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Sustainable Product Lifecycle in Critical Power Solutions

Recommendations and an action plan for reducing
the CO₂ footprint in the product lifecycle

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Foreword

Firstly, I thank my company and dear team for this development opportunity and their support throughout this busy work environment. Special thanks to my company instructor Juha Ulvinen, who mentored me from the beginning to the end, the product management team, and all my colleagues who gave their input and spared their time for this study.

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Abstract

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This thesis identifies CO2 footprint sources throughout the product lifecycle and develops recommendations to reduce the CO2 footprint in the product lifecycle. The study analyzes carbon footprint sources in manufacturing, packaging, distribution, use, and end-of-life phases for the selected product. The case company operates in a market where product carbon footprint numbers must be low, and sustaining environmental product declarations is crucial.

The study contains good practices of CO2 footprint source identification in literature, which were utilized to design a conceptual framework to map CO2 footprint identification. Based on the conceptual framework, product lifecycle stages are analyzed in the current state analysis to summarize CO2 sources and weights of the product. After highlighting the main contributors to the CO2 footprint, an initial proposal was developed and presented to decision-makers and key stakeholders. After receiving feedback, the final proposal was developed following validated recommendations and action plans, focusing on the manufacturing and use phases.

By following these recommendations, the study aims to significantly reduce the CO2 footprint throughout the product lifecycle. The study contributes to a broad understanding of CO2 footprint reduction and provides an overview for future development and best practice sharing within the company.

In addition, the latest section contains discussion and conclusion, where an executive summary and credibility evaluation are presented.

Keywords: CO2 Footprint, Product lifecycle, lifecycle assessment, UPS

List of Abbreviations

CO₂: Carbon Dioxide

UPS: Uninterruptible Power Supply

UPM : Uninterruptible power modules

EMEA: Europe, the Middle East and Africa

SiC: Silicon Carbide

ESS: Energy Saver System

PEP: Product Environmental Profile

LCI: Life Cycle Inventory

GHG: Greenhouse Gas

IO: Input-Output

LCA: Lifecycle Assessment

IO-LCA: Input-Output + Lifecycle Assessment

IPCC: Intergovernmental Panel on Climate Change

EFDB: Emission Factor Database

CCS: Carbon Capture and Storage

WEEE: Waste Electrical and Electronic Equipment

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1 Introduction

In this thesis, CO2 footprint sources throughout the product lifecycle are identified, and recommendations to reduce the CO2 footprint are developed within the case company. The study identifies carbon footprint sources in manufacturing, packaging, distribution, use of the final goods, and end-of-life phases of the products. By utilizing this identification, the CO2 footprint is analysed for the selected product family in the company's portfolio, and recommendations on how to reduce them are proposed.

The CO2 footprint level is critical in the market where the case company operates since key customers require product carbon footprint data to achieve their goals of becoming carbon neutral. Due to new prerequisites for the customer offering, environmental product declarations are needed.

With the product CO2 footprint source identification, the case company can detect lifecycle steps that increase the overall carbon footprint of the product and can take actions to reduce the footprint based on the proposed action plan.

1.1 Business Context

The case company is an intelligent power management company with more than 95,000 employees worldwide. It operates in more than 170 countries with annual sales of over \$23.2 billion USD (2023 sales). In electrification, energy transition, and connectivity, the company solves customers' challenges in electrical, hydraulic, and mechanical power management.

With the aim of manufacturing excellence and innovative solutions, the company provides clean, safe, and reliable power for critical applications in various markets such as power distribution, power quality, life safety, control and automation, aerospace, vehicle, filtration, and mobility.

Regarding the operations of the case company in Finland, it has a centre of excellence for UPS (Uninterruptible Power Supply) since 1962. By manufacturing three-phase UPS, it serves the EMEA (Europe, the Middle East, and Africa) market by solving the most critical challenges in backup power protection.

In the Finland facility, the company has complete support functions for customer testing, application engineering, project engineering, and technical support, besides operational functions such as manufacturing and supply chain. In addition, R&D, product marketing, business development, finance, marketing, and sales functions are also located in the same location.

All these functions form the case company's Critical Power Solutions business unit. The unit has standard offerings as well as customized solutions for specific customer needs. It provides manufacturing of UPS, marketing of the products, technology development, customer support, and selling activities to the region.

Critical Power Solutions (CPS) is under the Critical Systems (CS) branch of the Electrical business, which contains CPS, ESS (Electrical Solutions & Services), LS (Life Safety), and DPQ (Distributed Power Quality).

1.2 Business Challenge, Objective and Outcome.

Due to corporate-level sustainability targets, which include reducing carbon emissions in operations, lowering product and supply chain emissions, certifying all manufacturing sites as zero waste to landfill and carbon-neutral operations, reducing the product lifecycle CO₂ footprint is a crucial goal for the CPS business unit in Finland. Additionally, key customers' sustainability targets and market needs mean that a reduced carbon footprint plays a critical role in sustaining the product offering.

In the CPS business, product lifecycle assessments to analyse each stage's environmental impact holistically and environmental product declarations have become prerequisites because of the points mentioned above.

The objective of this thesis is to develop recommendations and an action plan for reducing the CO₂ footprint in the product lifecycle. Pinpointing high carbon footprint steps throughout the lifecycle and choosing focus areas to develop improvement ideas is the main part of the study.

The outcome of the thesis is recommendations and an action plan to reduce the case company's CO₂ footprint in the product lifecycle. These key actions can serve the CPS Business Unit to fulfil the sustainability requirements of corporate strategy and market standards.

1.3 Scope and Outline of Thesis Report

The study contains six sections, starting with Section 1, Introduction. In Section 2, data collection, analysis methods, and research design are covered.

In Section 3, good practices of product lifecycle CO₂ footprint source identification in the literature are presented. In Section 4, the current state of the company's CO₂ footprint, the metrics, how the company utilizes regulations, and pinpointing the areas with the most CO₂ weight in the overall CO₂ values are covered. Then, Section 5 proposes development ideas to reduce the CO₂ footprint by giving an overview of actions to reduce the CO₂ footprint.

Finally, in Section 6, the reviewed and updated final proposal is presented to be used in the organization. It summarizes the study and brings the conclusion on improvement recommendations to reduce the CO₂ footprint in the product lifecycle.

In the next section, project plan that is used in this study is covered.

2 Project Plan

This section introduces the research approach, research design, and data plan of the study. The research approach describes the chosen method for the study. The research design explains the detailed plan, including an illustrative table. Lastly, the section provides a description of data collection for the study.

2.1 Research Approach

After developing a research problem, an approach and methodologies are required to frame the methods of a solution or proposal. The definition of research is followed by a selection of methods required for solving the problem.

The subject of the study is to understand a phenomenon and often aims to have a positive impact. A broad approach to the subject of the study is research methodology, which includes data gathering, analysis, and interpretation methods (Kananen, 2013, p. 27).

In design research, the researcher must rely on qualitative and quantitative research and their methodologies. Through qualitative research, the researcher generates theories from practice, while through quantitative research, practice is developed from theory (Kananen, 2013, pp. 28-29).

Qualitative research is more suitable for problems where the researcher has less information or when the phenomenon is new as an object of research. When the goal is to get a more detailed view on the topic rather than analyzing mostly countable variables, unlike quantitative research. Qualitative research uses words and sentences, whereas quantitative research is based on numbers (Kananen, 2013, pp. 31-34).

Additionally, there is no exact methodological framework when conducting qualitative research, unlike quantitative research. There are fewer strict rules for qualitative research as it's more flexible in the early stages of the process. Interpretation, developed suggestions, and results depend on the researcher. Following these points, qualitative research is used more in the business environment (Kananen, 2013, p. 32).

One of the main reasons why qualitative research is more common is that interview questions, workshops, and discussions are more open. On the other hand, quantitative research is more structured and stricter in generating countable analysis.

This study utilizes qualitative research due to its context and design research approach, which suits the need for process improvement in the product lifecycle as a topic of the research. Since the purpose of the study is to propose a change, the researcher is not an active actor but an external participant, and research questions are based mainly on open questions.

Additionally, documentation of the development ideas using scientific methods is required to generate new information on the problem.

2.2 Research Design

The research design (project plan), which contains each execution stage, how the study stages are planned, and their outputs, is shown below.

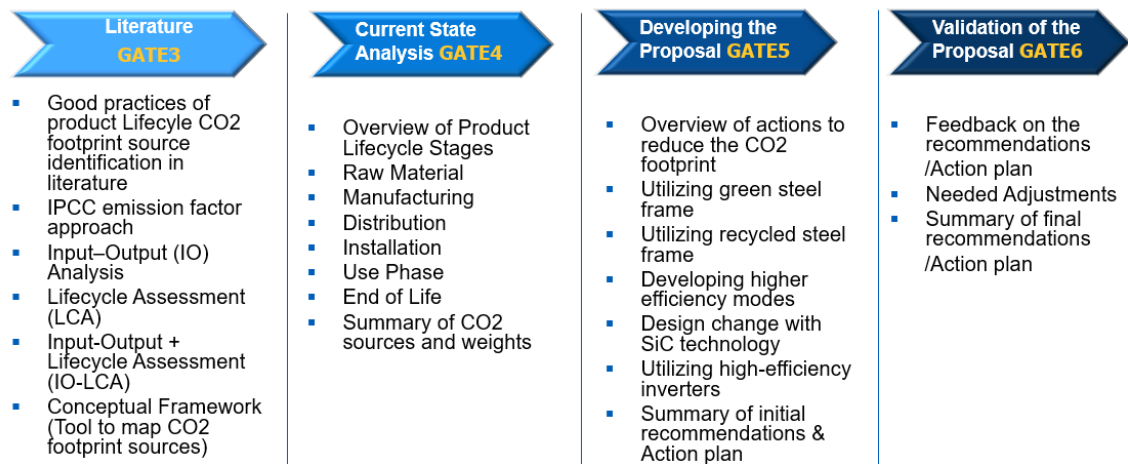


Figure 1. Research design

As seen in Figure 1, four execution stages form the complete research design of the study, which includes three data stages for current state analysis, proposal, and validation of the proposal. As the objective of the study is to develop recommendations and an action plan for reducing the CO2 footprint in the product lifecycle for the case company, the first step is the literature review of good practices for CO2 footprint identification. By implementing this stage, possible practices are analyzed, and the conceptual framework for mapping CO2 footprint sources is the output.

The second step is the current state analysis, which maps product lifecycle stages to identify carbon footprint sources and summarize CO2 sources and their weights. By applying this practice, high contributor steps are highlighted. Additionally, the conceptual framework from the previous stage is used in the analysis.

