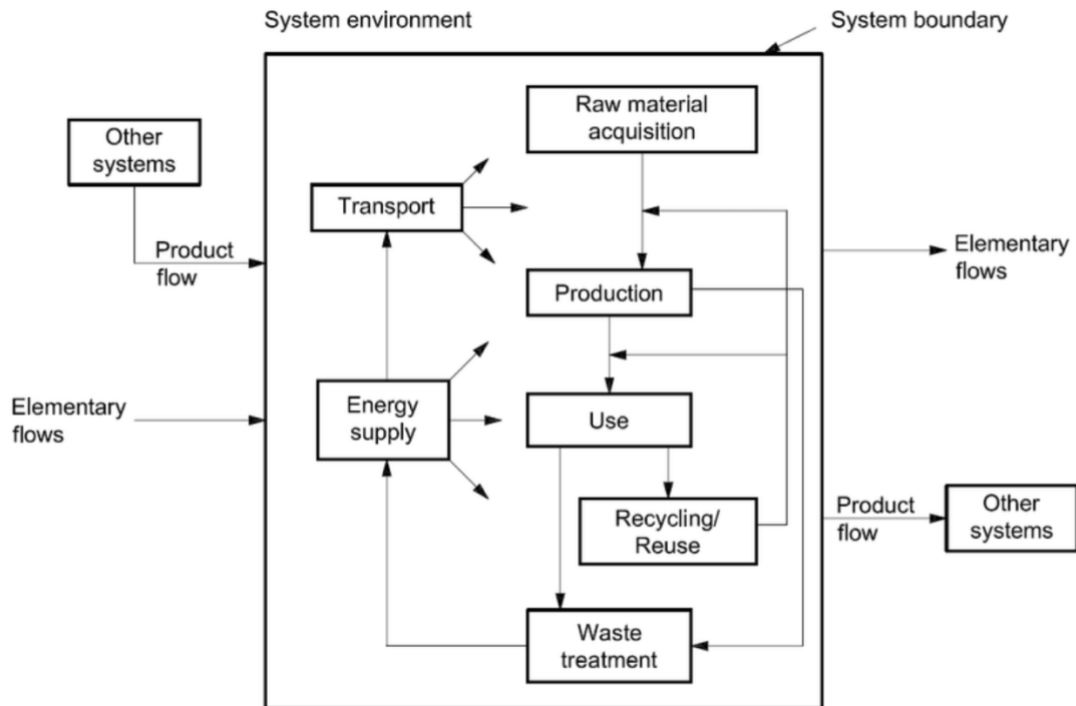
#### **2.2.2.1 Goal and scope definition**

To conduct a meaningful Life Cycle Assessment (LCA) analysis, it is imperative to establish clear goals and define the scope of the study, as this forms the foundation for all subsequent work (ISO14040:2006; ISO14044:2006).

The first step in goal and scope definition is to precisely articulate the research objectives and expected outcomes (ISO14044:2006). The definition of objectives serves to elucidate the primary purposes of the research. For instance, an objective could be to assess the environmental impact of two different manufacturing materials and provide decision-making information for the selection of environmentally preferable materials.

Scope definition determines what will be included and excluded from the assessment, ensuring that the research remains manageable and relevant. This definition aids in specifying the scope of data collection and the level of detail required for each lifecycle stage. It also clarifies temporal aspects, such as whether the entire lifecycle will be considered or if the assessment will focus on specific stages, like production or transportation (ISO14040:2006). Scope definition also involves setting temporal

boundaries, which determine the time frame of the assessment, including the initiation and conclusion of the lifecycle (ISO14040:2006). For example, when assessing the environmental impact of two manufacturing materials, one scenario might begin the study from the stages of raw material extraction and processing, while another may initiate the assessment when the materials enter the manufacturing phase. Consequently, the final research outcomes may differ significantly.



**Figure 2. System boundaries (from ISO 14040:2006)**

From Figure 2, it can be observed that the establishment of the system boundary should be rational. In addition to providing textual descriptions and visual representations of the chosen system boundary, it is also essential to explain the reasons behind selecting and using such a system boundary and demonstrate its validity.

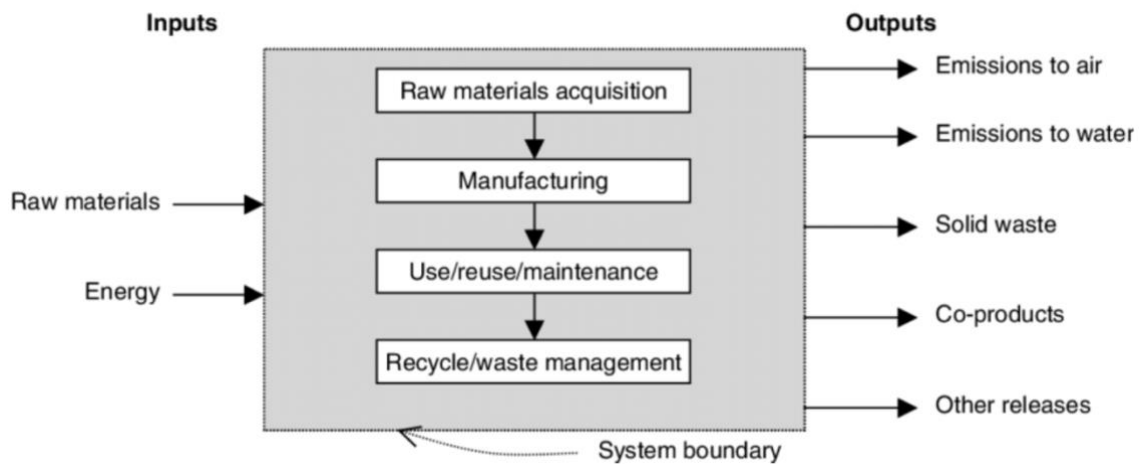
Another crucial aspect of goal and scope definition is the concept of the functional unit, representing a quantifiable measure of the environmental impacts to be assessed (ISO14040:2006). For example, when assessing the environmental impact of mailboxes, the functional unit might be defined as "the environmental impact per unit of mailbox

production." Goal and scope definition also encompasses meticulous planning for data collection to ensure that data quality meets the required standards (Wolf et al., 2010). This phase includes specifying data sources and outlining the methods for data collection and analysis.

In summary, goal and scope definition is the foundational step in conducting LCA. It clarifies the objectives, system boundaries, and functional units of the assessment. These aspects, as defined in international standards (ISO14040:2006; ISO14044:2006), ensure a well-structured LCA study capable of providing meaningful insights into the environmental impacts of a product, process, or system. Precisely defining the goals and scope contributes to informed decision-making and aligns with the overarching goal of achieving environmental sustainability. However, there are several challenging factors in goal and scope definition, such as differing stakeholder concerns and priorities, which can complicate the process. Additionally, data collection and availability must be considered. As an iterative process, when data or supplementary information is insufficient or unavailable, previously defined research objectives may need to be adjusted or revised to some extent (Wolf et al., 2010).

#### **2.2.2.2 Life cycle inventory analysis**

Life Cycle Inventory (LCI) analysis is a crucial component of Life Cycle Assessment (LCA), a systematic method for evaluating the environmental impacts of products, processes, or systems over their entire lifecycle (ISO 14040:2006). LCI focuses on the collection and quantification of relevant data during the lifecycle assessment process (Curran, 2015).



**Figure 3. Life cycle inventory template (Cruz-Romero, 2010)**

As shown in Figure 3, the first step in Life Cycle Inventory analysis is data collection. Prior to this, the identification and construction of processes are necessary. For each lifecycle stage and related process, data and parameters related to environmental impacts are identified and collected. This includes data on material and energy inputs, waste and emissions outputs, and data from the use phase. The collected data serves as inputs and outputs to the LCA system.

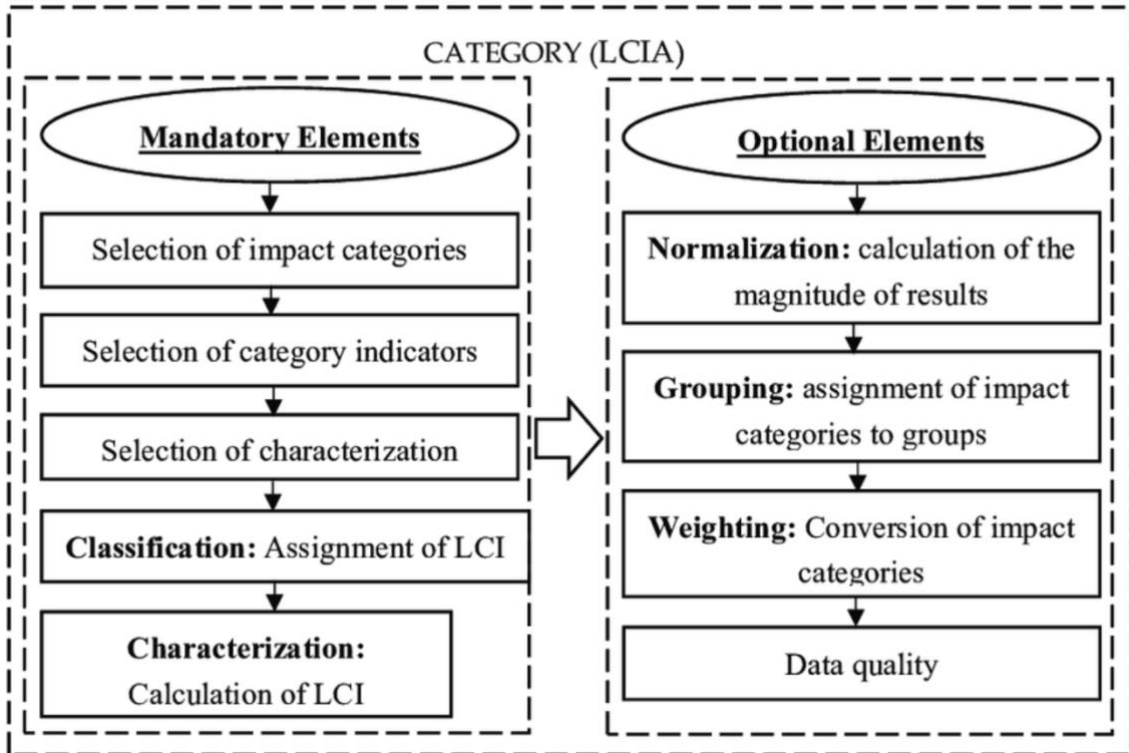
Data can be sourced from various places, such as suppliers, manufacturers, databases, and other literature. Once collected, data is categorized, such as into resource consumption categories (e.g., materials, energy, transportation), emission categories (e.g., greenhouse gases, wastewater, pollutants), and production waste categories (ISO 14044:2006). According to ISO 14044:2006, in industrial production processes, it is common to produce more than one product simultaneously, referred to as multi-output processes. Before allocation, allocation methods should be defined, which vary based on the specific objectives and scope of the LCA.

According to Curran (2015), common allocation methods employed in life cycle assessments encompass physical allocation, economic allocation, and energy allocation. Physical allocation distributes impacts according to physical attributes or mass, as exemplified when a process concurrently generates products A and B. In this scenario,

impacts are apportioned relative to the mass of each product, with the more substantial product incurring a correspondingly higher proportional impact. Economic allocation, on the other hand, assigns impacts based on the economic value of by-products, particularly when products possess distinct market values, with the product of higher market value receiving a greater impact allocation. Lastly, energy allocation is predicated on the energy content of by-products, facilitating the distribution of impacts in proportion to this energy content. Afterward, data from different categories is allocated values and quantified. For instance, the carbon dioxide emissions generated per mailbox produced, and these are standardized into units like kilograms, megajoules, cubic meters, etc. Allocation can be a complex and contentious aspect of LCI, with different stakeholders potentially having varying opinions on the most appropriate method. Therefore, careful justification of the chosen allocation method's reasonability and alignment with the purpose and goals of LCA is crucial (Curran, 2015). Life Cycle Inventory analysis plays a pivotal role in life cycle assessment by providing comprehensive, quantitative inventories of resource use and environmental emissions. (Wolf et al., 2010).

### **2.2.2.3 Life cycle impact assessment**

Life Cycle Impact Assessment (LCIA) is a crucial component of Life Cycle Assessment (LCA), which examines the environmental impacts of products, processes, or systems throughout their entire lifecycle. LCIA goes beyond quantifying inputs and outputs; it focuses on the potential environmental impacts, potential harm to human health, ecosystems, and resources (Rosenbaum et al., 2018).



**Figure 4. Structure of the life cycle impact assessment (LCIA) (Piotrowska et al.,2019)**

In Figure 4, we can see the overall structure of LCAI. It involves several key steps:

1) Impact Categories:

According to Rosenbaum et al. (2018) impact Categories in LCIA is a structured approach to understanding various environmental impacts associated with products, processes, or systems. These impact categories provide a systematic framework for assessing environmental performance, guiding sustainability assessments, and providing information for decision-making. This step helps organize and categorize various environmental impacts associated with the lifecycle of products, processes, or systems. Impact categories include:

Global Warming Potential (GWP): GWP is a widely recognized and essential impact category in LCIA. It quantifies the potential for greenhouse gas emissions to contribute

to global warming and climate change, usually expressed in carbon dioxide equivalent (CO<sub>2</sub>e) units to assess a product's or process's carbon footprint (Rosenbaum et al., 2018).

**Acidification Potential:** It assesses the potential for emissions of acidifying substances, such as sulfur and nitrogen oxides, to cause acid rain. It focuses on emissions of acidifying substances like sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>), which can lead to soil and water acidification (Rosenbaum et al., 2018).

**Eutrophication Potential:** Eutrophication refers to the excessive enrichment of water bodies with nutrients, primarily nitrogen and phosphorus. Eutrophication potential assesses the potential for nutrient pollution caused by products or processes and its harmful effects on aquatic ecosystems (Rosenbaum et al., 2018).

**Ozone Depletion Potential:** This category assesses the potential impact of emissions on depleting the ozone layer, primarily through the release of ozone-depleting substances. Although international agreements have addressed this issue, LCIA still considers its potential impacts (Rosenbaum et al., 2018).

**Human Health Impacts:** LCIA evaluates various aspects of human health impacts, including respiratory issues, carcinogenicity, and other diseases. It often uses metrics like Disability-Adjusted Life Years (DALYs) to quantify potential harm to human health due to exposure to pollutants. Some LCIA methods consider impacts related to worker safety and health, especially in industries with significant occupational hazards (Rosenbaum et al., 2018).

**Ecotoxicity:** The ecotoxicity impact category assesses the potential harm to ecosystems and aquatic life caused by the release of toxic substances. These categories evaluate the potential ecological risks associated with pollutants (Rosenbaum et al., 2018).

Resource Depletion: LCIA considers the impact category of resource consumption, assessing the depletion of non-renewable resources such as minerals and fossil fuels and their environmental impacts (Rosenbaum et al., 2018).

The choice of impact categories depends on the specific objectives and scope of the LCA study, making it a flexible and adaptable tool for assessing environmental impacts.

## 2) Characterization:

According to Rosenbaum et al. (2018) characterization is a critical step in LCIA that involves quantifying environmental inventory data and transforming it into meaningful and comparable impact scores within selected impact categories. It bridges the gap between raw inventory data (e.g., emissions, resource consumption) and the final environmental impact assessment results.

Normalization: Normalization is often the initial step in characterization. It makes impact scores comparable by scaling them relative to a reference or baseline, such as global average emissions (Rosenbaum et al., 2018).

Weighting: Not all impact categories have the same importance according to societal values and priorities. Weighting assigns relative significance to different impact categories, allowing decision-makers to prioritize certain environmental impacts over others (Rosenbaum et al., 2018).

Characterization Factors: Characterization factors are numerical coefficients used to quantify the potential environmental impact of unit processes on specific impact categories. They provide a conversion between raw inventory data (e.g., resource consumption, emissions) and the specific environmental impact being assessed. Characterization factors are expressed in units relevant to the impact category under consideration. For example, in the context of Global Warming Potential (GWP), the

model multiplies the emissions of substances by GWP characterization factors, often expressed in carbon dioxide equivalent (CO<sub>2</sub>e) per unit of emitted substance (e.g., kilograms of CO<sub>2</sub>e per kilogram of emitted substance) (Rosenbaum et al., 2018).

### 3) Impact Assessment Models:

According to Rosenbaum et al. (2018) impact assessment models are used to calculate actual impact scores within each impact category. Different models should consider different characterization factors and standardized inventory data. The core of LCIA involves assessing the potential environmental impacts within each category. At this stage, characterized, normalized, and weighted data are used to calculate the overall environmental performance of a product, process, or system. Analysts may identify significant contributors to overall impacts, which can guide improvement efforts.

One of the primary objectives of characterization is to make the results of LCIA studies comparable. By using common units, factors, and weighting schemes, it is possible to assess and benchmark different LCAs, facilitating decision-making and policy development (Rosenbaum et al., 2018). After describing impacts within individual categories, results can be aggregated across categories to provide an overall assessment of the environmental performance of a product, process, or system. Aggregation involves merging scores into a single indicator. Aggregation can result in a single aggregated score, often referred to as a single score or an environmental performance indicator (e.g., Ecological Quality Indicator 90 points). Alternatively, it can generate a profile showing performance across multiple impact categories. The choice between a single score or a profile depends on the intended audience and the complexity of the assessment (Rosenbaum et al., 2018).

According to Rosenbaum et al. (2018) aggregation should consider the uncertainty associated with LCIA results. Sensitivity analysis may be conducted to assess how variations in data, modeling assumptions, or weighting factors affect the aggregated outcomes. Understanding the robustness of the aggregated results is essential for

decision-making. Aggregated results are typically presented transparently, often in charts, graphs, or tables. These results help stakeholders, including policymakers, product designers, and consumers, understand the overall environmental performance of a product or process. Acknowledging the limitations of aggregation is crucial. Summarizing various environmental impacts into a single score can oversimplify complex environmental issues, and the choice of weighting factors can be subjective and contentious, potentially leading to different interpretations of results. Aggregation allows for a more comprehensive assessment of environmental impact, considering multiple facets simultaneously. This holistic perspective helps identify trade-offs and hotspots, guiding decision-makers toward more sustainable choices. Aggregation in LCIA is a process that combines results from multiple impact categories to provide a comprehensive assessment of the environmental performance of a product or process. It involves the standardization, weighting, and consideration of the functional unit, and plays a crucial role in simplifying complex environmental data for informed decision-making. However, careful consideration of uncertainty in reporting is essential in the aggregation process (Rosenbaum et al., 2018).

#### **2.2.2.4 Interpretation**

The Interpretation phase involves a thorough analysis, evaluation, and discussion of the results from both the Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA). It is a complex stage where a vast amount of data is transformed into meaningful insights and feasible recommendations (Curran, 2015).

The Interpretation phase in life cycle assessment encompasses several key aspects that are integral to the comprehensive understanding and analysis of LCA results. It initiates with the identification of stakeholders and an exploration of their concerns and interests, a pivotal step that guides the entire interpretation process (Curran, 2015). Issue identification is another critical component as it necessitates discerning the specific questions to which the LCI and LCIA results are pertinent. These questions can span diverse aspects of the life cycle, including emissions, waste management, and energy

efficiency, and providing corresponding explanations is vital to this phase. Result evaluation, as outlined by ISO 14044:2006, is a fundamental facet of interpretation, involving a thorough scrutiny of the data employed in the LCA. This scrutiny encompasses assessing the quality, sources, accuracy, and reliability of the data. Furthermore, sensitivity analysis is employed to gauge the robustness of LCA results, ensuring a comprehensive and reliable interpretation process.

**Conclusions, Recommendations, and Limitations:** The aim of interpretation is to provide decision support. It should assist stakeholders in making informed choices, prioritizing environmental sustainability while considering economic and social aspects. LCA results can inform product design, supply chain decisions, policy-making, and eco-labeling initiatives. Conclusions from the interpretation should be presented in a clear, transparent, and easily understandable manner to ensure stakeholders effectively comprehend and utilize this information (Curran, 2015). According to Curran (2015), interpretation is a dynamic and iterative process within the LCA framework, essential for deriving meaningful insights from environmental assessments. It empowers decision-makers and stakeholders to make informed choices, support sustainability objectives, and drive continuous improvement in products, processes, and systems. While interpretation involves various challenges, its role in shaping sustainable practices and policies cannot be understated (Curran, 2015). The final conclusions drawn from interpretation also have limitations, primarily because interpretation involves subjective judgments, especially when balancing environmental impacts or making value-based decisions (Curran, 2015).

### **2.2.3 LCA tool and databases**

Early in the history of Life Cycle Assessment (LCA), researchers and practitioners conducted assessments manually due to limited data and tools. Since the 1960s, LCA emerged as a widely recognized method for sustainability assessment, leading to the necessity of LCA tools (Curran, 2015). As the scope and detail of research expanded, collecting, storing, and managing LCA data became increasingly challenging. LCA involves

integrating large datasets, numerous impact categories, and complex calculations. The development of LCA tools aimed to streamline this process. To ensure consistency and comparability of results, LCA tools began to adopt standardized impact categories, methods, and data sources (Klöpffer, Grahl, & Klöpffer, 2014).

According to Klöpffer, Grahl, and Klöpffer (2014) discussed, LCA tools automate data collection, calculations, and analysis, significantly reducing the time and effort required for assessments, thus enhancing work efficiency. They facilitate the organization and storage of vast data, ensuring data integrity and accessibility. LCA tools employ standardized approaches, ensuring consistency and comparability of results across studies and industries. LCA inherently involves complex calculations and multiple impact categories, and tools assist in managing this complexity. LCA tools enable users to explore various scenarios and alternatives, aiding decision-making in sustainable practices. They help present LCA results in a clear, intuitive, and understandable manner for effective communication to stakeholders (Klöpffer, Grahl, & Klöpffer, 2014).

In the realm of LCA tools, there is a diverse array of options at one's disposal. These include Simapro, a widely recognized commercial LCA software celebrated for its expansive database and user-friendly interface. GaBi is another notable choice, offering extensive databases and frequently employed for sustainability assessments of industrial products and processes. Additionally, OpenLCA, an open-source LCA tool, serves as a valuable platform for crafting, exchanging, and scrutinizing life cycle inventories.

For this research, OpenLCA has been selected as the LCA tool for several compelling reasons. Firstly, it aligns with the principles of open-source software, granting free access to all users and substantially reducing software procurement expenses while providing access to abundant data resources (Curran, 2015). Secondly, OpenLCA offers transparency and robust data management capabilities, allowing users to oversee and curate their LCA databases, as well as import data from diverse sources and databases, thereby fostering data control, precision, and uniformity (Curran, 2015). Furthermore,

its support for data exchange formats like ILCD (International Reference Life Cycle Data System) and EcoSpold enhances interoperability with other LCA tools and databases, streamlining data sharing in research endeavors (Curran, 2015). Lastly, OpenLCA's cross-platform compatibility, suitable for operating systems such as Windows, macOS, and Linux, ensures accessibility and flexibility throughout the research process (Curran, 2015).

OpenLCA's database covers a wide range of industries, making it suitable for LCA assessments in diverse sectors, from agriculture to manufacturing. In this research, external data from factories, literature, suppliers, and EPD databases (Ecoinvent EN15804) integrated with OpenLCA software will be utilized (Curran, 2015).

Environmental Product Declarations (EPDs) are standardized documents providing comprehensive information on the environmental performance of products throughout their life cycle. Ecoinvent EN15804 is a specific EPD database adhering to the EN15804 standard (Hunsager, Bach, & Breuer, 2014). The key features of EPD databases, such as Ecoinvent EN15804, are designed to offer several advantages. These databases follow a standardized format, simplifying comparisons of the environmental performance of different products within the same category, a valuable resource for stakeholders like architects, builders, and policymakers (Hunsager, Bach, & Breuer, 2014). Moreover, EPDs promote transparency by providing clear information on the environmental impacts of products, including their carbon footprint, energy consumption, and resource use, empowering informed decision-making in support of sustainability (Hunsager, Bach, & Breuer, 2014). These databases also contain comprehensive data on construction materials, covering items like cement, steel, insulation, and more, which are essential for assessing the environmental impact of building projects (Hunsager, Bach, & Breuer, 2014). Additionally, given that EPDs are often required by regulations and green building certification programs, utilizing EPD databases ensures compliance with these standards (Hunsager, Bach, & Breuer, 2014).

#### **2.2.4 LCA applications**

Life Cycle Assessment (LCA) is a versatile and powerful tool with various direct and indirect applications for both profit and non-profit organizations (ISO 14044:2006). LCA assists organizations and decision-makers in gaining in-depth insights into the environmental impacts of products, processes, or systems throughout their entire lifecycle. Here are some key applications of LCA (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010):

**Product Design and Development:** LCA is used to assess and optimize the environmental performance of products during the design phase. It helps identify opportunities to reduce environmental impacts, such as minimizing resource use, energy consumption, and emissions (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010).

**Supply Chain Management:** LCA is employed to evaluate and manage the environmental impacts of supply chains. By analyzing the entire lifecycle of a product, organizations can identify "hotspots" within the supply chain and collaborate with suppliers to enhance sustainability (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010).

**Sustainable Procurement:** Organizations use LCA to make environmentally responsible procurement decisions. By considering the lifecycle impacts of products, they can choose suppliers and materials with lower environmental footprints (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010).

**Waste Management:** LCA aids in evaluating waste management strategies. It assesses the environmental impacts of various waste disposal options, promoting waste reduction, recycling, and responsible disposal practices (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010).

Energy Planning: LCA is used to compare the environmental impacts of different energy generation methods, assisting policymakers and energy providers in making informed decisions about energy and infrastructure (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010).