The next stage is developing the proposal, which includes recommendations on how to reduce the CO2 footprint in the product lifecycle steps that were

pinpointed as high contributors in the current state analysis. Multiple action items are listed on how to reduce the footprint. As an outcome, a summary of initial recommendations and an action plan are proposed.

Finally, the summary of recommendations and the action plan are presented to the decision-makers and all relevant stakeholders, including the sustaining team, R&D team, and product management team. At this stage, feedback from the mentioned teams is collected, and necessary adjustments to the action plan are made. Then, the final version of the proposal is demonstrated.

2.3 Data Plan

In this study, various data sources are used in different stages of the research plan. Three different data collection activities are followed as detailed in Table 1.

Table 1. Data plan 1-3

	CONTENT	SOURCE	INFORMANT	TIMING	OUTCOME
DATA 1 Current State Analysis	Overview of Product Lifecycle Stages -Raw Material -Manufacturing -Distribution -Installation -Use Phase -End of Life	Sustainability related work processes LCA (Lifecycle Assessments) / EcoPassports Mutual workshop for PM and Sustaining team	R&D Engineer 1 R&D Engineer 2 Sustaining Team Manager Product Manager 1	12/2024 - 02/2025	Summary of CO2 sources and weights
DATA 2 DEVELOPING PROPOSAL	Developing recommendations on how to reduce the CO2 footprint in the product lifecycle -Utilizing green steel frame -Utilizing recycled steel frame -Developing higher efficiency modes -Design change with SiC technology -Utilizing high-efficiency inverters	Summary of CO2 Sources and weights	Sustaining Team Technology Manager Product Manager 1	02/2025 -03/2025	Summary of initial recommendations & Action plan
DATA 3 VALIDATION OF THE PROPOSAL	Feedback on the recommendations/action plan	Feedbacks from related teams	Decision maker(Sustaining team manager)	03/2025- 05/2025	Summary of final recommendations & Action plan

As seen above, the study contains three different data sources at different stages of the project plan. In the current state analysis, sustainability-related process documents, product lifecycle assessments, and workshop sessions with the product management and sustaining team are the collected sources of data 1. By utilizing these sources, carbon footprint sources in different lifecycle stages are analyzed. The outcome is a summary of CO₂ footprint sources and their weights in the overall value.

In data 2, the data source is utilized on developing recommendations on how to reduce CO₂ footprint in the product lifecycle. The summary of CO₂ weights is used to highlight high footprint stages, then action items to reduce them are listed. As a result of data 2, summary of initial recommendations and actions is set.

Lastly in data 3, initial action plan is presented to decision maker and the relevant teams to collect all feedback and to validate the proposal.

Table 2. Details of data collection Data 1

Participants/ Role	Data type	Topic, description	Date, length	Documented as
R&D Engineer 1	Face to face interview	-Understanding current sustainability related work processes	08.01.2025 60 min	Field notes & Recording
		-Going through Lifecycle Assesment and framing how to summarize co2 sources and their weights		
R&D Engineer 2	Face to face interview	-Discussing their view and the possible approaches	10.01.2025 60 min	Field notes & Recording
		-Collecting their expectations		
Sustaning Team Manager	Face to face interview	-Understanding current sustainability related work processes	13.01.2025 60 min	Field notes & Recording
		-Going through Lifecycle Assesment and framing how to summarize co2 sources and their weights		
Product Manager 1	Face to face interview	-Discussing their view and the possible approaches	15.01.2025 60 min	Field notes & Recording
		-Collecting their expectations		
		-On higher level, what is currently missing and how we can improve our lifecycle assesments, is it doable to have impact on reducing the footprint after pinpointing the high contributor stages		
		-Discussing their view and the possible approaches		
		-Collecting their expectations		
		-how we can leverage lower CO2 footprint?		
		-which product management activities are part of sustainability/co2 field and what can be done differently		

In table 2 above, data 1 sources are shown under the current state analysis. By having face-to-face interviews with R&D engineers, current exercises on CO2 footprint on products, and the execution of lifecycle assessments are discussed. Their views on how to identify the carbon source are analysed to utilize these outputs in the conceptual framework. With the sustaining team manager, who is the key actor in the study objective, the improvement areas in the identification

of the CO2 source, the feasibility of the areas the study can impact, and the high-level sustainability topics are discussed. Finally with the product manager, PM activities for sustainability topic are discussed to understand how we can leverage a lower CO2 footprint as part of the outcome of the study.

Table 3. Details of data collection Data 2

Participants/ Role	Data type	Topic, description	Date, length	Documented as
Sustaining Team	Workshop	<ul style="list-style-type: none"> -Discussion on lifecycle stages and their CO2 weight. Details on the stages and possible actions to reduce them. -Mapping the other stakeholders that can contribute on action items 	07.02.2025 90 min	Field notes, board notes and charts
Technology Manager	Workshop	<ul style="list-style-type: none"> -Discussion on lifecycle stages and their CO2 weight. Details on the stages and possible actions to reduce them. -Mapping the other stakeholders that can contribute on action items 	07.02.2025 90 min	Field notes, board notes and charts
Product Manager	Workshop, Face to Face interview	<ul style="list-style-type: none"> -Discussion on lifecycle stages and their CO2 weight. Details on the stages and possible actions to reduce them. -Mapping the other stakeholders that can contribute on action items -Understanding product management's global view and discussion on global level support possibilities on the action plan 	13.02.2025 90 min	Field notes, board notes and charts, recording

As the development proposal data source, data 2 table is shown above. A workshop with sustaining team, technology manager and product manager is organized. The main goal is to discuss the product lifecycle stages that contribute to a higher portion of the overall CO2 emissions and what type of

actions can be taken to reduce the contribution. To achieve that, more stakeholders' input, and actions are needed, such as supply chain, warehouse, manufacturing, and services. During this workshop, key people in these fields are identified, and the next steps are outlined. Together with the product manager, global product line activities and possible support functions at the global level are analyzed.

Table 4. Details of data collection Data 3

Participants/Role	Data type	Topic, description	Date, length	Documented as
Sustaining Team	Group Interview/ Final Presentation	-Validation, evaluation of the proposal	07.04.2025 60 min	Field notes, board notes and charts
Product Management	Group Interview/ Final Presentation	-Validation, evaluation of the proposal	07.04.2025 60 min	Field notes, board notes and charts

As the final data collection, Table 4 is the source for the validation of the proposal stage of the research plan. Initial recommendations and the action plan are presented in a group interview that includes the sustaining team and the product management team. Each action item is validated, and adjustment needs are collected in a face-to-face final presentation.

In the following section, good practices of product lifecycle CO2 Footprint source identification in the literature are analysed. Different identification approaches are presented, and the conceptual framework of mapping CO2 footprint source is presented as an outcome.

3 Good practice of product Lifecycle CO2 footprint source identification in literature

In this section, good practices of product lifecycle CO2 footprint source identification are analysed, compared and utilized to create conceptual framework. First approach is IPCC emission factor that calculates carbon emissions from different activities using standardized emission factors. It utilizes a straightforward calculation method; it doesn't account for the specific conditions of an individual region (Sheng et al, 2025).

The second way of analysing the CO2 source is Input–Output (IO) Analysis. Mostly national-level studies utilize a top-down input-output (IO) analysis approach (Gao, Liu and Wang, 2013). It evaluates transactions between activities in monetary terms and translates them to environmental metrics, such as greenhouse gas (GHG) emissions, to estimate carbon footprints across different scales (Caro, 2019).

The third approach of CO2 source identification is Lifecycle Assessment (LCA) which is preferred in consumer product CO2 analysis with bottom-up analysis (Gao, Liu and Wang, 2013). It is the primary method used for evaluating the carbon footprint of products. LCA encompasses all phases of a product's life cycle, including raw material extraction, production, usage, and disposal (Huppel and Curran 2012).

Lastly, Input-Output + Lifecycle Assessment (IO-LCA) combined practice is used to analyze CO2 footprint source identification. The strengths of both Lifecycle Assessment (LCA) and Input-Output Analysis (IOA) are currently a significant focus of research. Integrated economic input-output models with environmental data are utilized to evaluate the carbon footprint of products (Gao, Liu and Wang, 2013). This approach is beneficial to monitor total emissions throughout the entire supply chain (Matthews, Weber and Hendrickson, 2008).

<p>IPCC emission factor approach</p> <ul style="list-style-type: none"> - Estimates carbon emissions from various activities by employing standardized emission factors (Sheng,2025) - Simple calculation process, not considering the unique circumstances of specific regions (Sheng,2025) 	<p>Input–Output (IO) Analysis</p> <ul style="list-style-type: none"> - Studies at the national level would apply top-down IO analysis (Gao,2014) - Measures transactions between activities in monetary units and extends them to environmental levels, such as GHG emissions, to estimate carbon footprints at various scales.(Caro,2019) 	<p>Lifecycle Assessment (LCA)</p> <ul style="list-style-type: none"> - Consumer products prefer bottom-up LCA (Gao,2014) - LCA analysis is the major method for project carbon footprint evaluation(Huppes,2012) - All stages of a product's life cycle, from raw material extraction, production, and use, to disposal (Huppes,2012) 	<p>Input-Output + Lifecycle Assessment (IO-LCA)</p> <ul style="list-style-type: none"> - Strength of both LCA and IOA are an active area of research (Gao,2014) - Available to track total emissions across the entire supply chain(Scoot,2008) - Combined economic IO models with environmental data to assess the carbon footprint of products(Gao,2014)
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Figure 2. Practices for Product Lifecycle CO2 footprint Source Identification

3.1 IPCC emission factor approach

The IPCC Emission Factor Approach is used to estimate CO2 emissions, especially from burning fossil fuels. This method is included in the guidelines set by the Intergovernmental Panel on Climate Change (IPCC) for national greenhouse gas inventories, including CO2 emissions (Eggleston,2006).

The data is collected from national fuel production, imports, exports, and stock changes. The collected data and results are reported in the International Energy Agency (IEA) conventions. This method provides top-down estimation of CO2 emissions and serves as an independent check compared to more detailed bottom-up sectoral approaches. (Eggleston,2006).

Companies utilize the IPCC Emission Factor Database (EFDB) to identify suitable emission factors for their activities. These factors measure the amount of CO2 released per unit of activity (e.g., per ton of fuel burned) and are based on IPCC guidelines, research, and industry studies. The collected activity data is multiplied by the selected emission factors to estimate the total CO2 emissions. As an example, if a company knows how much diesel fuel is

consumed, it can use the emission factor for diesel combustion to calculate the resulting CO₂ emissions (Couwenberg, 2011).