Marketing and Communication: LCA finds widespread applications in marketing and communication, particularly in the context of eco-labels and environmental declarations. LCA data is often used to support eco-labels and eco-certifications. Eco-labels are symbols awarded to products that meet specific environmental standards. According to ISO 14025:2006, Environmental Product Declarations (EPDs) offer detailed environmental information about a product's entire lifecycle. These declarations transparently communicate a product's environmental attributes, helping consumers and stakeholders understand its environmental impacts and make informed purchasing decisions.

In conclusion, LCA is a versatile tool that serves various purposes across industries. It guides decision-making processes, promotes sustainability, and empowers consumers with information to make environmentally conscious choices. Whether applied to product design, supply chain management, waste reduction, or energy planning, LCA continues to play a pivotal role in addressing environmental challenges and fostering responsible practices.

### **2.2.5 Limitation**

While Life Cycle Assessment (LCA) is a valuable tool for evaluating the environmental impacts of products, processes, or systems, it is not without limitations. According to Klöpffer, Grahl, & Klöpffer (2014), LCA heavily relies on the quality and availability of data. Obtaining accurate and comprehensive data for every stage of a product's lifecycle can be challenging, and inaccurate data may introduce uncertainties into the results. The definition of the boundaries of an LCA study is subjective, and different system boundaries may yield disparate outcomes, underscoring the importance of clearly

defining the scope of the assessment. Additionally, dynamic changes in time and location can render LCA unable to capture long-term environmental effects (Klöpffer, Grahl, & Klöpffer, 2014).

Due to this Life Cycle Assessment (LCA) serves as a self-declaration aimed at investigating the environmental aspects of products. And this assessment has not undergone certification by an independent third-party organization, making it distinct from LCA processes in compliance with ISO 14025. ISO 14025 primarily pertains to verified declarations by third-party entities, while this work aligns with the principles of ISO 14021, which involve self-declarations without third-party verification (International Organization for Standardization, 2016). ISO 14021, which pertains to Type II environmental labeling, serves as a central standard within this series. It is often associated with self-declared environmental claims. In essence, Type II labels are initiated and provided by the product manufacturer or service provider, typically without third-party validation (International Organization for Standardization, 2016). It's crucial to highlight that this LCA is a rigorous and insightful evaluation, though it remains a self-declaration, marking a significant step towards understanding the environmental performance of the products under investigation.

Despite these constraints, LCA remains a crucial instrument for assessing and comparing the environmental performance of products and systems. Recognizing these limitations empowers practitioners to employ LCA results more effectively and make informed decisions, while also driving continuous refinement and enhancement of the methodology.

## **2.3 Environmental product declaration (EPD )**

### **2.3.1 Background**

According to ISO 14025:2006 (International Organization for Standardization, 2006), Environmental Product Declarations (EPDs) are standardized documents that provide

comprehensive information about a product's environmental performance throughout its entire lifecycle. The emergence of EPDs can be traced back to the need for a means to communicate the results of Life Cycle Assessments (LCAs) to a broader audience. The development and use of EPDs were initially driven by businesses seeking to distinguish their products in the market by showcasing their environmental credentials (ISO 14025:2006).

In 1998, the International Organization for Standardization (ISO) published ISO 14025, laying the foundation for the development of EPDs. This standard defined the principles and procedures for creating Type III environmental declarations, which later became known as EPDs. EPDs are typically prepared in accordance with ISO 14025 and other relevant standards. These declarations serve to assist consumers, businesses, and policymakers in making informed choices about environmentally friendly products and services (ISO 14025:2006). According to ISO 14025:2006 (International Organization for Standardization, 2006), throughout the 2010s, the use of EPDs continued to expand, with various industries adopting them as tools for communicating environmental performance. Today, EPDs are widely recognized and utilized across various sectors and regions as valuable tools for assessing and communicating a product's environmental performance. Their development and standardization have contributed to the adoption of more informed and sustainable approaches to product decision-making. EPDs facilitate easy comparisons among different products within the same category. Users can assess which products have a smaller environmental impact based on standardized indicators. The evolution of EPDs reflects a response to the pressing environmental challenges of our time and the need to provide consumers, businesses, and policymakers with reliable and standardized environmental information to support decision-making (ISO 14025:2006).

PCR 2023:01 represents a standardized framework comprising rules, criteria, and directives specifically designed for the development of Environmental Product Declarations (EPDs) pertaining to metal mailbox products. It delineates crucial aspects

to be considered during the creation of an EPD, including the delineation of system boundaries, specification of the functional unit for declaration, and establishment of criteria for defining utilization and disposal phases (PCR 2023:01, 1.0.1). PCR ensures consistency and uniformity in assessing products falling under the same category, irrespective of industry, thus facilitating transparency and comparability among various EPDs (PCR 2023:01, 1.0.1). In this research, adherence to the guidelines outlined in PCR 2023:01 will be maintained throughout the data processing and analysis phases.

### **2.3.2 Relationship between LCA and EPD**

An Environmental Product Declaration (EPD) is a standardized and transparent document that communicates the environmental performance of a product throughout its lifecycle significance (Hunsager, Bach, & Breuer, 2014). EPDs provide quantitative and qualitative information about the environmental impacts of a product, making it easier for consumers, businesses, and policymakers to make informed decisions and comparisons regarding the environmental aspects of products significance (Hunsager, Bach, & Breuer, 2014).

The relationship between EPDs and Life Cycle Assessment (LCA) is fundamental. LCA is the scientific methodology used to evaluate and quantify the environmental impacts of a product, process, or system across its entire lifecycle (Curran, 2015). It considers various dimensions such as resource consumption, energy usage, emissions, and waste generation during the raw material extraction, manufacturing, transportation, use, and end-of-life phases of a product. LCA aims to provide a comprehensive and objective understanding of how a product affects the environment (Curran, 2015). On the other hand, EPDs are a means to communicate the results of LCA studies in a standardized and user-friendly format. They are typically based on LCA data and conclusions. When a company conducts an LCA of its product, it generates a wealth of technical data, graphs, and charts, which may be complex and overwhelming for consumers or non-experts (Meijer, 2023). An EPD serves as a summary of this data, presenting the key findings in a clear, concise, and easily understandable format (Moré, Galindro, & Soares, 2022). As

shown in Figure 5, Bobi company's supplier Outokumpu company has provided an Environmental Product Declaration (EPD) for its ferrochrome product. This allows for a more intuitive way to identify the required data when compared to the Life Cycle Assessment (LCA) results.

## 6.2. Additional mandatory and voluntary impact category indicators

Table 6. Mandatory and voluntary impact category indicators. Human toxicity and ecotoxicity are voluntary impact categories.

Results per declared unit		
Indicator	Unit	A1-A3
GWP-GHG <sup>1</sup>	kg CO <sub>2</sub> eq.	1,75E+03
Human toxicity Cancer <sup>2</sup>	CTUh	8,26E-07
Human toxicity Non-Cancer <sup>2</sup>	CTUh	2,76E-04
Ecotoxicity, freshwater <sup>2</sup>	CTUe	5,44E+04

<sup>1</sup> This indicator accounts for all greenhouse gases except biogenic carbon dioxide uptake and emissions and biogenic carbon stored in the product. As such, the indicator is identical to GWP-total except that the CF for biogenic CO<sub>2</sub> is set to zero.

<sup>2</sup> The results of this environmental impact indicator shall be used with care as the uncertainties of these results are high or as there is limited experience with the indicator.

Table 7. Resource use indicators

Results per declared unit			
Indicator		Unit	A1-A3
Primary energy resources - Renewable	Used as energy carrier	MJ	2,53E+03
	Used as raw material	MJ	0
	Total	MJ	2,53E+03
Primary energy resources – Non-renewable	Used as energy carrier	MJ	5,10E+04
	Used as raw material	MJ	0
	Total	MJ	5,10E+04
Secondary materials		kg	0,00E+00
Renewable secondary fuels		MJ	0,00E+00
Non-renewable secondary fuels		MJ	0,00E+00
Net use fresh water		m <sup>3</sup>	8,83E+01

Figure 5 Example of Ferrochrome EPD impact category indicators and Resource use indicators results (Outokumpu)

According to Meijer (2023), EPDs are based on the data and findings derived from LCA studies. LCA provides the scientific foundation by quantifying the environmental impact of a product, and EPDs use this data for communication. EPDs follow specific standards

and guidelines, ensuring that the information they present is consistent and comparable. This standardization helps consumers and businesses make apples-to-apples comparisons between products. EPDs simplify the complex data from LCA studies, presenting it in a more accessible manner. They typically include information on a product's carbon footprint, energy usage, water consumption, and other environmental indicators. EPDs offer transparency by revealing the data sources, methodologies, and assumptions used in the LCA. This transparency builds trust and credibility in the environmental claims made by manufacturers. EPDs are subject to review and verification by third-party experts to ensure that they meet established standards. This external validation enhances the credibility of the environmental claims made by the product manufacturer (Meijer, 2023). Overall, EPDs play a critical role in making the results of LCA studies practical and applicable. They bridge the gap between complex scientific data and the need for transparent, credible, and easily understood information on a product's environmental performance. This aids consumers in making informed choices and encourages manufacturers to enhance the sustainability of their products.

In the context of Bobi Company, the generation of EPDs based on LCA studies contributes to their environmental responsibility, transparency, and the promotion of eco-conscious products in the market.

## **2.4 Research studies in the field of metal mailboxes (metal sheet products)**

In the realm of metal sheets, numerous studies have explored the applications and preservation of metal sheet products in the construction industry. Research on the life cycle assessment (LCA) of building components made from metal sheets has been a prominent focus. Similarly, in the automotive sector, there have been extensive LCAs conducted on sheet metal parts, as well as studies on the life cycle of metal sheet welding processes.

However, when it comes to the specific field of metal mailboxes, there is currently a noticeable gap in research. Existing studies have primarily revolved around mailbox testing, product design, and comparative analyses of linear and circular manufacturing system paradigms within the context of metal mailboxes. While these studies contribute valuable insights to mailbox production and design, there has yet to be a comprehensive life cycle assessment (LCA) dedicated to metal mailbox products. The absence of LCA studies in this domain presents a significant opportunity for understanding the environmental footprint, sustainability, and overall life cycle impacts of metal mailbox products. Such research could provide valuable insights for manufacturers, consumers, and policymakers in the mailbox industry, aiding in the development of more sustainable and eco-friendly mailbox solutions. Therefore, this thesis aims to bridge this research gap by conducting a detailed LCA study on Bobi Company's Classic and Cargo mailboxes, thus contributing to the existing knowledge in the field of metal mailbox products.

### **3 Methodology**

This study was commissioned by the Leinolat Group and conducted as a case study. Its subsidiary companies Leimec Company provided comprehensive and accurate production data and collaborated with its suppliers to provide data for other stages of the product lifecycle. Subsequently, the data were reviewed and submitted by Bobi Company. The research adhered to the standardized methods of life cycle assessment outlined in ISO 14040 and ISO 14044.

#### **3.1 Research design and approach**

The primary objective of this study is to meet the case company's demands for a comprehensive Life Cycle Assessment (LCA) and Environmental Product Declaration (EPD) of their mailbox products. Specifically, it focuses on conducting a thorough LCA study of two mailbox product series (Cargo and Classic) manufactured by Leimec Company. Additionally, it aims to develop EPDs based on the research findings. This study also contributes to the literature on metal sheet products.

As a result, the study has formulated one main research question and two secondary research questions: The primary research question seeks to uncover the principal environmental impacts spanning the entire lifecycle of the mailbox product. The first secondary question explores the distinct influence of various stages, including raw material extraction and manufacturing, on the mailbox's overall environmental footprint. The second secondary question delves into the specific stages within the mailbox's lifecycle where opportunities arise for enhancing resource efficiency, reducing waste, and minimizing emissions.

This research is descriptive in nature, primarily involving the collection and organization of information about the research subject to depict its characteristics, attributes, and conditions (Saunders, Lewis, & Thornhill, 2016). It does not involve intervening or manipulating variables. The methodology employed in this study is a mixed research

approach, encompassing the collection of quantitative data, such as product parameters, transportation parameters, waste parameters, and energy parameters, as well as the collection of qualitative data, including product manufacturing processes, production techniques, and surface treatments.

### **3.2 Data collection and analysis**

This study involves the collection and analysis of both quantitative and qualitative data. This section provides an overview of the data. Open LCA software will be utilized for data analysis. Data will be sourced from various avenues:

Quantitative Data:

- a) Real production, transportation, energy consumption data from Leimec Company, as well as production data from its suppliers.
- b) Bill of Materials (BOM) data provided by Bobi Company.
- c) EPD databases (Ecoinvent EN15804) integrated with OpenLCA software.
- d) Estimation of direct or indirect transportation distances between suppliers using Google Maps.

Qualitative Data:

- a) Production processes and manufacturing techniques employed by Leimec Company.
- b) Relevant material production processes and surface treatment processes from literature sources.