The calculated emissions are then reported in the company's greenhouse gas inventory. This inventory is verified by third parties to ensure accuracy and compliance with reporting standards. By using IPCC emission factors, companies create reliable and standardized CO₂ emission inventories, that are important to track progress towards sustainability goals and complying with regulatory requirements (Sheng et al ,2025)

As an example, analysis for CO₂ capture and storage based on IPCC 2006 guidelines, schematic representation of the carbon capture and storage process are shown below.

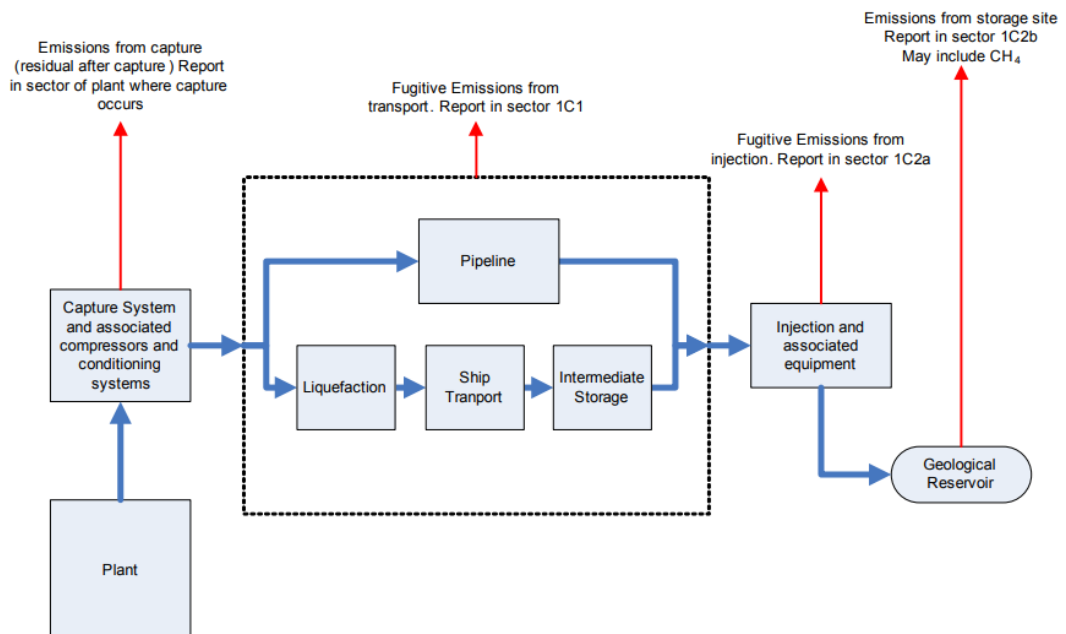


Figure 3. Schematic representation of the carbon capture and storage process (adapted from Eggleston, 2006, IPCC Guidelines for National Greenhouse Gas Inventories)

CO₂ emissions which can be captured originated from fuel combustion in large stationary plants and many industrial processes such as cement manufacturing, natural gas processing, and hydrogen production.

Technology typically captures between 85% and 95% of carbon dioxide in a capture facility. The capturing process involves compression and conditioning before transportation. Thanks to these practices, high-pressure concentrated CO₂ stream is captured.

Capturing CO₂ can cause two sources of emissions, increased energy consumption and inefficiencies in the capture process. Emissions from the plant can be estimated based on uncaptured emissions and the amount captured. (Eggleston, 2006)

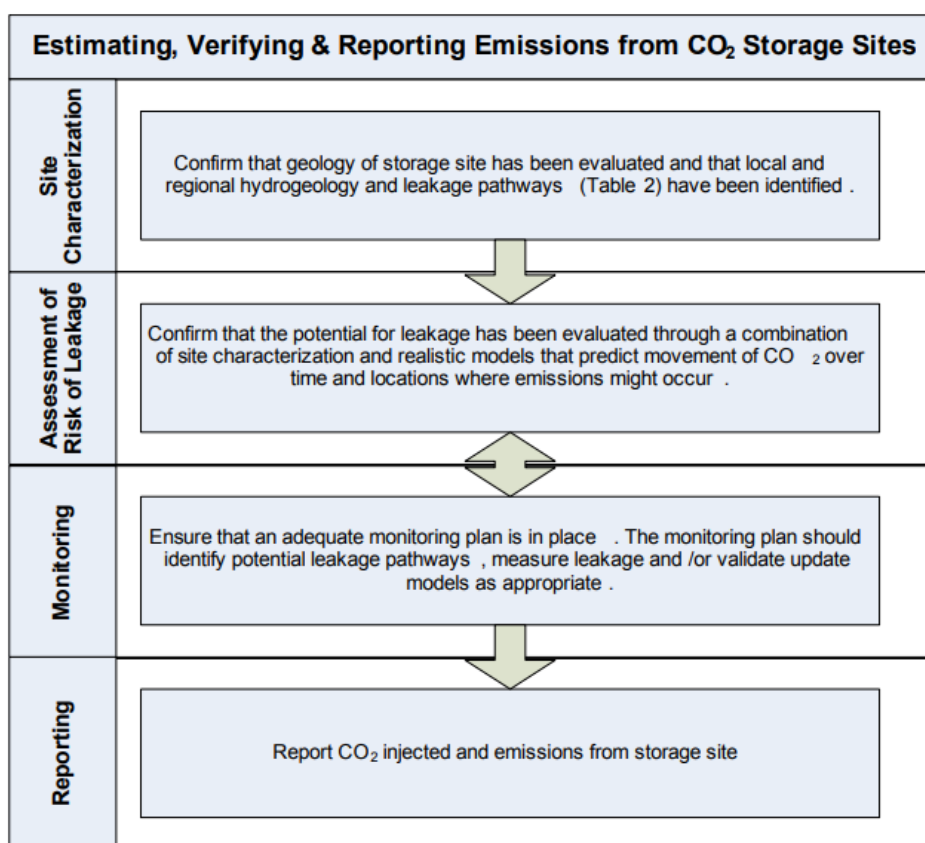


Figure 4. Procedures for estimating emissions from CO₂ storage sites (adapted from Eggleston, 2006, IPCC Guidelines for National Greenhouse Gas Inventories)

Reservoir simulations, along with additional numerical modeling techniques are utilized to forecast the location, timing, and flux of emissions. These forecasts should be frequently validated using direct monitoring methods. Numerical simulations must be confirmed with direct measurements from the storage site. These measurements should be part of the monitoring program, and comparisons between monitoring results and forecasts should be used to clarify numerical models (Eggleston, 2006).

Additionally, expert opinions are important to analyze if the numerical models accurately represent the storage site and surrounding strata, and if simulations provide reliable predictions of site performance (Eggleston, 2006).

Monitoring should be managed at leakage locations predicted by the models. Site managers are commonly responsible for installing and operating CO₂ storage monitoring technologies. Regulatory authorities and inventory compilers need to be sure that they have sufficient information from each storage site to analyze annual emissions. To facilitate this analysis, there should be a formal arrangement with each site operator for annual reporting, review, and verification of site-specific data. Since carbon capture and storage (CCS) becomes more frequent practice, countries may implement domestic permitting systems and other regulations relevant to inventory steps outlined in the 2006 Guidelines. For instance, risk assessment, site-specific modeling, and monitoring may be required as part of groundwater protection measures (Eggleston, 2006).

As a result of the analysis, total leakage (CO₂ emission) is calculated as shown below:

$$[total\ captured] + [net\ imports] - [total\ injection] = [total\ leakage]$$

Figure 5. Procedures for estimating emissions from CO₂ storage sites

The method does not consider the efficiency of capture or storage sites, and it doesn't make any assumptions about the duration of how long gas can be stored although it relies on detailed modeling and measurements for storage sites and uses conventional emission factors for transport where current technologies are applied (Eggleston, 2006).

Due to the points above, small discrepancies may arise from several factors such as uncertainties in the measurements of amounts captured, injected and of any leaks, or from intermediate storage.

In summary, there are many benefits and downsides of using IPCC factor to identify CO₂ footprint. The factor is a valuable resource for those involved in environmental management and policymaking. It is accessible online, making it easy for users to obtain the information they need without any cost barriers. The database offers well-documented emission factors, which are derived from IPCC guidelines, peer-reviewed papers, and industry studies, ensuring their reliability. Another benefit of using IPCC factor is its support for national inventories. Developing national emission factors independently can be both costly and time-consuming for countries. It helps by providing a comprehensive set of emission factors that can be used to develop these inventories more efficiently. It is also a dynamically updated tool, allowing for the incorporation of new and more accurate emission factors over time. This ensures that users have access to the most current data available, which is crucial for accurate environmental assessments.

On the other hand, there are some drawbacks to the IPCC factor approach. One issue is the inconsistencies between the IPCC definitions of organic soils and climate zones. These discrepancies can lead to potential mismatches in the data. Additionally, some of the default CO₂ and N₂O values in the 2006 IPCC Guidelines are outdated and substantially too low, often by an order of magnitude, necessitating updates.

Lastly, the approach used by the IPCC may not fully account for indirect emissions, such as off-site decomposition of organic material and dissolved CO₂ leached through drainage ditches. This can result in an incomplete picture of the total emissions associated with certain activities. (Eggleston,2006).

3.2 Input–Output (IO) Analysis

The second practice to identify the CO₂ footprint in the product lifecycle is Input-Output (IO) analysis. Research on IO analysis conducted at the national level as a top-down input-output (IO) analysis approach. This method, as highlighted by Gao, Liu and Wang (2013), involves examining the economic transactions between different sectors of the economy from a macroeconomic perspective. With that approach, it provides a comprehensive overview of the interdependencies and interactions within the entire economic system. This approach is useful for understanding the broader economic impacts and environmental implications of CO₂ sources.

As described by Caro (2019), IO analysis allows for the estimation of carbon footprints at multiple scales by translating financial data into measures of greenhouse gas (GHG) emissions. It creates a detailed understanding of the environmental impacts associated with economic activities, enabling the estimation of carbon footprints for various industries, sectors, and regions.

This method involves complex calculations and requires extensive economic data that can estimate emissions at the sectoral level, such as private consumption. It also supports national and regional policymaking by providing

insights into the main drivers of emissions. Nevertheless, these complex calculations might be challenging to put together. Additionally, IO analysis accuracy is heavily dependent on assumptions made, such as non-competitive import assumptions and specific time period-based limitations (Zhu, 2007).

Since the goal of this study is to analyze and recommend actions to reduce the CO₂ footprint of a product, this macro-scale approach is not suitable for the objective. It doesn't rely on actual processes that have a comprehensive view of product lifecycle stages and their CO₂ impacts.

3.3 Lifecycle Assessment (LCA)

Lifecycle assessment (LCA) analyzes carbon emission throughout the entire life cycle of a product as it captures the actual production, distribution, maintenance, product usage, and end of life stages which rely on reliable data. This approach is based on bottom-up analysis that focuses on each stage in detail. Thus, consumer product prefers Lifecycle assessment (Gao, Liu and Wang, 2013). Even LCA is not suitable for macro-scale carbon emissions research, it is the major method for project carbon footprint evaluation (Huppel and Curran, 2012).

All stages of a product's life cycle, from raw material extraction, production, and use to disposal are considered by utilizing highly reliable data and detailed analysis from the beginning to the end of a product's life cycle. (Huppel and Curran, 2012).

Based on the above information, LCA is the most suitable approach for this study, which is the approach used in the conceptual framework to analyze CO₂ Footprint in the product lifecycle.

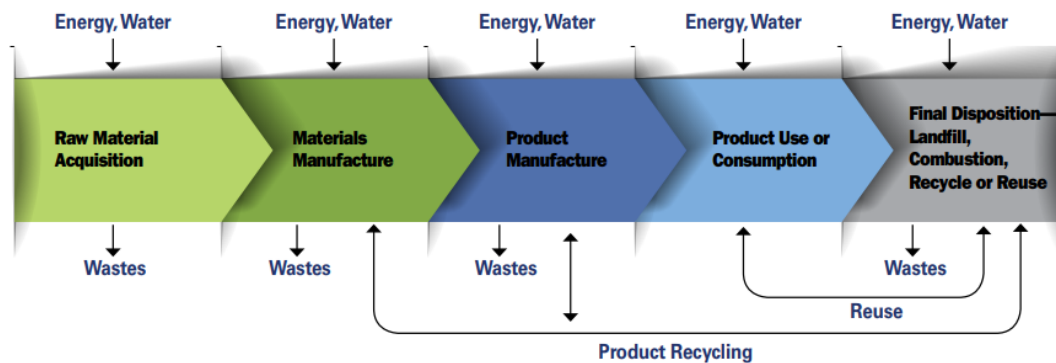


Figure 6. LCA Systems Approach (adapted from ICCA ,2020, p.11)

LCA helps organizations to highlight efficiency opportunities in the value chain, to understand the manufacturing systems, and to optimize these systems by identifying CO₂ footprint heavy steps. Additionally, LCA enables companies to compare two systems delivering the same product or industry averages which creates improvement possibilities. By providing CO₂ footprint data for each stage, LCA highlights improvement areas for the organizations. (ICCA, 2020)

On the other hand, there are some disadvantages, missing of LCA such as exclusion of energy and wastes associated with the manufacture of capital equipment, research, development, sales, and administrative activities. Additionally, most of the LCAs omit the energy used for heating, cooling, and lighting of manufacturing facilities. Also, minor material impacts (less than one percent by weight of the inputs) are often excluded from the analysis which can still have some environmental impact. (ICCA, 2020)

3.4 Input-Output + Lifecycle Assessment (IO-LCA)

In I/O (Input-Output) and LCA (Lifecycle assessment) combined methods, the strength of both approaches is utilized to have a comprehensive CO₂ footprint identification of an organization. Economic IO models are combined with environmental data from LCA to assess CO₂ footprint of a product (Gao, Liu and Wang, 2013).

The Input-Output (IO) method adopts a 'top-down' perspective, examining economic sectors and their interactions, while Lifecycle Assessment (LCA) uses a 'bottom-up' approach, focusing on process analysis to compile a life cycle inventory of inputs and outputs (such as pollutant emissions and waste). By combining these two methods, IO-LCA can mitigate errors and is suitable for analyzing both large-scale entities like cities and industries, as well as smaller-scale entities like technologies and products (Sheng et al., 2025).

This method is more complex compared to just using LCA due to the combination of two different methodologies that require extensive data collection and analysis from both economic sectors and specific processes. In this study, the focus is just UPS manufacturing and product lifecycle stages of the case company. Since the study analyses only the product, not entire organization, IO-LCA approach is not chosen.

3.5 Conceptual Framework (Tool to map CO2 footprint sources)

This section summarizes the chosen elements from relevant literature and best practices that are suitable for mapping CO2 footprint sources. The conceptual framework includes five main stages, which follows the lifecycle assessment approach as shown in figure 7.

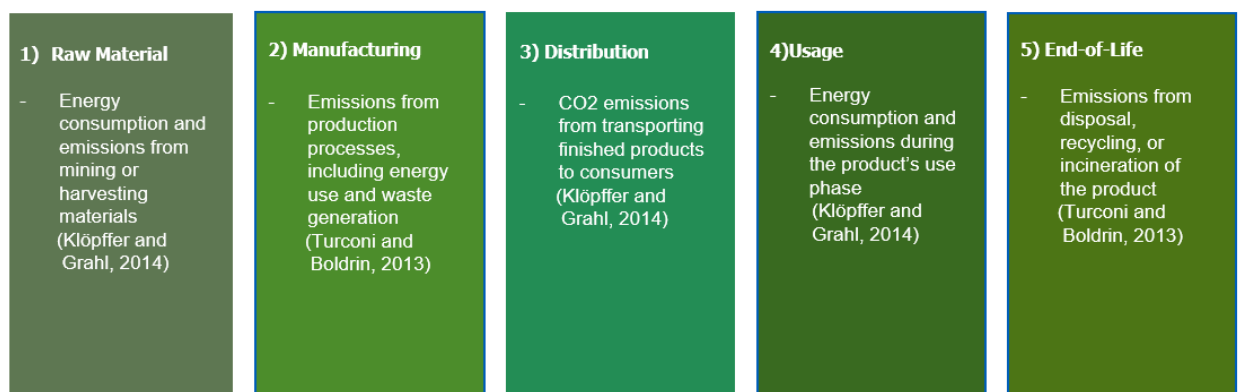


Figure 7. Conceptual framework of the study

To identify CO₂ sources in each product lifecycle stage, the framework starts from raw material, which contains energy consumption and emissions from mining or harvesting materials to the end-of-Life stage, which includes CO₂ emissions from disposal, recycling, or incineration of the product. And in between these stages, there are manufacturing, distribution, and usage are considered. Manufacturing step has emissions from production processes, including energy use and waste generation. (Turconi and Boldrin,2013). Distribution contains CO₂ emissions from transporting finished products to consumers and usage has energy consumption and emissions during the product's use phase (Klöpffer and Grahl,2014) This conceptual framework is the output of the extensive literature review of best practice findings that can be applied to business context of the study.

The next section is a current state analysis that focuses on product lifecycle stages. Each stage's CO₂ footprint impact is analyzed in detail to summarize CO₂ sources and weights of the whole lifecycle.

4 Mapping product lifecycle stages to identify sources of carbon footprint

In this section, each product lifecycle stage is mapped to identify sources of CO₂ footprint. The section starts with an overview of the product lifecycle, then identifies CO₂ portions of each stage and the main impact contributors of raw material, manufacturing, distribution, installation, use phase, and end of life.

As an outcome of section 4, a summary of CO₂ sources and weights is provided.

4.1 Product Lifecycle stages

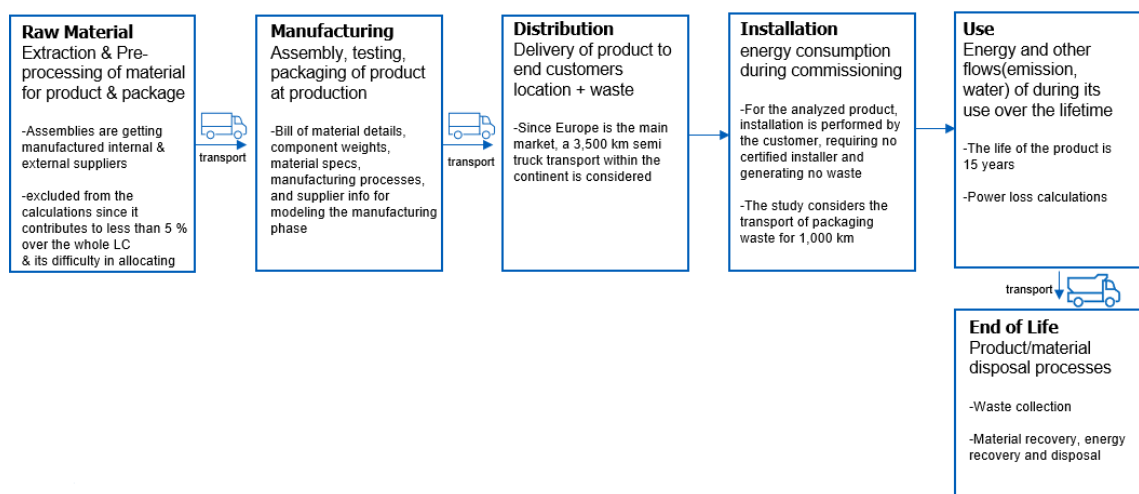


Figure 8. Product Lifecycle Stages

All product lifecycle stages are shown on the above figure. Based on Life cycle assessment (LCA) / Conceptual framework, this section contains the entire lifespan of a product from raw material extraction to end of life (disposal or recycling).

“The operational/ manufacturing stage often dominates in energy requirements and greenhouse gas (GHG) emissions, emphasizing the importance of optimizing energy retrofits. The choice of building materials, such as steel, concrete, or wood, significantly impacts the overall environmental footprint, with

insulation materials reducing the impact throughout the building's life cycle. Architectural designs incorporating passive strategies can significantly reduce global energy demands during the use phase. At the end-of-life stage, reducing waste materials and maximizing recycling are crucial for minimizing the overall environmental impact. Understanding the lifecycle stages of a product through LCA helps identify key areas for environmental improvement, providing a comprehensive view of the environmental impacts associated with a product and enabling more informed decision-making for sustainability (Vilches and Garcia-Martinez,2017) “

In the following sub sections, the case companies' product, Uninterruptible power supply (UPS)'s LC stages are analyzed. Chosen product for this study is manufactured in Finland, Vantaa facility.

4.2 Raw Material

This stage involves extracting the raw materials needed for the product. All extraction and pre-processing of material for product including packaging are considered. Additionally, all assemblies that part of the product procured by the internal or external suppliers are part of the assessment (Vilches, Garcia-Martinez and Sanchez-Montañes, 2017).

The studied product's analysis and available data exclude the raw material stage in PEP eco passport (EATO-00075-V01.01, 2023) whereas raw material impacts are considered under manufacturing stage based on their 'PEP Material Category' such as 'metals', 'plastics' and 'others'.