### **3.3 Reliability and Validity**

This study adheres to the standardized LCA methodology outlined in ISO 14040 and ISO 14044. The consistency of the entire research methodology ensures that the results are

replicable, thereby enhancing reliability (Saunders, Lewis, & Thornhill, 2016). The reliability of data is crucial in LCA studies. It is imperative to use accurate and up-to-date data from reliable sources (Saunders, Lewis, & Thornhill, 2016). In this study, data obtained from Leimec Company, Bobi Company, and the EPD database (Ecoinvent EN15804) ensures the authenticity and reliability of the data sources. According to Saunders, Lewis, & Thornhill (2016), several crucial measures are undertaken to validate the data's reliability and validity. These measures encompass a Completeness Check, which assures the dataset's comprehensiveness without omitting vital data points; a Consistency Check, which diligently identifies any contradictions or inconsistencies within the data; and a Sensitivity Analysis, which rigorously evaluates the robustness of the research results. This entails varying key parameters or data inputs within reasonable ranges to gain insights into how changes affect the outcomes.

These steps are essential in verifying the reliability and validity of the data and the subsequent analysis, ultimately ensuring the credibility and trustworthiness of the research outcomes (Saunders, Lewis, & Thornhill, 2016).

## 4 LCA case study

### 4.1 Goal and scope

Bobi Company is steadfast in its commitment to advancing environmental sustainability and actively encourages suppliers and customers to engage in the ecosystem of environmental sustainability. To achieve this goal, a lifecycle assessment (LCA) analysis was conducted on two product lines, codenamed Bobi Cargo (Figure 6) and Bobi Classic (Figure 7). Subsequently, environmental product declarations (EPDs) were formulated based on the assessment results. These two products entail different raw materials, production processes, and transportation methods throughout their respective lifecycles, making them representative subjects for analysis.



**Figure 6. Bobi Cargo mailbox (Bobi, 2023)**



**Figure 7. Bobi Classic mailbox (Bobi,2023)**

#### 4.1.1 Functional unit

The functional unit refers to the quantified definition of a product's performance used as a reference unit (ISO14044:2006). In this study, the functional units are represented by two distinct types of mailboxes, Bobi Cargo and Bobi Classic, each constructed from

different materials. Therefore, the functional unit for the Metal mailbox is based on the quality parameter of the environmental impact generated by each mailbox, such as the quantity of carbon dioxide emissions produced over the lifecycle of each mailbox.

#### **4.1.2 System boundaries**

The International EPD System employs an approach where it is essential to encompass all attributional processes spanning from the product's creation to its disposal, guided by the principle of "minimizing the loss of information at the final product stage." This approach holds particular significance in the context of business-to-consumer communication (PCR 2023:01, 1.0.1).

PCR (2023:01, 1.0.1) outlines two optional scopes for EPD-based LCAs, offering a choice between a "cradle-to-gate" EPD, which draws data from the UPSTREAM and CORE life cycle stages, and a "cradle-to-grave" EPD, which extends to encompass the DOWNSTREAM stage. However, preparing a "cradle-to-grave" EPD necessitates the development of comprehensive information that defines the product's function and encompasses scenarios for managing its usage and end-of-life stage, a critical step for ensuring comparability within the specific application of the product group. Achieving this entails gathering detailed data to define the product's function and outline scenarios for managing its usage and end-of-life stage within the specific context of the metal product group. Given the complex nature of end customers for mailboxes, involving individual users in various countries, the task of acquiring relevant data on disposal processes for mailboxes and their packaging is challenging. To maintain the precision and reliability of this study, the chosen EPD type is "cradle-to-gate," with careful consideration of the specified boundaries.

### **4.1.3 Life cycle stages**

To adhere to various data quality regulations and for the presentation of findings, and as per the EPD boundary type chosen based on our PCR (2023:01, 1.0.1) selection, the product's life cycle is divided into two distinct life cycle phases:

Upstream processes (from cradle-to-gate): This encompasses Leimec's factory's direct or indirect procurement activities, involving the production and transportation of steel sheet materials, as well as the production and transportation of other components and packaging materials.

Core processes (from gate-to-gate): This includes the processing, manufacturing, assembly, and testing of metal sheet materials within Leimec's factory. It also incorporates equipment consumption, energy consumption and on-site production waste.

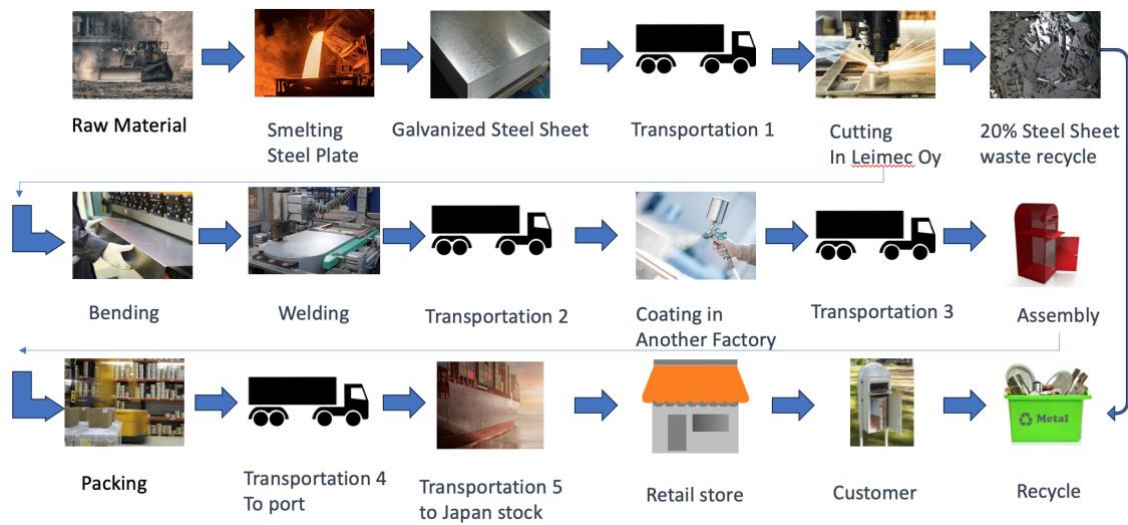
### **4.1.4 Other boundaries**

Temporal and Geographic Boundaries: In terms of temporal scope, all primary data collected by Bobi Company are sourced from the year 2022. The EPD databases (Ecoinvent EN15804 3.9.1) integrated with OpenLCA software also pertain to the year 2022. Regarding the geographic scope, the suppliers involved in the mailbox manufacturing process are all based in Finland.

### **4.1.5 System diagram**

Figure 8 presents a system diagram of the Cargo mailbox. This diagram provides a comprehensive representation of the various stages within the product's lifecycle, including upstream, core, and downstream processes. Through this visual representation, it becomes possible to trace the relevant upstream processes, core manufacturing processes, and downstream handling processes. This aids in gaining a holistic understanding of the entire lifecycle of the Cargo mailbox.

Similarly, Figure 9 illustrates a system diagram for the Bobi Classic mailbox. In contrast to the Cargo mailbox, the Classic mailbox employs stainless steel as its primary material, resulting in the omission of a surface coating process during manufacturing. These two system diagrams facilitate a comparative analysis of the lifecycles of these two mailbox variants, highlighting distinctions, particularly in terms of material selection and production processes.



**Figure 8. Bobi Cargo mailbox system diagram**



**Figure 9. Bobi Classic mailbox system diagram**

#### 4.1.6 Cut-off rules

In accordance with the standards outlined in the PCR (2023:01, 1.0.1) concerning Cut-off criteria, the 1% cut-off rule should be applied. In simpler terms, the inventory data included should collectively account for at least 99% of the results for any environmental impact category. Furthermore, this consideration should extend to encompass 99% of the product's mass and 99% of the energy usage throughout its lifecycle. However, it is advisable to avoid cut-off for inventory data and utilize all available inventory data whenever possible.

#### 4.1.7 Allocation rules

As Leimec Company solely focuses on mailbox production, the total consumption and waste generation for the year 2022 need only be averaged out across the total quantity of mailboxes produced in that same year.

Regarding the allocation procedure for waste and recycling activities, waste allocation should adhere to the Polluter Pays Principle and its interpretation in EN 15804: "The waste treatment processes shall be allocated to the product system that generated the

waste until a waste termination state is reached." The waste termination state is attained when all criteria for waste termination (PCR 2023:01, 1.0.1). Metal products typically have well-established processes for recycling significant amounts of metal waste generated within the value chain. Some principles to be followed is internal recycling waste generated during the manufacturing process should not be considered as input for secondary materials (PCR 2023:01, 1.0.1).

#### **4.1.8 Data quality**

The life cycle inventory data is divided into specific data and generic data (PCR 2023:01, 1.0.1). Specific data, also known as primary data, comprise actual data collected from Leimec factory and its suppliers regarding the life cycle of Cargo and Classic mailboxes. It includes the production and transportation of materials, distances to relevant production sites, transportation methods, the number of transports, and product quantities. Additionally, a material bill of materials (BOM) is provided by Bobi Mailbox Design Company.

Generic data, also referred to as secondary data, will be utilized for processes where specific data cannot be obtained. These generic data are sourced from EPD databases (Ecoinvent EN15804 3.9.1) integrated with OpenLCA software. The Ecoinvent EN15804 3.9.1 database was last updated in 2022, aligning with the year of original data collection and complying with the rules of generic data as specified in the PCR (2023:01, 1.0.1).

## **4.2 Life cycle inventory analysis**

Life Cycle Inventory (LCI) analysis primarily involves the analysis, organization, and modeling of data. It includes defining the scope of the study and specifying the functional unit. The objective is to identify and quantify all materials, energy, and resources used in each life cycle stage from the raw data. This encompasses raw materials, water, electricity, energy sources, and any other resources involved throughout the product's life cycle. In this study, we are examining the LCA of two

mailbox models, "Cargo" and "Classic," for the year 2022. This requires the compilation and analysis of both quantitative and qualitative research data provided by the Leimec factory and Bobi company. These data need to be standardized into consistent units and quantified for each specific process, subsequently input into the Open LCA tool.

Quantitative research data encompasses the total purchased raw materials data, bill of materials (BOM), which includes all the parts, materials, and packaging required for each mailbox, the number of shipments, transportation methods, distances traveled, materials and energy consumed for surface treatment, waste generation, energy consumption, outputs, emissions, and all other relevant data.

Qualitative research data includes information about manufacturing processes and procedures, types of materials, and surface treatment processes provided directly by Leimec factory and its suppliers.

In the data, the manufacturing stage is divided into two parts: upstream manufacturing and core manufacturing. According to the Product Category Rules (PCR) (2023:01, 1.0.1) description, data related to raw materials in the upstream manufacturing stage are sourced from the EPD databases (Ecoinvent EN15804 3.9.1) integrated with OpenLCA software. This data is then combined with transportation information provided by the Leimec factory, including transportation locations, distances, methods, frequency, weights, etc. Finally, this information is connected to the core manufacturing stage for data modeling.

### **4.3 Life cycle impact assessment**

Life Cycle Impact Assessment (LCIA) involves the computation of results based on Life Cycle Inventory (LCI) data within the OpenLCA tool, which are presented in tables and graphs. Users have the flexibility to select impact assessment categories, and the top four or five processes contributing the most to each category are visually displayed in chart form. In LCIA, a comprehensive list of system processes, inputs, outputs, their

numerical values, and units is also provided for all products. Furthermore, it allows for the assessment of contributions from processes and flows to specific environmental impact categories, along with their respective shares, based on the outcomes of different impact classifications. By conducting regional analysis, it becomes possible to estimate the geographic location of the selected item, its contributions within that region, and identify the processes responsible for the same impact category within that region. LCIA also facilitates the adjustment of variable data groups to compare the differences in results. The results of the impact assessment and the evaluation of the results is presented in Chapter 5.

#### **4.4 Interpretation of results**

As the final phase of LCA, it is imperative to iteratively categorize and interpret the entire research findings. This interpretation of results serves the purpose of discussing and addressing the research questions posed earlier. A comprehensive evaluation of the interpretation of results, their significance, effectiveness, and reliability, will be presented in Chapter 5.

## 5 Results and recommendations

This chapter provides an overview of the findings from the LCA investigation. These findings serve a dual purpose: not only for the subsequent creation of an EPD but also for the identification of areas with significant environmental impact and potential enhancements. The chapter commences with an introduction to the primary material used in the Cargo and Classic mailbox, followed by an assessment of their recyclability potential. Subsequently, it delves into the essential conclusions derived from the impact assessment outcomes and conducts an analysis of process contributions.

### 5.1 Component materials

Table 1 and Table 2 present the material composition of Classic mailboxes and Cargo mailboxes, encompassing both the mailbox itself and its packaging. Table 1 demonstrates that stainless steel predominates as the primary material in Classic mailboxes, constituting a substantial 81.35% of the composition. Packaging materials account for 17.50%, while the remaining components of the mailbox consist of a limited proportion of plastic materials, amounting to just 1.15%.

**Table 1. Classic mailbox materials**

Material	Name	Weight (kg)	Weight %
Metal	Steel, stainless steel	5.67	81.35%
Plastics	ABS,DPE, film,bags	0.08	1.15%
Wood products	Carton board, cardboard,pallet	1.22	17.50%
Total		6.97	100.00%

Table 2 demonstrates that galvanized steel predominates as the primary material in Cargo mailboxes, constituting a substantial 79.63% of the composition. Packaging materials account for 19.48%, while the remaining components of the mailbox consist of a limited proportion of plastic materials, amounting to just 0.88%.

**Table 2. Cargo mailbox materials**

Material	Name	Weight (kg)	Weight %
Metal	Galvannealed steel	11.73	79.63%
Plastics	ABS,DPE, film,bags	0.13	0.88%
Wood product	Carton board, cardboard,pallet	2.87	19.48%
Total		14.73	100.00%

## 5.2 Impact assessment

### 5.2.1 Bobi Classic mailbox impact assessment

According to the Product Category Rules (PCR) (2023:01, 1.0.1) description, the impact assessment can be analyzed from two perspectives, impact category indicators and resource use indicators. In the impact category indicators, Table 3 displays the results for the Classic mailbox, including Global Warming Potential (GWP), Ozone Layer Depletion (ODP), Acidification Potential (AP), Eutrophication Potential (EP), Photochemical Oxidant Creation Potential (POCP), Abiotic Depletion Potential (ADP), and Water Deprivation Potential (WDP). Table 4 presents resource use indicators for the Classic mailbox, including Primary Energy Resources - Renewable, Primary Energy Resources - Non-renewable, Renewable Secondary Fuels, Non-renewable Secondary Fuels, and Net Use of Freshwater, along with their respective quantities in both the Upstream and Core stages.

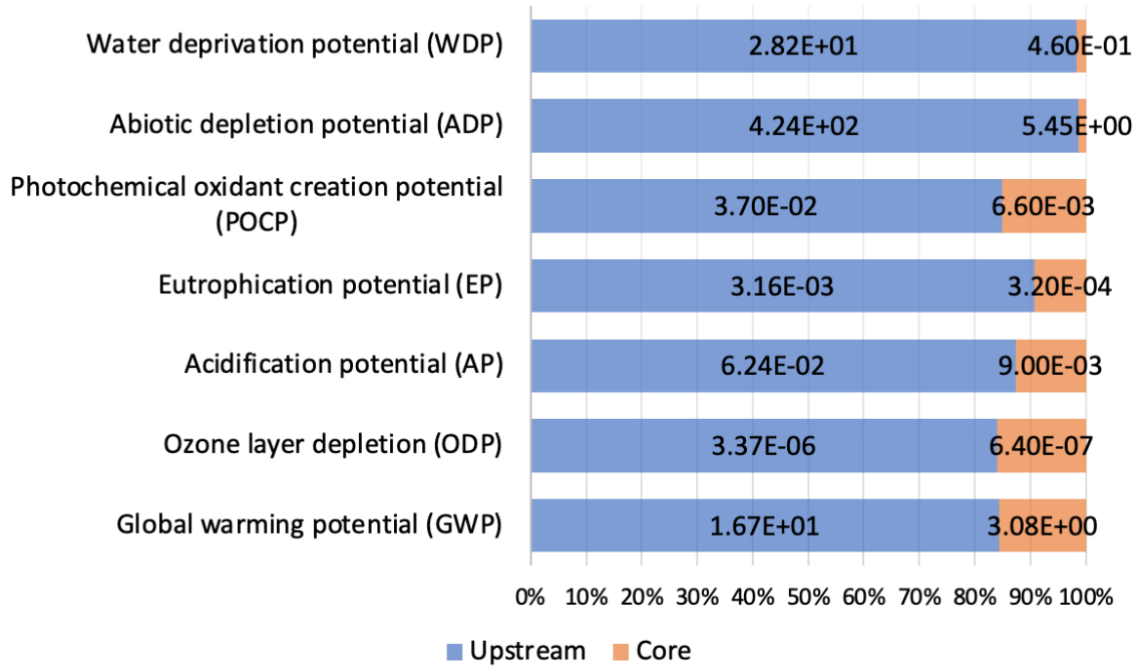
**Table 3. Classic mailbox impact category indicators**

PARAMETER		UNIT	Upstream	Core	TOTAL
Global warming potential (GWP)	Fossil	kg CO <sub>2</sub> eq.	1.81E+01	3.05E+00	2.11E+01
	Biogenic	kg CO <sub>2</sub> eq.	-1.35E+00	2.85E-02	-1.32E+00
	Land use and land transformation	kg CO <sub>2</sub> eq.	9.45E-03	3.18E-03	1.26E-02
	TOTAL	kg CO <sub>2</sub> eq.	1.67E+01	3.08E+00	1.98E+01
Ozone layer depletion (ODP)		kg CFC 11 eq.	3.37E-06	6.40E-07	4.01E-06
Acidification potential (AP)		mol H <sup>+</sup> eq.	6.24E-02	9.00E-03	7.14E-02
Eutrophication potential (EP)	Aquatic freshwater	kg P eq.	3.16E-03	3.20E-04	3.48E-03
Photochemical oxidant creation potential (POCP)		kg NMVOC eq.	3.70E-02	6.60E-03	4.36E-02
Abiotic depletion potential (ADP)	Fossil resources	MJ, net calorific value	4.24E+02	5.45E+00	4.30E+02
	Metals and minerals	kg Sb eq.	6.39E-05	1.73E-05	8.12E-05
Water deprivation potential (WDP)		m <sup>3</sup> world eq. deprived	2.82E+01	4.60E-01	2.87E+01

**Table 4. Classic mailbox resource use indicators**

PARAMETER		UNIT	Upstream	Core	TOTAL
Primary energy resources – Renewable	Use as energy carrier	MJ, net calorific value	2.42E+01	1.53E+00	2.57E+01
	Used as raw materials	MJ, net calorific value	3.57E+01	5.70E-01	3.63E+01
	TOTAL	MJ, net calorific value	5.99E+01	2.10E+00	6.20E+01
Primary energy resources – Non-renewable	Use as energy carrier	MJ, net calorific value	4.68E+02	1.05E+01	4.78E+02
	Used as raw materials	MJ, net calorific value	9.58E+00	3.89E+01	4.85E+01
	TOTAL	MJ, net calorific value	4.77E+02	4.94E+01	5.27E+02
Renewable secondary fuels		MJ, net calorific value	-1.30E-02	2.90E-02	1.60E-02
Non-renewable secondary fuels		MJ, net calorific value	1.35E-01	1.66E-01	3.01E-01
Net use of fresh water		m <sup>3</sup>	6.86E-01	1.09E-02	6.97E-01

## IMPACT CATEGORY INDICATORS



**Figure 10. Compare the proportion of impact category indicators for the Classic mailbox in the upstream stage and the core manufacturing stage**

Figure 10 compares the proportion of impact category indicators for the Classic mailbox in the upstream and core manufacturing stages. Combining the analysis with Table 3 and Figure 10, we can see the Global Warming Potential (GWP) is the most significant environmental impact category in both the upstream and core manufacturing stages. The total GWP for the product is 19.8 kg CO<sub>2</sub> equivalent. The notable reduction in GWP from the upstream to the core manufacturing stage (from 16.7 kg CO<sub>2</sub> equivalent to 3.08 kg CO<sub>2</sub> equivalent) suggests that a substantial portion of greenhouse gas emissions is associated with the earlier stages of the product's lifecycle, such as raw material extraction and transportation. This finding underscores the critical importance of directing sustainability efforts towards the upstream stages to mitigate carbon emissions.

In relative terms, the Ozone Layer Depletion (ODP) metric assumes a less substantial role within the overall environmental impact assessment, yielding a cumulative value of 4.01E-6 kg CFC 11 eq. Conspicuously, ODP contributions in the core manufacturing stage register notably lower than those in the upstream stage, signifying a marginal role of the

latter in exacerbating ozone layer depletion. Although ODP values remain modest, prudent adherence to environmental regulations warrants consistent monitoring and minimization of emissions associated with ozone-depleting substances.

The acidification potential (AP) parameter manifests itself as relatively diminutive in magnitude, culminating in a cumulative total of  $7.14 \times 10^{-2}$  mol H<sup>+</sup> eq. across the entire product lifecycle. Eutrophication potential (EP) assumes a relatively modest dimension, aggregating to  $3.48 \times 10^{-3}$  kg P eq. for the entirety of the product's life cycle. A discernible feature is the greater significance attributed to the upstream stage regarding eutrophication potential contributions relative to the core manufacturing phase. To mitigate eutrophication potential, concerted attention should be directed toward the sources of phosphorus emissions during the phases of raw material extraction and processing. Photochemical Oxidant Creation Potential (POCP) emerges as a parameter of relatively marginal consequence, amassing to  $4.36 \times 10^{-2}$  kg NMVOC eq. across the product's entire life cycle. The upstream phase registers a notably higher degree of influence on POCP relative to the core manufacturing stage. Abiotic Depletion Potential (ADP) in its evaluation of fossil resource depletion, attains a cumulative sum of 430 MJ encompassing the entire product lifecycle. The upstream stage assumes a substantial portion of ADP, underscoring the resource-intensive attributes of raw material acquisition and preliminary processing.

The most notable environmental impact pertains to Global Warming Potential (GWP), totaling approximately 19.8 kilograms of CO<sub>2</sub> equivalent. Additionally, a significant impact category is the Abiotic Depletion Potential (ADP), which can be attributed mainly to fossil resource consumption, resulting in a total of approximately 430 megajoules of net calorific value. This underscores the critical role of resource efficiency during the production of materials. Conversely, the impact associated with Acidification Potential is considerably smaller, estimated at around 0.07 moles of H<sup>+</sup> equivalent. The effect on the ozone layer is rather modest concerning Classic mailboxes. Classic mailboxes also exhibit relatively low eutrophication potential. Photochemical Ozone Creation Potential (POCP)

values remain small in Classic mailboxes, primarily associated with core manufacturing stages. It's important to note that water scarcity potential is not a dominant concern within this context.

Most of the environmental impacts, particularly categories like Global Warming Potential (GWP) and Abiotic Depletion Potential (ADP) are primarily attributed to the upstream stages. These stages encompass activities such as raw material extraction, transportation, and preliminary processing, among others. It is noteworthy that the core manufacturing process, by showcasing minimal pollution and energy consumption, serves as evidence of effective environmental management within the manufacturing domain.

### **5.2.2 Bobi Cargo mailbox impact assessment**

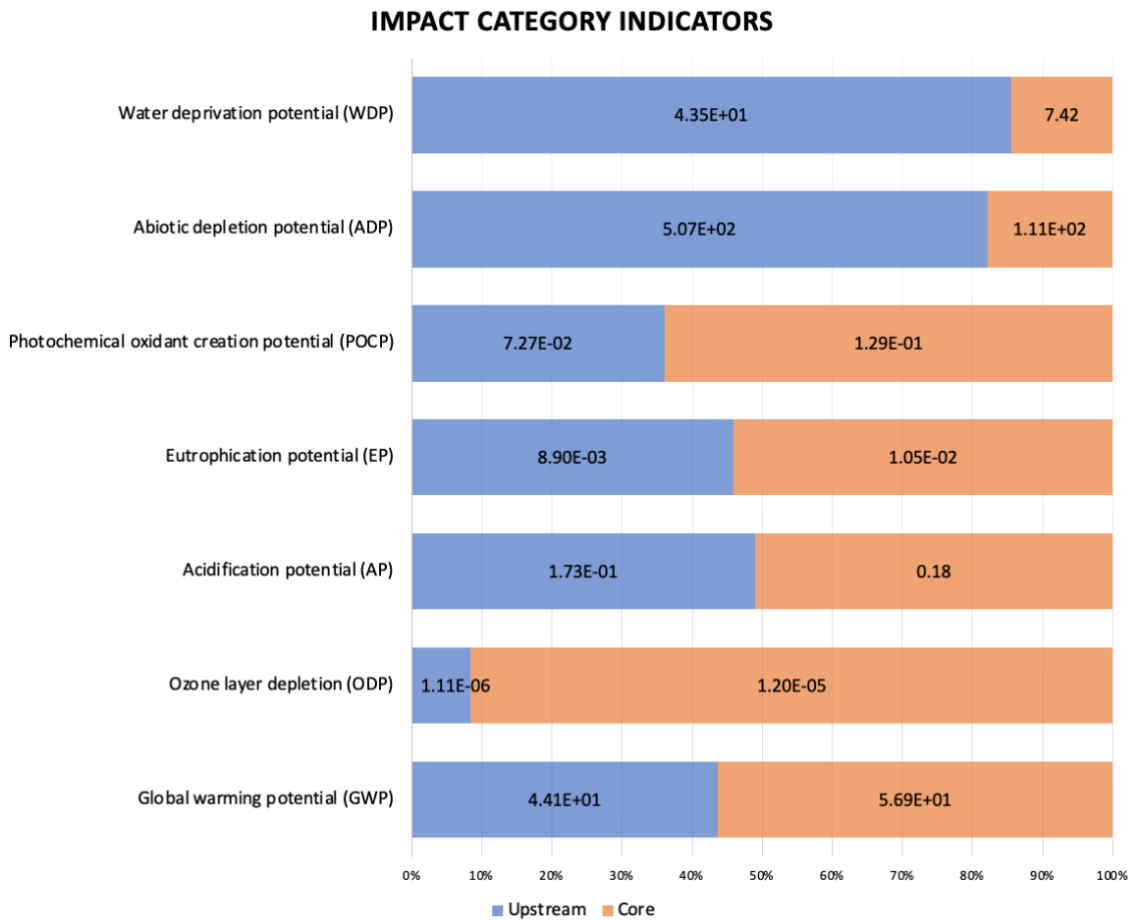
According to the Product Category Rules (PCR) (2023:01, 1.0.1) description, the impact assessment can be analyzed from two perspectives, impact category indicators and resource use indicators. In the impact category indicators, Table 5 displays the results for the Cargo mailbox, including Global Warming Potential (GWP), Ozone Layer Depletion (ODP), Acidification Potential (AP), Eutrophication Potential (EP), Photochemical Oxidant Creation Potential (POCP), Abiotic Depletion Potential (ADP), and Water Deprivation Potential (WDP). Table 6 presents resource use indicators for the Cargo mailbox, including Primary Energy Resources - Renewable, Primary Energy Resources - Non-renewable, Renewable Secondary Fuels, Non-renewable Secondary Fuels, and Net Use of Freshwater, along with their respective quantities in both the Upstream and Core stages.