4.3 Manufacturing

Manufacturing stage is the process of converting raw materials and assemblies into the final product. Testing and packaging at production is also considered in CO₂ emissions calculation. Bill of material details, component weights, material specs, manufacturing processes, and supplier info are used for modeling the manufacturing phase. (*EATO-00075-V01.01*, 2023)

The manufacturing stage encompasses various essential inputs and outputs associated with production. This involves extracting raw materials for both the product and its packaging, undergoing industrial transformation and manufacturing procedures, generating waste during these processes, and transporting materials, components, and sub-assemblies to the company's facility.

For the modeling of the manufacturing phase, Bill of Material (BOM) is used to detail above processes. Then, Life Cycle Inventory (LCI) method is used which is a way to measure the energy and raw materials needed, as well as the emissions to air and water, solid waste, and other discharges throughout the entire life cycle of a product, process, or activity (Curran, 2008). LCI databases are identified for each material or component based on standard and internal guidelines.

The known location of the material or components production is impacting CO₂ emissions. When the data is unavailable, global average is applied depending on the similar level of technological development or industry. Transportation of components is also considered based on supplier information and its location. Road transportation or sea transportation affect CO₂ impact. (*EATO-00075-V01.01*, 2023).

Given the manufacturing location in Finland, there is an existing dataset for energy usage related to soldering, assembly, and similar applications that is utilized in the analysis.

As shown in Table 5 below, 71.9% of the product consists of metal, 2.6% of plastic, and 25.5% of other materials, with a total mass of 590 kg.

Table 5. Summary of PEP Material Category Weight Percentages for the analysed product (adapted from PEP EATO-00075-V01.01, 2023)

Bill of material			
Total mass	590 kg		
Constitution	<i>Plastic</i>	<i>Metal</i>	<i>Other</i>
	2.60 %	71.90 %	25.50 %
	0.00000 kg	0.00000 kg	0.00000 kg

Table 6 details all the materials used in the analyzed product, their material category, mass (kg), and percentages of the overall product mass. Main materials, their weight & contribution to the total weight of the product is shown below.

Table 6. Details of PEP Material Category Weight Percentages for the analysed product (adapted from PEP EATO-00075-V01.01, 2023)

Constituent Materials of Reference Product:			
	5.90E+02 kg (with packaging)		
Materials	Category PEP Material	Mass (kg)	Percentage (%)
Stainless steel	Metals	2.14E+02	36.3%
Steel	Metals	1.38E+02	23.4%
Inductor	Others	5.22E+01	8.9%
Aluminium Heatsink	Metals	4.73E+01	8.0%
Capacitor	Others	2.72E+01	4.6%
Wood	Others	2.31E+01	3.9%
PWB	Others	1.25E+01	2.1%
Copper	Metals	1.01E+01	1.7%
Cable	Others	9.98E+00	1.7%
Aluminium	Metals	8.21E+00	1.4%
PBT	Plastics	7.78E+00	1.3%
Brass	Metals	6.36E+00	1.1%
Transformer	Others	6.31E+00	1.1%
Polycarbonate	Plastics	4.26E+00	0.7%
Nylon 66	Plastics	3.37E+00	0.6%
Miscellaneous	Others	1.92E+01	3.3%
	Total	5.90E+02	100%

Stainless steel and steel have the biggest contribution, which are mainly used on the UPS frame. In the product, the greatest impact comes from the UPS

stainless steel frame, which has a higher weight contribution and high impact intensity per kilogram. It's followed by power electronic components, circuit boards and other electronics. Inductors make 8.9% contribution, which is used for the inductor board. Additionally, Inductor has a higher impact per kilogram of the material used.

Table 7. Mandatory Environmental Impact Indicators, Manufacturing Stage CO2 Impact (adapted from PEP EATO-00075-V01.01, 2023)

Environmental impact indicators	Units	Total	Manufacturing	Manufacturing CO2 Impact (%)
Climate change-Total (GWP)	kg CO ₂ eq.	3.07E+05	1.24E+04	4.04%
Climate change-Biogenic (GWPb)	kg CO ₂ eq.	4.57E+02	5.09E+01	11.14%
Climate change-Fossil (GWPf)	kg CO ₂ eq.	3.07E+05	1.24E+04	4.04%
Climate change-Land use and land use change (GWPlu)	kg CO ₂ eq.	7.92E-05	1.12E-05	14.14%

As shown in Table 7, manufacturing stage's impact on total CO2 footprint in the product lifecycle varies between 4.04%-14.14% depending on environmental impact indicator.

This manufacturing stage CO2 footprint's main impact is coming from stainless steel frame as indicated in Table 6. This impact is one of the focus areas of the study.

4.4 Distribution

The distribution stage involves transporting raw materials and finished products to different locations. It consists of product delivery to end customer location and associated waste. The product in its packaging is considered from the last logistic platform of the case company to the installation place in Europe.

The case company asserts in the PEP ecopassport their dedication to reducing the weight and volume of both the product and its packaging materials, with an emphasis on optimizing transport efficiency.

Table 8. Mandatory Environmental Impact Indicators, Distribution Stage CO₂ Impact (adapted from PEP EATO-00075-V01.01, 2023)

Environmental impact indicators	Units	Total	Distribution	Distribution CO ₂ Impact (%)
Climate change-Total (GWP)	kg CO ₂ eq.	3.07E+05	1.41E+02	0.05%
Climate change-Biogenic (GWPb)	kg CO ₂ eq.	4.57E+02	0.00E+00	0.00%
Climate change-Fossil (GWPf)	kg CO ₂ eq.	3.07E+05	1.41E+02	0.05%
Climate change-Land use and land use change (GWPlu)	kg CO ₂ eq.	7.92E-05	0.00E+00	0.00%

Since the CO₂ footprint impact of distribution stage varies between 0%-0.05% shown in Table 8, It's negligible for the next steps of the study.

4.5 Installation

This stage involves energy consumption during the commissioning of the product at the customer's site and the associated CO₂ emissions (PEP ecopassport® PROGRAM,' 2014).

The installation of the product is a manual process carried out by the customer, and a certified installer is not required. Therefore, the transport of a certified installer to the customer's location is not included in the study. Additionally, the UPS installation process does not require any additional energy source and does not generate any waste. For the analyzed product, the installation is performed by the customer, without the need for a certified installer and without generating waste. Only the management of packaging waste is considered in the installation phase, and the impacts of homogeneous family products are directly proportional to the packaging weight (PEP EATO-00075-V01.01, 2023).

Table 9. Mandatory Environmental Impact Indicators, Installation Stage CO₂ Impact (adapted from PEP EATO-00075-V01.01, 2023)

Environmental impact indicators	Units	Total	Installation	Installation CO ₂ Impact (%)
Climate change-Total (GWP)	kg CO ₂ eq.	3.07E+05	3.04E+01	0.01%
Climate change-Biogenic (GWPb)	kg CO ₂ eq.	4.57E+02	1.17E-01	0.03%
Climate change-Fossil (GWPf)	kg CO ₂ eq.	3.07E+05	3.03E+01	0.01%
Climate change-Land use and land use change (GWP _{lu})	kg CO ₂ eq.	7.92E-05	-8.25E-09	-0.01%

Since the CO2 footprint impact of installation stage varies between 0%-0.03% shown in Table 8, It's negligible for the next steps of the study.

4.6 Use

Energy and other flows (emission, water) of during products use over the lifetime are the contributor to CO2 footprint. Power loss during It's use time has significant impact on the overall CO2 numbers. The analyzed product's standard lifetime is 15 years (PEP EATO-00075-V01.01, 2023).

All the main impact indicator categories are dominated by the use phase (power losses) as shown on Table 10 below.

Additionally, the product needs maintenance in Use phase, which is calculated separately below. Since the impact of the maintenance is minor compared to the overall use phase, it's excluded from the next steps of the study.

Table 10. Mandatory Environmental Impact Indicators, Use Stage CO2 Impact (adapted from PEP EATO-00075-V01.01, 2023)

Environmental impact indicators	Units	Total	Use (Maintenance)	Use	Use (Maintenance) CO2 Impact (%)	Use CO2 Impact (%)
Climate change-Total (GWP)	kg CO ₂ eq.	3.07E+05	1.47E+03	2.92E+05	0.48%	95.11%
Climate change-Biogenic (GWPb)	kg CO ₂ eq.	4.57E+02	1.11E+01	3.90E+02	2.43%	85.34%
Climate change-Fossil (GWPf)	kg CO ₂ eq.	3.07E+05	1.46E+03	2.92E+05	0.48%	95.11%
Climate change-Land use and land use change (GWPlu)	kg CO ₂ eq.	7.92E-05	0.00E+00	0.00E+00	0.00%	0.00%

The environmental impacts during the Use phase vary depending on power losses and the number of UPM (power module) assemblies.

Consequently, the findings indicate that the CO₂ impact of product is mainly caused by use phase. Products operating in Energy saving mode have a lower impact compared to those operating in double conversion mode(default), primarily due to the higher average efficiency (approx. 3% efficiency difference). The detailed operating mode impacts are shown in Figure 9 below.

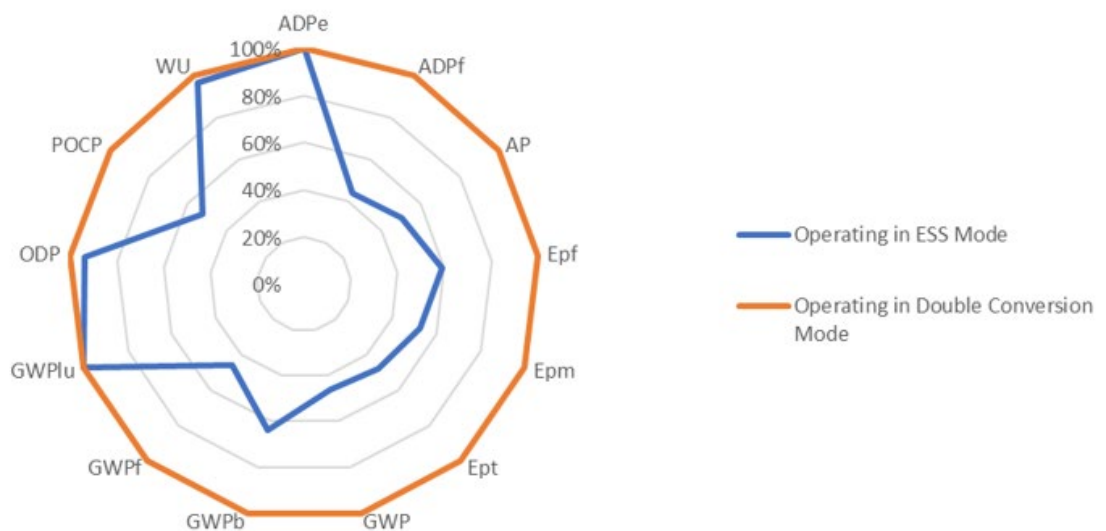


Figure 9. Use Phase Environmental Impacts on Different Operating Modes (adapted from PEP EATO-00075-V01.01, 2023)

Based on the above conclusion, use phase is one of the key focus areas of this study due to high impact percentages.