**Table 5. Cargo mailbox impact category indicators**

PARAMETER		UNIT	Upstream	Core	TOTAL
Global warming potential (GWP)	Fossil	kg CO <sub>2</sub> eq.	4.48E+01	5.67E+01	1.01E+02
	Biogenic	kg CO <sub>2</sub> eq.	-7.25E-01	1.45E-01	-5.80E-01
	Land use and land transformation	kg CO <sub>2</sub> eq.	4.20E-02	5.01E-02	9.21E-02
	TOTAL	kg CO <sub>2</sub> eq.	4.41E+01	5.69E+01	1.01E+02
Ozone layer depletion (ODP)		kg CFC 11 eq.	1.11E-06	1.20E-05	1.31E-05
Acidification potential (AP)		mol H <sup>+</sup> eq.	1.73E-01	0.18	3.53E-01
Eutrophication potential (EP)	Aquatic freshwater	kg P eq.	8.90E-03	1.05E-02	1.94E-02
Photochemical oxidant creation potential (POCP)		kg NMVOC eq.	7.27E-02	1.29E-01	2.02E-01
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq.	5.08E-03	3.67E-04	5.45E-03
	Fossil resources	MJ, net calorific value	5.07E+02	1.11E+02	6.18E+02
Water deprivation potential (WDP)		m <sup>3</sup> world eq. deprived	4.35E+01	7.42	5.09E+01

**Table 6. Cargo mailbox resource use indicators**

PARAMETER		UNIT	Upstream	Core	TOTAL
Primary energy resources – Renewable	Use as energy carrier	MJ, net calorific value	4.25E+01	1.66E+01	5.91E+01
	Used as raw materials	MJ, net calorific value	8.13E+01	5.91E+00	8.72E+01
	TOTAL	MJ, net calorific value	1.24E+02	2.25E+01	1.46E+02
Primary energy resources – Non-renewable	Use as energy carrier	MJ, net calorific value	5.54E+02	1.47E+02	7.01E+02
	Used as raw materials	MJ, net calorific value	8.78E+01	7.33E+02	8.21E+02
	TOTAL	MJ, net calorific value	6.42E+02	8.80E+02	1.52E+03
Renewable secondary fuels (optional)		MJ, net calorific value	1.61E-01	4.60E-01	6.21E-01
Non-renewable secondary fuels (optional)		MJ, net calorific value	1.67E+00	1.91E+00	3.58E+00
Net use of fresh water (optional)		m <sup>3</sup>	2.45E-01	1.80E-01	4.25E-01



**Figure 11. Compare the proportion of impact category indicators for the Cargo mailbox in the upstream stage and the core manufacturing stage**

Figure 11 compares the proportion of impact category indicators for the Cargo mailbox in the upstream and core manufacturing stages. Combining the analysis with Table 5 and Figure 11, we can observe the following:

The total Global Warming Potential (GWP) of 101 kg CO<sub>2</sub> equivalent indicates the product or process's contribution to climate change, with the core phase being the predominant contributor at 56.9 kg CO<sub>2</sub> equivalent. This disparity suggests that a substantial portion of greenhouse gas emissions occurs in the core activities. Within the lifecycle of a Cargo mailbox, transportation activities contribute 50.30 kg CO<sub>2</sub> equivalent to the GWP. To mitigate this impact, seeking cleaner transportation options can contribute to lowering emissions.

Although the total Ozone Depletion Potential (ODP) is relatively small, at  $1.31\text{E-}5$  kg CFC 11 equivalent, its contribution in the core phase is more significant compared to the upstream phase. It was found that the primary equivalent emissions originate from transportation during the core process. This is because the Cargo mailbox requires powder coating, necessitating two rounds of transportation. Despite the coating factory selected by Leimec being near the mailbox production facility, the relatively large size of the Cargo mailbox results in the need for frequent transportation.

The total acidification potential (AP) of  $0.35$  mol  $\text{H}^+$  equivalent signifies the potential environmental acidification caused by the product or process. Interestingly, the upstream phase exhibits a similar impact compared to the core phase. The Eutrophication potential (EP) of  $1.94\text{E-}02$  kg P equivalent is better than the average, indicating a lower impact on eutrophication of freshwater ecosystems. The core phase is the primary contributor. The significant total Photochemical Oxidant Creation Potential (POCP) of  $2.02\text{E-}01$  kg NMVOC equivalent implies a notable potential for creating photochemical smog. As in previous categories, the core phase is the major contributor. Photochemical oxidants (photochemical oxidizers) are a central possibility in automotive tailpipe emissions. These compounds are formed through complex chemical reactions in the presence of sunlight between volatile organic compounds (VOCs) and nitrogen oxides ( $\text{NO}_x$ ) in the emissions of automotive tailpipes and atmospheric oxygen. Due to the process requirements of the Cargo mailbox, there is a need for two transportations during production. It is recommended to choose environmentally friendly transportation methods, such as electric vehicles, whenever possible. The Abiotic Depletion Potential (ADP) of  $618$  MJ denotes the depletion of non-renewable resources, with the upstream phase contributing significantly more than the core phase. This underscores a heavy reliance on fossil resources in the upstream supply chain. Strategies to reduce ADP should include exploring sustainable sourcing options and improving resource efficiency in the upstream phases. Water scarcity potential (WDP), reflected in the WDP of  $51$  m<sup>3</sup> world equivalent deprived, is primarily associated with the upstream phase, indicating

the importance of addressing water consumption and pollution in early supply chain stages.

The most substantial environmental impact is attributed to Global Warming Potential (GWP), totaling approximately 101 kilograms of CO<sub>2</sub> equivalent. Another noteworthy impact category is Abiotic Depletion Potential (ADP), primarily stemming from fossil resource consumption, and it amounts to approximately 618 megajoules of net calorific value. This impact category underscores the critical role of resource efficiency in the production of materials. In contrast, the impact related to Acidification Potential is considerably smaller, estimated at around 0.35 moles of H<sup>+</sup> equivalent. The impact on the ozone layer is relatively minor in the case of Cargo mailboxes. Eutrophication potential is also relatively low in Cargo mailboxes. Furthermore, Cargo mailboxes exhibit minimal Photochemical Ozone Creation Potential (POCP) values. Water scarcity potential does not emerge as a dominant concern within this context.

In summary, a comprehensive review of the OpenLCA results reveals that the core stage plays a critical role in the overall environmental impact of the Bobi Cargo product. Within this core stage, the transportation process emerges as the primary contributor to this phenomenon, and transportation is largely driven by the production process requirements of the Cargo mailbox, making it an unavoidable factor. A holistic approach that involves optimizing the manufacturing process and improving transportation can significantly mitigate the environmental impact of Bobi Cargo mailbox products.

### **5.3 GWP contributions**

From the analysis in section 5.2, it is evident that the two most significant impact categories are GWP (Global Warming Potential) and ADP (Abiotic Depletion Potential), each representing different types of environmental impacts. GWP measures the contribution of an activity or product to global warming through the emissions of greenhouse gases, primarily carbon dioxide. On the other hand, ADP quantifies the consumption of non-renewable resources, such as fossil fuels. Depending on the goals of sustainability and a company's environmental values, one may lean towards either

reducing carbon emissions and addressing climate change (GWP) or focusing on preserving non-renewable resources (ADP).

The primary research focus of this thesis is to identify the principal environmental impacts throughout the entire lifecycle of mailbox products. To achieve this goal, the study strategically adopts Global Warming Potential (GWP) as the primary metric for assessment. There are several reasons for this deliberate choice. Firstly, GWP is renowned for its comprehensive nature. It goes beyond merely assessing greenhouse gas emissions and considers the intricate interplay of various environmental components. This offers a holistic understanding of the environmental consequences of the mailbox product, which is essential for guiding sustainable decision-making and product design. Secondly, GWP serves as a tangible and widely accepted benchmark. It facilitates informed decisions for eco-conscious product development and lifecycle management. This comprehensive metric aids in assessing a product's overall environmental performance, allowing for a more well-rounded evaluation. Lastly, GWP effectively resonates with both the industry and consumers. It provides a clear and tangible indicator of environmental impact, which can readily influence decision-making processes at multiple levels. From manufacturing processes to purchasing behaviors, GWP plays a pivotal role in guiding environmentally responsible choices.

Therefore, the selection of GWP as the primary environmental impact metric is not only conceptually robust but also pragmatically aligned with contemporary environmental assessment practices and corporate sustainability. It empowers this study to shed comprehensive light on the mailbox product's environmental performance, enabling the formulation of informed strategies to minimize its ecological footprint.

### **5.3.1 Bobi Classic mailbox GWP contributions**

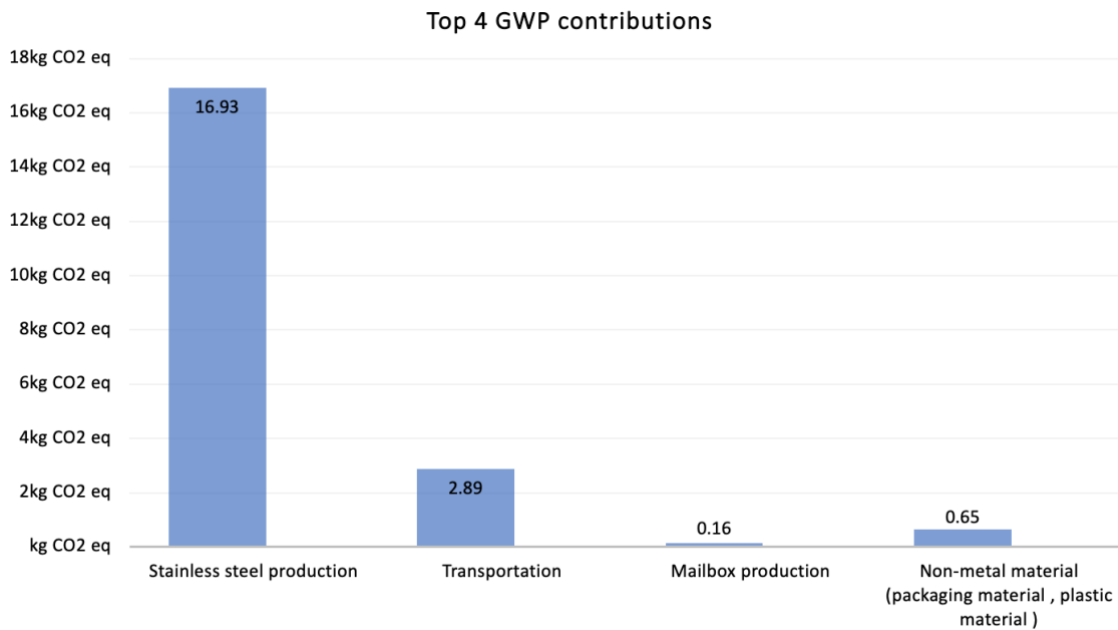
Based on the analysis results above, the principal environmental impact of the entire lifecycle of Bobi classic mailbox products is in the GWP (Global Warming Potential) category. This also addresses the main question of this study. This chapter primarily

focuses on the analysis of carbon footprint distribution at various stages within the lifecycle of mailboxes.

Table 7 display the results of GWP contributions, total Global Warming Potential (GWP) is 21.13 kg CO<sub>2</sub> equivalent. This signifies that the production of a Bobi classic mailbox results in the emission of 21.13 kilograms of carbon dioxide equivalent. This measurement encompasses not only carbon dioxide emissions but also the summation of all greenhouse gases, converted into CO<sub>2</sub> equivalents. For instance, if a specific activity emits 1 kg of methane (CH<sub>4</sub>), and methane has a GWP of 25 over a 100-year period, then the impact of that emission would be quantified as 25 kg CO<sub>2</sub> equivalent. This implies that it exerts the same warming effect as emitting 25 kilograms of carbon dioxide over a span of 100 years.