4.7 End of Life

The end-of-life stage of a product involves several critical processes. Deconstruction or demolition marks the beginning, where the product is taken down at the end of its useful life. This is followed by waste processing, which involves handling and processing the waste materials generated during deconstruction emissions (PEP ecopassport® PROGRAM,' 2014). The final disposal of these waste materials is an essential step, ensuring that they are managed appropriately. Recycling plays a significant role in this stage, as it converts waste materials into reusable resources. The product and material disposal processes have a notable impact on climate change land use, with major contributions coming from the treatment of product waste.

Additionally for the analyzed product, disposing is done according to European WEEE guidelines and used energy model is European standards (PEP EATO-00075-V01.01, 2023).

"The recyclability rate of the overall product is 71.8% if properly dismantled prior to further processing at a recycling facility. The rate is calculated based on "ECO'DEEE recyclability and recoverability calculation method" (PEP EATO-00075-V01.01, 2023)."

Table 11. Mandatory Environmental Impact Indicators, End of Life CO2 Impact (adapted from PEP EATO-00075-V01.01, 2023)

Environmental impact indicators	Units	Total	End of Life	End of Life CO2 Impact (%)
Climate change-Total (GWP)	kg CO ₂ eq.	3.07E+05	1.06E+03	0.35%
Climate change-Biogenic (GWPb)	kg CO ₂ eq.	4.57E+02	4.57E+00	1.00%
Climate change-Fossil (GWPf)	kg CO ₂ eq.	3.07E+05	1.06E+03	0.35%
Climate change-Land use and land use change (GWPlu)	kg CO ₂ eq.	7.92E-05	6.80E-05	85.86%

As seen on Table 11 above, End of Life stage has a minor impact on the first three indicators while having a major impact on 'Land use and land use change' with 85.86%.

Due to the complexity of analyzing waste management and recycling in the end-of-life stage, these impacts are not studied in the further steps.

4.8 Summary of CO2 Sources and Weights

In this section, CO2 sources and weights of the product lifecycle stages provides a comprehensive analysis of the CO2 emissions associated with the studied UPS throughout its lifecycle. It identifies the primary sources of CO2

emissions, which include the manufacturing phase, distribution, installation, use phase, and end-of-life treatment.

The manufacturing phase contributes significantly to the overall CO₂ emissions due to the energy-intensive processes involved in producing the components and assembling the product. Main CO₂ footprint contributor is ‘Stainless Frame’ which is one of the focus areas of the study.

The use phase also has a substantial impact, primarily due to power losses during operation. Thus, the use phase and efficiency are other focus points for the next steps.

The end-of-life phase considers the environmental impact of recycling and energy recovery and analyzes waste management.

Table 12. Mandatory Environmental Impact Indicators, All Product Lifecycle Stages (adapted from PEP EATO-00075-V01.01, 2023)

Environmental impact indicators	Units	Manufacturing CO ₂ Impact (%)	Distribution CO ₂ Impact (%)	Installation CO ₂ Impact (%)	Use (Maintenance) CO ₂ Impact (%)	Use CO ₂ Impact (%)	End of Life CO ₂ Impact (%)
Climate change-Total (GWP)	kg CO ₂ eq.	4.0%	0.0%	0.0%	0.5%	95.1%	0.3%
Climate change-Biogenic (GWPb)	kg CO ₂ eq.	11.1%	0.0%	0.0%	2.4%	85.3%	1.0%
Climate change-Fossil (GWPf)	kg CO ₂ eq.	4.0%	0.0%	0.0%	0.5%	95.1%	0.3%
Climate change-Land use and land use change (GWPlu)	kg CO ₂ eq.	14.1%	0.0%	0.0%	0.0%	0.0%	85.9%

The focus areas, which are the main product lifecycle stages, are chosen as the output of the analysis of this section, specifically the Manufacturing stage and Use stage. Each stage's CO2 footprint impact is analyzed in detail to summarize CO2 sources and weights for the entire lifecycle.

This CO2 contribution is studied in the next section to develop recommendations and an action plan to reduce the company's CO2 footprint in the product lifecycle.

5 Developing recommendations on how to reduce the CO2 footprint in the Product Lifecycle

In this section, findings and focus areas from the current state analysis (Section 4), based on the merged conceptual framework for identifying CO2 footprint sources in the product lifecycle, are studied. Accordingly, initial recommendations to reduce the CO2 footprint are proposed.

Firstly, overviews of actions to reduce the CO2 footprint are discussed, then initial recommendations such as utilizing green steel frame and recycled steel frame for the manufacturing stage are detailed.

For the use phase recommendations, higher efficiency modes, product design change with SiC (Silicon carbide), and utilizing high-efficiency inverters are discussed.

Finally, a summary of the initial recommendations and action plan is presented.

5.1 Overview of actions to reduce the CO2 footprint

Reducing the CO2 footprint of a product involves a comprehensive approach that addresses each stage of its lifecycle as discussed in the previous section. By mapping the product lifecycle stages, primary sources of CO2 emissions are identified. In this section, recommendations and actions to mitigate them are studied. This overview outlines the key actions to reduce the CO2 footprint based on the findings from the lifecycle stages of the product.

The product lifecycle includes several phases: raw material extraction, manufacturing, distribution, installation, use, and end-of-life. Each phase has a different impact on the overall CO2 footprint, and understanding these impacts is essential for developing effective reduction strategies.

Based on mapping product lifecycle stages to identify sources of carbon footprint (Section 4), manufacturing and use phase stages are focus areas for reducing CO2 footprint recommendations.

The manufacturing stage is a significant contributor to the CO2 footprint due to the energy-intensive processes involved in converting raw materials into the final product. For the product, the stainless-steel frame was identified as a major impact contributor. Actions to reduce CO2 emissions in this stage include using green steel frame and recycled steel frame instead of current steel frame in production.

In green steel frame manufacturing, only renewable energy sources are used, which significantly reduces the carbon footprint of the component. Additionally, using recycled steel frames reduces the carbon footprint by preventing raw material extraction and mining, as scrapped steel is utilized.

The use phase is a critical focus area due to its substantial impact on the overall CO2 footprint. Power losses during the product's operation contribute significantly to emissions. To reduce CO2 impact, developing higher efficiency modes is crucial. Designing products to operate in energy-saving modes can reduce power losses is one of the recommendations.

In addition, utilizing Silicon Carbide (SiC) technology in product design can enhance efficiency and lower emissions. Similarly, utilizing high-efficiency inverters can improve the overall energy performance of the product.

By focusing on the manufacturing and use phases, which are the primary sources of CO2 emissions, and implementing targeted actions such as using sustainable materials and enhancing product efficiency, CO2 footprint can be significantly reduced throughout its lifecycle.

5.2 Utilizing green steel frame

Green steel is produced without the use of fossil fuels, aiming to significantly reduce the carbon footprint. Traditional steel manufacturing, which relies heavily on coal-fired blast furnaces, contributes approximately 8% of global CO₂ emissions. The production of green steel involves using electric arc furnaces and green hydrogen, which emits only water when burned and can be generated from renewable energy sources. However, the transition to green steel faces several challenges, including high costs and the need for large quantities of low-carbon hydrogen. The shift from coal-based blast furnaces to electric arc furnaces is gradual, and the availability of green hydrogen is limited. Despite these obstacles, green steel is essential for meeting global climate goals, with a target to reduce emissions by 50% by 2050 (Ellerbeck,2022).

There are some examples of utilizing green steel in electrical products from the industry. One electrical manufacturer has introduced its first industrial control cabinet made entirely from green steel. This results in a 70% reduction in CO₂ emissions compared to conventional steel, translating to a savings of 308 kilograms of CO₂ per unit. (Siemens entirely from green steel..., 2024).

Green steel is manufactured by using renewable energy sources like solar, wind, and hydropower instead of coal and fuel which can reduce steel CO₂ footprint up to 95%. This will have a reduced impact on the overall product's CO₂ footprint up to 4.5% based on Table 6 and Table 7, stainless steel frame percentage.

Additionally, long-term savings through reduced carbon taxes and compliance with stricter environmental regulations are other benefits of utilizing green steel. On the other hand, initial costs are significantly higher due to the need for renewable energy infrastructure and advanced production technologies with green steel frames.

Table 13. Replacing Stainless steel frame by green steel frame action plan

Manufacturing Stage Action Plan Goal :Replacing Stainless Steel Frame	STEP 1	STEP 2	STEP 3	Stakeholders
	Initiation and Impact Analysis	Approval and Planning	Implementation and Verification	
by Green steel	<p>1)Change Request:details of the proposed change and the reasons</p> <p>2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits</p>	<p>1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams</p> <p>2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources</p>	<p>1)Implementation: modifying the design, updating manufacturing processes, and training personnel</p> <p>2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks</p>	<p>•Responsible:Associate Product Manager</p> <p>•Accountable:Mid-Range Product Manager</p> <p>•Accountable:Procurement Manager</p> <p>•Consulted:Technology Manager</p> <p>•Informed:Sustaining Manager</p>

To replace stainless steel with green steel in product development, above Table 13 shows the action plan steps. Main stakeholders for the proposal are product management, procurement, technology manager and sustaining team of the case company.

The first step of the action plan is initiation and impact analysis. Change requests must be detailed with all proposed changes and the reasons. Then by applying impact analysis, impact on cost, quality, schedule, and other components need to be studied which evaluates potential risks and benefits of the change.

Then, approval and planning steps should be conducted which starts with review and approval by relevant stakeholders, including engineering, manufacturing, and quality assurance teams. After the approvals, planning to implement the change including updates of documentation, scheduling the change, and allocating resources.

Lastly, implementation by modifying the design, updating manufacturing processes and training personnel must be done. Verification process to ensure it meets the desired outcomes and does not cause new issues by testing and quality checks must follow.

5.3 Utilizing recycled steel frame

By using scrap metal, recycled steel frame reduces the need for new raw materials and energy-intensive processes. This approach prevents the need for mining, refining, and processing raw materials. By changing conventional steel frame to recycled steel frame in case companies' products, CO2 footprint of raw material can reduce by 75% which can lower the overall product CO2 up to 3.7%.

This change can also lower waste management costs and ensure compliance with environmental regulations. Recycling steel uses less energy than producing steel from raw materials, which further helps in reducing the overall carbon footprint. Additionally, using recycled steel prevents construction waste from landfills, supporting the circular economy and reducing the environmental impact.

There are some examples in the industry where the entire cabinet of the product is made from 100% scrap metal, recycled steel. This results in a 70% reduction in CO2 footprint compared to conventional steel. (Siemens entirely from green steel..., 2024)

As shown on Table 14, action plan for the change implementation of recycled steel steps are identical as green steel actions on the previous subsection.

Table 14. Replacing Stainless steel frame by recycled steel frame action plan

Manufacturing Stage Action Plan Goal :Replacing Stainless Steel Frame	STEP 1	STEP 2	STEP 3	Stakeholders
	Initiation and Impact Analysis	Approval and Planning	Implementation and Verification	
•by Recycled steel	<p>1)Change Request:details of the proposed change and the reasons 2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits</p>	<p>1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams 2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources</p>	<p>1)Implementation: modifying the design, updating manufacturing processes, and training personnel 2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks</p>	<p>•Responsible:Associate Product Manager •Accountable:Mid-Range Product Manager •Accountable:Procurement Manager •Consulted:Technology Manager •Informed:Sustaining Manager</p>

5.4 Developing higher efficiency modes

Use stage of the product lifecycle is the major contributor to CO₂ footprint due to power Loss and product efficiency. The products' operating modes have different efficiency percentages that cause different CO₂ impacts.

In the case companies' products, there are already higher efficiency modes that increase the operational efficiency up to 99% by using energy saving mode. In comparison, double conversion efficiency of the studied product is up to 96.65% in double conversion (PEP EATO-00075-V01.01, 2023).

The Energy Saver System (ESS) boosts efficiency to 99% by turning off power modules when power conditioning isn't needed and enabling inverters to start switching within two milliseconds when required. Even though double-conversion mode is already highly efficient, ESS can still cut losses by 75% with a typical UPS load (Paananen, 2015)

In ESS mode, the UPS operates very efficiently by bypassing the inverter during normal operation and only engaging it when necessary for power conditioning and protection. (Paananen, 2015)

On the other hand, some other operating modes in the industry keep the inverter running in parallel with the bypass source, supplying the reactive part of the load and maintaining input factor close to unity while providing continuous battery charging, power factor correction, and harmonic filtering. By developing this operating mode in the case product, up to 2% efficiency improvement and a proportional CO₂ footprint reduction in double conversion can be achieved. Compared to the currently available Energy Saving mode, this approach might be more suitable for some applications that need the inverter running in parallel and providing a more efficient mode during operation as it reduces the overall CO₂ footprint.

Table 15. Utilizing higher efficiency modes action plan

Use Phase Action Plan Goal :Reducing Power Loss --> Improving Product Efficiency	STEP 1	STEP 2	STEP 3	Stakeholders
	Initiation and Impact Analysis	Approval and Planning	Implementation and Verification	
•Higher efficiency modes (ESS+)	1)Change Request: details of the proposed change and the reasons 2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits	1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams 2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources	1)Implementation: modifying the design, updating manufacturing processes, and training personnel 2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks	.Responsible:Associate Product Manager .Accountable:Mid-Range Product Manager .Consulted:Technology Manager .Informed:Sustaining Manager

As shown in Table 15, the action plan for the change implementation of higher efficiency modes in the use phase is identical as green steel actions on the previous subsection except stakeholders. Main stakeholders for the proposal are product management, the technology manager and the sustaining team of the case company.

5.5 Design change with Silicon Carbide (SiC) technology

Silicon Carbide (SiC) has a wider bandgap than silicon (current product design), enabling it to operate at higher voltages with lower conduction and switching losses, which enhances energy efficiency by reducing wasted power and heat dissipation. SiC-based devices can switch faster than silicon, minimizing switching losses and allowing higher frequency operation, leading to smaller passive components and improved power density and system efficiency (Baek, 2019).

Additionally, SiC's robust material properties make it more resistant to extreme conditions, ensuring a longer lifespan and increased reliability in demanding applications. Ensuring longer lifespan might also reduce component maintenance related CO2 footprint impact (Silicon carbide (SiC) – the future of efficient UPS systems, 2025).

SiC technology allows UPS systems to achieve exceptional efficiency levels, e.g. up to 98.4% online double conversion efficiency compared to maximum 97% of the studied product. (Silicon carbide (SiC) – the future of efficient UPS systems, 2025)

Table 16. Utilizing SiC action plan

Use Phase Action Plan Goal :Reducing Power Loss --> Improving Product Efficiency	STEP 1	STEP 2	STEP 3	Stakeholders
	Initiation and Impact Analysis	Approval and Planning	Implementation and Verification	
•Silicon Carbide (SiC)	<p>1)Change Request:details of the proposed change and the reasons</p> <p>2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits</p>	<p>1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams</p> <p>2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources</p>	<p>1)Implementation: modifying the design, updating manufacturing processes, and training personnel</p> <p>2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks</p>	<p>•Responsible:Associate Product Manager</p> <p>•Accountable:Mid-Range Product Manager</p> <p>Accountable:Procurement Manager</p> <p>•Consulted:Technology Manager</p> <p>•Informed:Sustaining Manager</p>

As shown on Table 16, action plan for the change implementation of SiC are identical as green steel actions on the previous subsection since both proposals are component design change requests.

5.6 Utilizing high-efficiency inverters

Utilizing High-Efficiency Inverters in the product design minimizes energy loss during power conversion. There are some examples in the industry such as silicon carbide (SiC) inverters and multilevel inverter topologies.

Silicon Carbide (SiC) inverters are recognized for their exceptional efficiency and compact design, which is already covered in the previous subsection separately.

With multilevel inverter topologies, these inverters are engineered to enhance energy efficiency and availability in UPS applications. They minimize conduction loss, switching loss, and filter loss, resulting in greater overall efficiency.

The studied product uses three-level IGBT converters with advanced inverter topology helps improve efficiency and reduce total harmonic distortion (THD). For the further efficiency improvement to reduce CO2 footprint, there are various multilevel inverter topologies that can be utilized in the future to improve efficiency.

For example, by using a four-Level inverter, lowering switching loss is possible while it causes higher conduction losses. It also requires complex power circuitry. It can deliver higher efficiency but still has reliability challenges. By using five-level inverter which is not commercially implemented because of the more complex circuit design and control challenges. (Multilevel inverter topologies for UPS applications, no date).

In conclusion, research and technology development of topology should be studied, and after achieving proven performance, the impact must be analyzed for the implementation.

Table 17. Utilizing high-efficiency inverters action plan

Use Phase Action Plan Goal :Reducing Power Loss --> Improving Product Efficiency	STEP 1	STEP 2	STEP 3	Stakeholders
	Initiation and Impact Analysis	Approval and Planning	Implementation and Verification	
•High-Efficiency Inverters	<p>1)Change Request:details of the proposed change and the reasons</p> <p>2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits</p>	<p>1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams</p> <p>2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources</p>	<p>1)Implementation: modifying the design, updating manufacturing processes, and training personnel</p> <p>2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks</p>	<p>•Responsible:Associate Product Manager</p> <p>•Accountable:Mid-Range Product Manager</p> <p>Accountable:Procurement Manager</p> <p>•Consulted:Technology Manager</p> <p>•Informed:Sustaining Manager</p>

As shown on Table 17, an action plan for the change implementation of high efficiency inverters is identical as green steel actions on the previous subsection since both proposals are component design change requests.

5.7 Summary of the Initial Recommendations / Action Plan

In this section, recommendations to reduce the CO₂ footprint in the product lifecycle are proposed based on findings from the current state analysis. The focus is on the manufacturing and use phases, identified as primary sources of CO₂ emissions. For the manufacturing stage, utilizing green steel and recycled steel frames is recommended to reduce emissions. Green steel produced using renewable energy sources, and recycled steel, which prevents raw material extraction, both significantly lower the carbon footprint.

In the use phase, developing higher efficiency modes, incorporating Silicon Carbide (SiC) technology, and utilizing high-efficiency inverters are suggested to enhance energy performance and reduce emissions. By implementing these recommendations, the CO₂ footprint can be significantly reduced throughout the product lifecycle.

Table 18. Summary of the Recommendations, Action Plan to reduce CO2 footprint

Manufacturing Stage Action Plan Goal :Replacing Stainless Steel Frame	STEP 1	STEP 2	STEP 3	Stakeholders
	Initiation and Impact Analysis	Approval and Planning	Implementation and Verification	
•by Green steel	1)Change Request:details of the proposed change and the reasons 2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits	1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams 2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources	1)Implementation: modifying the design, updating manufacturing processes, and training personnel 2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks	•Responsible:Associate Product Manager •Accountable:Mid-Range Product Manager •Accountable:Procurement Manager •Consulted:Technology Manager •Informed:Sustaining Manager
•by Recycled steel	1)Change Request:details of the proposed change and the reasons 2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits	1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams 2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources	1)Implementation: modifying the design, updating manufacturing processes, and training personnel 2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks	•Responsible:Associate Product Manager •Accountable:Mid-Range Product Manager •Accountable:Procurement Manager •Consulted:Technology Manager •Informed:Sustaining Manager
Use Phase Action Plan Goal :Reducing Power Loss --> Improving Product Efficiency	STEP 1	STEP 2	STEP 3	Stakeholders
	Initiation and Impact Analysis	Approval and Planning	Implementation and Verification	
•Higher efficiency modes (ESS+)	1)Change Request:details of the proposed change and the reasons 2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits	1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams 2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources	1)Implementation: modifying the design, updating manufacturing processes, and training personnel 2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks	•Responsible:Associate Product Manager •Accountable:Mid-Range Product Manager •Consulted:Technology Manager •Informed:Sustaining Manager
•Silicon Carbide (SiC)	1)Change Request:details of the proposed change and the reasons 2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits	1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams 2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources	1)Implementation: modifying the design, updating manufacturing processes, and training personnel 2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks	•Responsible:Associate Product Manager •Accountable:Mid-Range Product Manager •Accountable:Procurement Manager •Consulted:Technology Manager •Informed:Sustaining Manager
•High-Efficiency Inverters	1)Change Request:details of the proposed change and the reasons 2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits	1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams 2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources	1)Implementation: modifying the design, updating manufacturing processes, and training personnel 2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks	•Responsible:Associate Product Manager •Accountable:Mid-Range Product Manager •Accountable:Procurement Manager •Consulted:Technology Manager •Informed:Sustaining Manager

To replace or update a component in the product design, the action plan involves several steps. The main stakeholders include product management, procurement, technology manager, and the sustaining team.