**Table 7. Classic mailbox GWP contributions**

Category	Results	Unit
Stainless steel production	16.93	kg CO <sub>2</sub> eq
Transportation	2.89	kg CO <sub>2</sub> eq
Mailbox production	0.16	kg CO <sub>2</sub> eq
Non-metal material (packaging material , plastic material )	0.65	kg CO <sub>2</sub> eq
Others	0.50	kg CO <sub>2</sub> eq
Total emission	21.13	kg CO <sub>2</sub> eq



**Figure 12. Bobi Classic mailbox Top 4 GWP contributions**

Analyzing the data presented in Table 7 and Figure 12, we can draw the following conclusions:

Stainless steel production constitutes the largest source of emissions, accounting for approximately 80.13% of the total emissions. This is primarily attributed to the energy-intensive nature of stainless-steel manufacturing. The production of one Bobi classic mailbox results in the emission of 16.93 kg of carbon dioxide equivalent from stainless steel production. Recommend exploring opportunities to optimize energy efficiency and reduce emissions in the stainless-steel production process. This may involve adopting cleaner technologies or increasing the use of renewable energy sources. Additionally, consideration should be given to sourcing stainless steel from suppliers with robust sustainable practices and lower carbon footprints.

Transportation accounts for approximately 13.67% of the total emissions, often related to the transportation of materials and products associated with mailbox production. The production of one Bobi classic mailbox results in the emission of 2.89 kg of carbon dioxide equivalent from transportation. Currently, Leimec factory selects local suppliers in Finland. From a sustainability perspective, Leimec factory has performed admirably in

its supplier selection process. Recommend optimizing transportation routes and logistics to reduce fuel consumption and emissions. This may involve using more fuel-efficient vehicles, implementing cargo consolidation, or promoting alternative transportation methods such as electric vehicles or partnering with sustainable transportation providers.

Bobi mailbox production contributes approximately 0.76% of the total emissions. The production of one Bobi classic mailbox results in the emission of 0.16 kg of carbon dioxide equivalent from the mailbox production process. This includes emissions associated with the manufacturing process but excludes transportation. This indicates that Bobi Company and Leimec factory have effectively integrated sustainability concepts into their production processes and materials, as well as reduced waste generation through recycling practices.

Non-metal materials, including packaging and plastic components, contribute around 3.08% of the total emissions. The production of one Bobi classic mailbox results in the emission of 0.65 kg of carbon dioxide equivalent from non-metal materials. We recommend selecting recyclable or biodegradable packaging materials to minimize environmental impact. Exploring alternatives to plastic materials or considering the use of recycled plastics in manufacturing should also be considered.

In summary, to mitigate the environmental impact associated with mailbox production, a comprehensive strategy is advisable. This includes adopting cleaner manufacturing processes, optimizing transportation logistics, utilizing sustainable materials, and reducing energy consumption. Collaborating with suppliers and partners committed to sustainability can also contribute to achieving these goals.

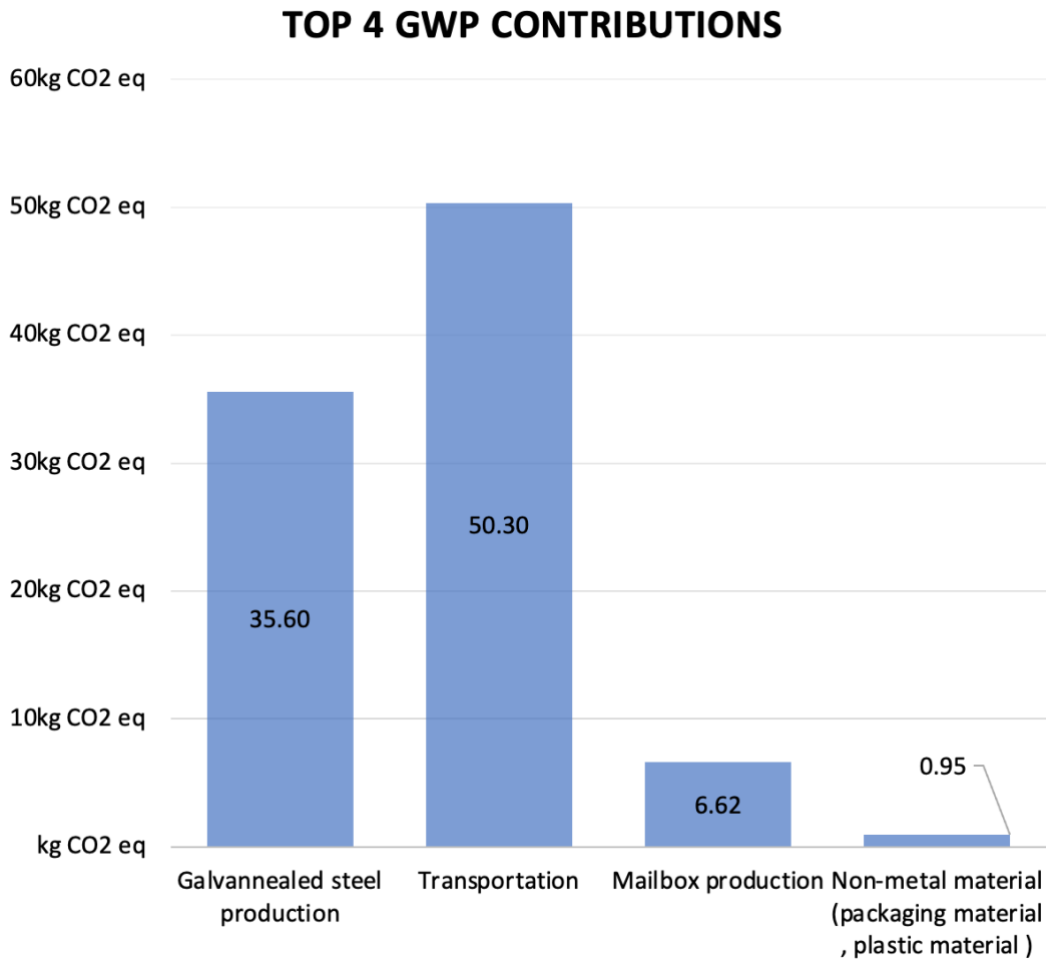
### **5.3.2 Bobi Cargo mailbox GWP contributions**

Based on the analysis results above, the principal environmental impact of the entire lifecycle of Bobi Cargo mailbox products is in the GWP (Global Warming Potential) category. This also addresses the main question of this study. This chapter primarily

focuses on the analysis of carbon footprint distribution at various stages within the lifecycle of mailboxes.

**Table 8. Cargo mailbox GWP contributions**

Category	Results	Unit
Galvannealed steel production	35.60	kg CO2 eq
Transportation	50.30	kg CO2 eq
Mailbox production	6.62	kg CO2 eq
Non-metal material (packaging material , plastic material )	0.95	kg CO2 eq
Others	7.54	kg CO2 eq
Total emission	101.01	kg CO2 eq



**Figure 13. Bobi Cargo mailbox Top 4 GWP contributions**

Analyzing the data presented in Table 8 and Figure 13, we can draw the following conclusions: within the lifecycle of a Cargo mailbox, the production phase of galvanized steel emerges as the foremost contributor to Global Warming Potential (GWP), equating to 35.6 kg of carbon dioxide equivalent. This suggests that the manufacturing of galvanized steel is the most carbon-intensive phase of the evaluated product or process. Strategies to reduce the carbon footprint in this category may involve adopting cleaner production methods or sourcing steel from more environmentally friendly suppliers. Transportation activities contribute 50.30 kg CO<sub>2</sub> equivalent to the GWP. In comparison to the Classic mailbox, the Cargo mailbox exhibits a notable increase in its carbon dioxide equivalent emissions during transportation. This disparity arises from the necessity of employing a powder coating process for painting the Cargo mailbox. The painting factory is located at 11.74 kilometers from the Leimec factory. Given the relatively large size of the Cargo mailbox and the frequency of transportation, typically involving the transportation of 96 mailboxes to the painting facility per week, optimizing transportation logistics and contemplating more energy-efficient or sustainable transport options may prove advantageous in mitigating emissions associated with this stage. Mailbox production accounts for 6.62 kg CO<sub>2</sub> equivalent. This observation suggests that the mailbox production phase does not significantly contribute to carbon dioxide equivalent emissions, constituting merely 6.56% of the entire lifecycle. While relatively small in comparison to steel production and transportation, it still represents a noteworthy contribution. Strategies to reduce emissions at this stage may involve process optimization, material selection, and waste reduction. Non-metal materials, including packaging and plastic components, contribute 0.95 kg CO<sub>2</sub> equivalent to the GWP. These materials have a relatively low impact on global warming potential. Exploring alternatives such as recyclable or biodegradable packaging materials could further reduce this impact. The total GWP for the entire product is 101.01 kg CO<sub>2</sub> equivalent. This is the sum of the contributions from all the categories. From this analysis we can see that core phase transportation is the dominant source of carbon emissions in this assessment, next is the production of galvanized steel. To reduce the overall GWP, a holistic approach may involve focusing on cleaner steel production methods,

optimizing transportation. Addressing emissions across multiple stages and components is essential for minimizing the environmental impact of the product.

## 6 Conclusions

The primary objective of this thesis is to conduct an LCA (Life Cycle Assessment) study on Bobi Company's Classic and Cargo mailboxes and, based on the results, produce an EPD (Environmental Product Declaration) report for Bobi company. The central research question guiding this study is "What are the primary environmental impacts of the entire lifecycle of mailbox products?" Secondary research questions include "How do different stages, such as raw material extraction and manufacturing, influence the overall environmental carbon footprint?" and "What potential improvement opportunities exist throughout the mailbox's lifecycle?" This investigation is carried out through a case study approach.

### 6.1 Summary of findings

Classic mailbox material composition: Stainless steel overwhelmingly dominates the material composition of Classic mailboxes, accounting for 81.35% of the total weight. Plastics and wood products constitute a relatively small proportion, at 1.15% and 17.50%, respectively.

Global Warming Potential (GWP) emerged as the most significant environmental impact category of Classic mailbox, with a total of 21.13 kg CO<sub>2</sub> equivalent. The distribution of GWP contributions is as follows:

Stainless steel production: 16.93 kg CO<sub>2</sub> eq (80.13%)

Transportation: 2.89 kg CO<sub>2</sub> eq (13.67%)

Mailbox production: 0.16 kg CO<sub>2</sub> eq (0.76%)

Non-metal materials: 0.65 kg CO<sub>2</sub> eq (3.08%)

Others: 0.5 kg CO<sub>2</sub> eq (2.36%)

Cargo mailbox material composition: Galvannealed steel is the predominant material in Cargo mailboxes, constituting 79.63% of the total weight. Packaging materials and plastic components represent 19.48% and 0.88%, respectively.

Global Warming Potential (GWP) is the paramount environmental impact category of Cargo mailbox, with a total of 101.01 kg CO<sub>2</sub> equivalent. The breakdown of GWP contributions is as follows:

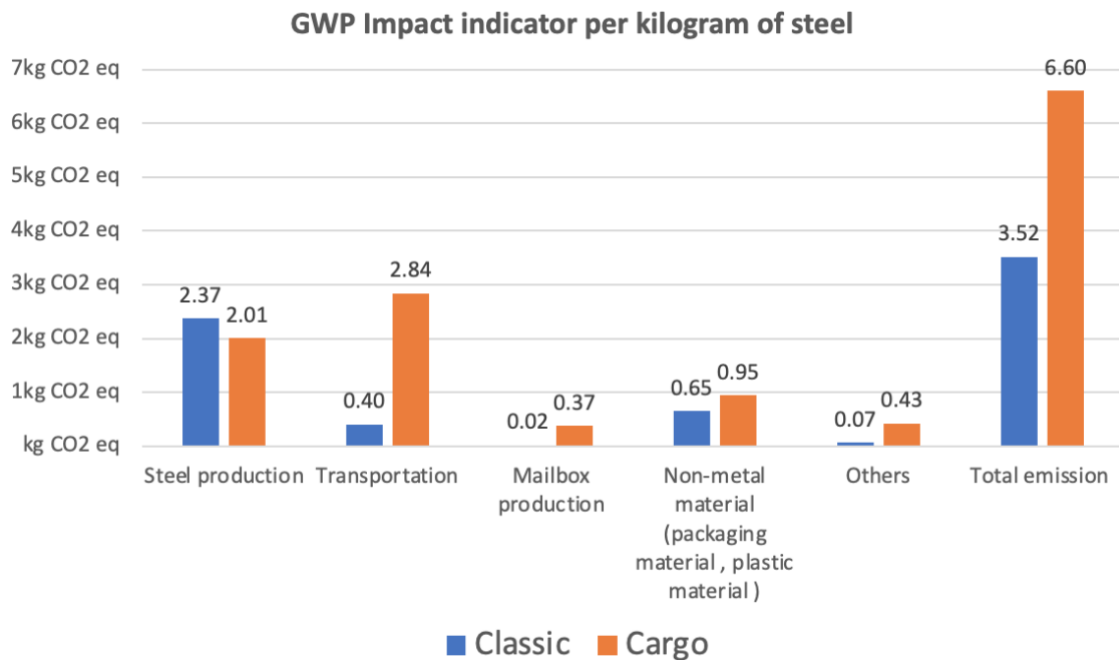
Galvanized steel production: 35.6kg CO<sub>2</sub> eq (59.70%)

Transportation: 50.30kg CO<sub>2</sub> eq (34.73%)

Mailbox production: 6.62kg CO<sub>2</sub> eq (4.57%)

Non-metal materials: 0.95 kg CO<sub>2</sub> eq (0.66%)

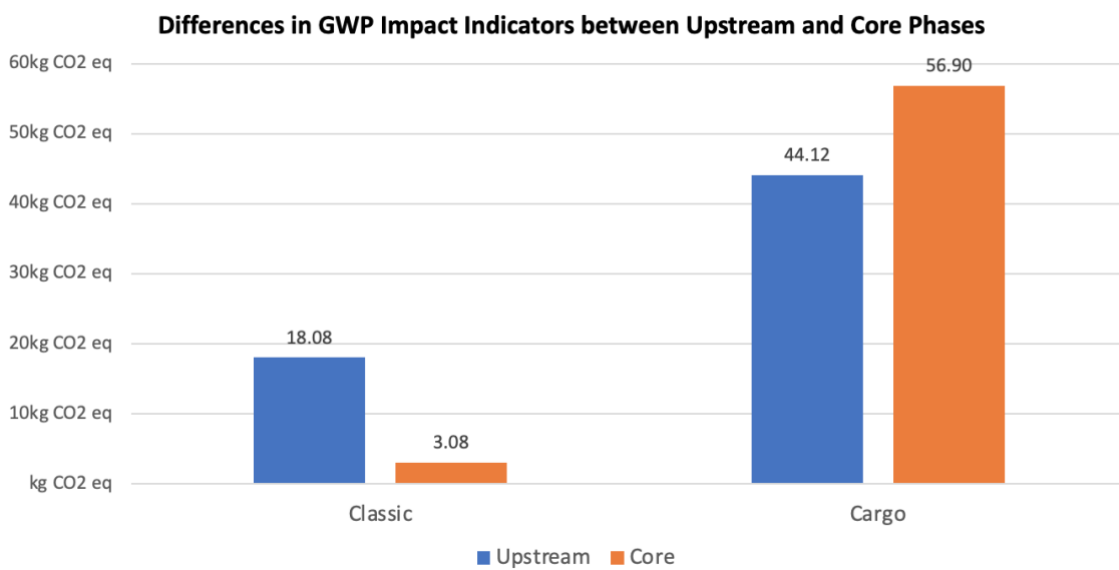
Others: 7.54 kg CO<sub>2</sub> eq (0.34%)



**Figure 14. GWP impact indicator per kilogram of steel**

Based on the data provided by the Figure14 illustrating emission indicators per kilogram of steel for both Classic and Cargo mailboxes, we can discern noteworthy distinctions in the environmental impacts of these two mailbox types when considering emissions per kilogram of steel. For Classic mailboxes, each kilogram of steel produced corresponds to approximately 2.37 kilograms of carbon dioxide equivalent emissions. In contrast, Cargo mailboxes exhibit slightly lower emissions, with approximately 2.01 kilograms of carbon dioxide equivalent emissions per kilogram of steel. When looking at the steel production

phase, galvanized steel generates fewer greenhouse gases than stainless steel. However, due to the need for an additional surface painting process for galvanized steel, stainless steel products are generally more environmentally friendly. From this analysis, it becomes apparent that, when comparing Classic and Cargo mailboxes, the use of one kilogram of steel results in higher overall emissions for Cargo mailboxes. Notably, the most significant disparity arises during the transportation phase.



**Figure 15. Differences in GWP impact indicators between Upstream and Core Phases**

Figure 15 provides a visual representation of the disparities in Global Warming Potential (GWP) impact indicators between the upstream and core phases for Classic and Cargo mailboxes. The insights gleaned from this chart shed light on how these impacts evolve throughout the entire lifecycle of mailbox products.

For Classic mailboxes, the decline in GWP values as we transition from the upstream to the core phase indicates that the manufacturing and operational processes have a relatively minor influence on global warming compared to the initial stages of raw material extraction and transportation. In contrast, the trend for Cargo mailboxes differs, with a noteworthy increase in GWP from the upstream to the core phase. This

points to a significant contribution of the core manufacturing and operational phase to the product's Global Warming Potential.

In summary, this chart underscores the contrasting environmental impacts between the upstream and core phases of these two mailbox product types and highlights the importance of understanding how various stages of their lifecycle affect their environmental footprint. These insights can be invaluable for optimizing processes and reducing their global warming impact.

A comprehensive review of the OpenLCA results reveals that the core stage plays a critical role in the overall environmental impact of the Bobi Cargo product. This is mainly due to the additional powder coating process in the case of the Cargo mailbox, which requires transportation to another facility for painting. Although the painting facility is only 11.74 km away from the Leimec factory where the mailboxes are produced, the larger volume of the Cargo mailbox after processing necessitates frequent transportation. Addressing this issue involves focusing on two key areas of improvement. Firstly, process optimization is essential, requiring a thorough reevaluation of the manufacturing process of the Cargo mailbox with the goal of reducing its environmental impact. This could encompass the adoption of more environmentally friendly production methods, the optimization of existing manufacturing processes, and the embrace of sustainable production practices aimed at enhancing the environmental performance at the core manufacturing stage. Secondly, there is a need for transportation improvement. Transportation is identified as the primary driver of environmental impact during the core stage of the product's lifecycle. As a result, various measures to mitigate the carbon footprint of transportation can be explored, including optimizing transportation routes, deploying more fuel-efficient vehicles, implementing cargo consolidation, and considering sustainable transportation methods such as electric vehicles or establishing partnerships with sustainable transportation providers. These efforts are expected to lead to significant reductions in the environmental impact during the core stage, specifically in terms of global warming potential.

In both scenarios, it is evident that the production of stainless steel is more environmentally friendly than galvanized steel, and the secondary painting of galvanized steel significantly increases the carbon footprint of the mailbox. Transportation also plays a significant role. These findings underscore that an overall approach involving the optimization of manufacturing processes and improvements in transportation can significantly reduce the environmental impact of Bobi Cargo mailbox products.

Therefore, in conclusion, a holistic approach that involves optimizing the manufacturing process and improving transportation can significantly mitigate the environmental impact of Bobi Cargo mailbox products. These actions will contribute to enhancing the product's sustainability, reducing its carbon footprint, and aligning it more closely with environmental standards and sustainability goals. This LCA study not only lays the foundation for creating an Environmental Product Declaration (EPD) report for Bobi Company but also provides valuable insights into enhancing the environmental sustainability of mailbox production.

## **6.2 Discussion**

The environmental impact assessment of both the Classic and Cargo mailboxes is scrutinized. The primary focus is on Global Warming Potential (GWP) and how it correlates with different stages of the product lifecycle. An analysis of Classic mailbox GWP contributions at different stages revealed that a substantial portion of greenhouse gas emissions occurs during the upstream stages, such as raw material extraction and transportation. Notably, the core manufacturing stage exhibited minimal pollution and energy consumption, underscoring effective environmental management within the manufacturing domain.

A comprehensive review of the OpenLCA results reveals that the core stage plays a critical role in the overall environmental impact of the Bobi Cargo product. This is mainly due to the additional powder coating process in the case of the Cargo mailbox, which requires transportation to another facility for painting. Although the painting facility is

only 11.74 km away from the Leimec factory where the mailboxes are produced, the larger volume of the Cargo mailbox after processing necessitates frequent transportation. To address this issue, a multifaceted approach is recommended. Firstly, from a design standpoint, it is crucial to minimize the dependence on painting processes, thus reducing the associated environmental impact. Secondly, considering the manufacturing process, the establishment of a small, on-site paint workshop within the Leimec factory could prove advantageous by eliminating the requirement for external transportation. Finally, when it comes to transportation, adopting eco-friendly alternatives such as electric or natural gas and biogas trucks is advisable. Furthermore, the consolidation of products for fewer transportation trips can significantly decrease transportation frequency, further contributing to the overall eco-friendliness of the production process. These strategies collectively ensure a more sustainable approach to mailbox production, aligning with environmental preservation and resource efficiency objectives. In both scenarios, it is evident that the production of stainless steel is more environmentally friendly than galvanized steel, and the secondary painting of galvanized steel significantly increases the carbon footprint of the mailbox. Transportation also plays a significant role. These findings underscore that an overall approach involving the optimization of manufacturing processes and improvements in transportation can significantly reduce the environmental impact of Bobi Cargo mailbox products. These actions will contribute to enhancing the product's sustainability, reducing its carbon footprint, and aligning it more closely with environmental standards and sustainability goals.

From a managerial perspective, this research accentuates the critical role of environmental sustainability in contemporary business practices. It underscores the importance of proactive measures to mitigate environmental impacts, enhance transparency, and meet the growing demand for eco-conscious products. Ultimately, this study not only lays the foundation for the creation of an Environmental Product Declaration (EPD) report for Bobi Company but also contributes to the broader discourse on sustainable business practices in an increasingly environmentally conscious world, allowing Bobi Company to enhance its strategic planning and showcase brand

value more effectively. Moreover, the interpretation of the results and the recommendations offered provide valuable insights for the product development process. Lastly, this thesis makes a valuable contribution to the domain of Metal Sheet series products, given the limited availability of lifecycle assessment research on such products at present.

### **6.3 Conclusions**

This study has made a significant contribution to our understanding of the environmental footprint of Bobi Company's Classic and Cargo mailboxes. The research findings underscore the crucial roles played by different product stages, both upstream and core stages, in terms of environmental impacts. It emphasizes the need to prioritize early-stage material selection and supplier choices, as well as process and transportation optimization in the context of sustainability.

Bobi Company's Classic mailbox product demonstrates excellent performance, with stainless steel production being the primary source of carbon emissions for the Classic mailbox. The optimization of the core production stage of Classic mailboxes has been highly successful in minimizing unnecessary emissions. Due to Cargo mailbox differences in raw materials and an additional painting process, has made the core production stage the primary source of carbon emissions. Bobi Company can make improvements in subsequent design and production by optimizing processes and transportation. Although galvanized steel production is not the main source of carbon emissions for Cargo mailboxes, there is still room for improvement. This includes exploring cleaner steel production methods, optimizing transportation logistics, adopting renewable energy sources, and considering alternative coating materials.

This study emphasizes the necessity of comprehensively understanding the environmental impacts throughout the entire lifecycle of a product. It has revealed that factors perhaps overlooked, such as transportation and material choices, play a significant role in determining a product's environmental footprint. The research

demonstrates the substantial influence of the core manufacturing and operational stages on a product's overall environmental impact. Identifying opportunities for improvement within these core phases is vital for reducing emissions. The role of transportation in a product's lifecycle cannot be understated. This research reveals that efficient transportation methods and eco-friendly logistics are key to minimizing a product's carbon footprint. The thesis provides insights into concrete strategies to reduce the environmental footprint of mailbox products, showcasing the need for ongoing efforts to make products more sustainable and ecologically responsible.

Bobi Company strives to make sustainability and environmental responsibility their mission and core values. This commitment should be deeply ingrained in the company's day-to-day operational decisions. The analysis of Classic and Cargo mailboxes underscores that Bobi Company effectively manages carbon emissions, particularly during the core production and operational phases of its mailboxes. However, in the case of Cargo mailboxes, certain processes such as painting, and transportation are intrinsic to the product's lifecycle but offer room for optimization in future mailbox designs and transportation choices. Thus, addressing the environmental impact of transportation should be prioritized. To further this commitment, Bobi Company should explore sustainable transportation options, including electric vehicles and other low-carbon methods. Additionally, the company should maintain transparency and openly communicate its environmental initiatives to customers. Implementing an Environmental Product Declaration (EPD) can effectively demonstrate the company's dedication to environmentally friendly products.

The insights gained from this study should be integrated into Bobi Company's strategic planning. The company can develop sustainable development strategies that align with environmental standards and cater to customer expectations. With an increasing environmental consciousness, Bobi Company is well-prepared to utilize these findings to continue its commitment to producing more environmentally friendly, sustainable, and responsible mailbox products. This study enriches the knowledge base within the

manufacturing industry concerning lifecycle assessments and sustainability. Its underscores the importance of rigorous evaluations to guide decision-making and drive positive change. As industries worldwide seek to minimize their environmental impact, the insights generated here provide a roadmap for sustainable practices and offer a blueprint for future research on eco-friendly manufacturing.

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