The first step is initiation and impact analysis, where the change request is detailed and its impact on cost, quality, schedule, and other components is evaluated. Next, the approval and planning step involves review and approval

by relevant stakeholders, followed by planning the implementation, updating documentation, scheduling, and allocating resources.

Finally, the implementation step includes modifying the design, updating manufacturing processes, training personnel, and executing verification processes to ensure desired outcomes and identify any new issues through testing and quality checks.

In the next section, feedback and validation of the initial proposal are discussed. Based on the updates from the validation, the final proposal is presented.

6 Feedback on the recommendations/action plan

This section presents the outcomes of the proposal validation and highlights further improvements to the initial proposal which was presented in Section 5. It starts with an overview of the validation stage procedure, followed by a discussion of the feedback and suggestions from stakeholders. The section concludes with the final proposal and an action plan for implementation.

6.1 Overview of the Validation Stage

The aim of this stage was to assess the feasibility of the initial proposal for practical use and gather feedback for further implementation from the decision makers. The evaluation stage is done by cross-functional interviews as the validation method due to the research approach that presented in section 2.

The validation interviews were facilitated by the researcher and included key stakeholders from Product Marketing, Technology, Product Development and Engineering, and Sustaining organizations. The cross-functional team evaluated the initial proposal and provided valuable feedback for further implementation.

During the interview, the team first reviewed the study progress, followed by the key findings from the current state analysis and the conceptual framework. After informing the team with the basis of the study and the results so far, the initial proposal and its development work were introduced. This introduction covered the development stage procedures, recommendations for reducing CO₂ in different lifecycle stages, and the proposed actions for implementation. Once the initial proposal was presented, the stakeholders evaluated its feasibility step by step in terms of practical implementation. After the evaluation, the findings were presented, discussed further, and decisions were made on whether to include them in the final proposal.

6.2 Feedback Received and Further Developments to the Proposal

Firstly, manufacturing stage CO2 reduction recommendations are validated as shown below in table 19.

Table 19. Manufacturing Stage Validated Proposal

Manufacturing Stage Action Plan Goal :Replacing Stainless Steel Frame	Validation/Feedback Additions
•by Using Old UPS Frame (Refurbished UPS)	1) 15 yrs of Product Life vs 25 yrs of Refurbished UPS .Instead of replacing with the new product , keeping the frame installed and change components inside of the frame
•by Green steel	1) High Initial Costs .Due to the need for renewable energy infrastructure and advanced production technologies .Recycled steel is better approach for relatively shorter term due to cost .Supply chain team actions and supplier collaboration are needed 2)Modular Design Effect .Modular product (multiple modules vs one block for the same power need) .CO2 footprint comparison of different designs is needed --> More steel consumption in modular?
•by Recycled steel	1) Consensus on utilize recycled steel .Using scrap metal, initial cost is significantly lower compare to green steel .Supply chain team actions and supplier collaboration are needed

Table 20. Manufacturing Stage Validated Proposal, Action plan

STEP 1	STEP 2	STEP 3	Stakeholders
Initiation and Impact Analysis	Approval and Planning	Implementation and Verification	
1) Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits	1) Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams 2) Planning: to implement the change. Including updates of documentation, scheduling the change, and allocating resources	1) Implementation: modifying the design, updating manufacturing processes, and training personnel 2) Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks	<ul style="list-style-type: none"> • Responsible: Associate Product Manager • Accountable: Services Product Manager • Consulted: Technology Manager • Informed: Sustaining Manager
1) Change Request: details of the proposed change and the reasons 2) Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits	1) Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams 2) Planning: to implement the change. Including updates of documentation, scheduling the change, and allocating resources	1) Implementation: modifying the design, updating manufacturing processes, and training personnel 2) Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks	<ul style="list-style-type: none"> • Responsible: Associate Product Manager • Accountable: Supply Chain Manager • Consulted: Technology Manager • Informed: Sustaining Manager
1) Change Request: details of the proposed change and the reasons 2) Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits	1) Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams 2) Planning: to implement the change. Including updates of documentation, scheduling the change, and allocating resources	1) Implementation: modifying the design, updating manufacturing processes, and training personnel 2) Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks	<ul style="list-style-type: none"> • Responsible: Associate Product Manager • Accountable: Supply Chain Manager • Consulted: Technology Manager • Informed: Sustaining Manager

During the discussion, in addition to replacing the stainless-steel frame with sustainable options, the idea of using the old product frame (refurbished UPS concept) emerged as a new improvement. Instead of replacing the entire product, the existing frame is retained, and the internal components are updated. This approach extends the product's life from 15 years to 25 years for the refurbished UPS. This approach involves installing new and improved electronics inside the existing frame, simply modernizing the unit by mainly replacing the UPM (uninterruptible power modules). Consumable parts like capacitors, fans, and batteries can also be replaced as needed.

Refurbished UPS systems offer several sustainability benefits. By refurbishing and reusing existing UPS units, the amount of electronic waste is significantly reduced, preventing these devices from ending up in landfills. Refurbishing UPS systems conserves raw materials and reduces the need for new components, which in turn lowers the environmental impact associated with mining and

manufacturing. The refurbishment process typically consumes less energy compared to manufacturing new units, leading to a lower overall carbon footprint. Extending the life of existing UPS systems through refurbishment maximizes the use of the resources already invested in their production, contributing to a more circular economy (Modernization Services by Eaton, no date)

Thus, both manufacturing and End of Life CO₂ footprint impacts are significantly reduced by utilizing refurbished UPS. By collaborating with the service organization, next actions should be planned.

The remaining recommendations in the manufacturing stage focus on using green steel and recycled steel instead of stainless-steel frames. One of the primary challenges is the high initial costs associated with green steel, due to the need for renewable energy infrastructure and advanced production technologies. In the short term, recycled steel is a more cost-effective approach, but it requires actions from the supply chain team and collaboration with suppliers. Additionally, the modular design effect needs to be considered, as modular products (multiple modules versus one block for the same power need) may consume more steel. A CO₂ footprint comparison of different designs is necessary to understand the impact. There is a consensus on utilizing recycled steel, as using scrap metal significantly lowers initial costs compared to green steel.

Secondly, use phase CO2 reduction recommendations are validated as shown below in table 21.

Table 21. Use Phase Validated Proposal

Use Phase Action Plan Goal :Reducing Power Loss --> Improving Product Efficiency	Validation/Feedback Additions
•Higher efficiency modes (ESS+)	1) End User Location impact .Green Energy vs Fossil energy usage on the customer location 2)Efficiency mode usage of End customer .User habit varies based on countries or zones
•Silicon Carbide (SiC)	1) Double conversion mode efficiency increase .Main focus to improve overall product efficiency by design change .Already used for the first time in the large/latest product(2 Level) --> Need to investigate/invest on 3 Level Topology .For the upcoming product launches , SiC possibility must be checked
•High-Efficiency Inverters	1) Double conversion efficiency increase .Not practical

Table 22. Use Phase Validated Proposal, Action plan

STEP 1	STEP 2	STEP 3	Stakeholders
Initiation and Impact Analysis	Approval and Planning	Implementation and Verification	
<p>1)Change Request:details of the proposed change and the reasons</p> <p>2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits</p>	<p>1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams</p> <p>2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources</p>	<p>1)Implementation: modifying the design, updating manufacturing processes, and training personnel</p> <p>2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks</p>	<ul style="list-style-type: none"> •Responsible:Associate Product Manager •Accountable:Mid-Range Product Manager •Consulted:Technology Manager •Informed:Sustaining Manager
<p>1)Change Request:details of the proposed change and the reasons</p> <p>2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits</p>	<p>1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams</p> <p>2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources</p>	<p>1)Implementation: modifying the design, updating manufacturing processes, and training personnel</p> <p>2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks</p>	<ul style="list-style-type: none"> •Responsible:Associate Product Manager •Accountable:Mid-Range Product Manager •Accountable:Procurement Manager •Consulted:Technology Manager •Informed:Sustaining Manager
<p>1)Change Request:details of the proposed change and the reasons</p> <p>2)Impact Analysis: impact on cost, quality, schedule, and other components. Evaluating potential risks and benefits</p>	<p>1)Review and Approval: by relevant stakeholders, including engineering, manufacturing, and quality assurance teams</p> <p>2)Planning: to implement the change.Including updates of documentation, scheduling the change, and allocating resources</p>	<p>1)Implementation: modifying the design, updating manufacturing processes, and training personnel</p> <p>2)Verification: verified to ensure it meets the desired outcomes and does not introduce new issues. Including testing and quality checks</p>	<ul style="list-style-type: none"> •Responsible:Associate Product Manager •Accountable:Mid-Range Product Manager •Accountable:Procurement Manager •Consulted:Technology Manager •Informed:Sustaining Manager

The use phase recommendations for reducing CO2 impact have been validated as seen above. Implementing higher efficiency modes can significantly improve energy efficiency. There is some feedback from the stakeholders, such as the impact of the end user's location and the customer's preference to use these modes. Product's end location impacts the CO2 footprint, as the use of green energy or fossil energy at the customer's site can affect overall CO2 emissions. Additionally, the efficiency mode usage varies based on user habits in different countries or zones. The preference of the customer affects CO2 impact of the use phase.

Another recommendation that was validated is that utilizing Silicon Carbide (SiC). This technology can further improve double conversion mode efficiency, with the focus on improving overall product efficiency through design changes. SiC has already been used in one of the latest products of the case company (2 Level), and there is a need to investigate and invest in 3 Level Topology for

future product launches. The team agrees that SiC should be utilized when it's feasible in the product design.

Lastly, high-efficiency inverters can also contribute to double conversion efficiency increases, although their practicality may vary. Due to complexity detailed in [5.6 Utilizing high-efficiency inverters](#), it is decided by the stakeholders that it's not part of the final proposal.

6.3 Final Proposal

The final proposal presents validated recommendations and action plans to reduce the CO₂ footprint in product development. The validation stage involved cross-functional interviews with key stakeholders from Product Marketing, Technology, Product Development, Engineering, and Sustaining organizations. Feedback highlighted the feasibility of some of the initial recommendations and suggested further improvements.

For the manufacturing stage, refurbished UPS Concept is the first action to reduce CO₂ footprint in the product lifecycle. By retaining the existing product frame and updating internal components to extend the product's life from 15 to 25 years, CO₂ impact is also reduced in the End-of-Life stage. This approach reduces electronic waste, raw material extraction, and lowers the overall carbon footprint.

The other action for the manufacturing stage is using recycled steel instead of stainless steel. Recycled steel's initial investment is feasible while supply chain team support, new supplier search and design change processes are needed.

For the use phase, silicon carbide (SiC) technology is the focus in the final proposal. By incorporating SiC, further improvement in double conversion mode efficiency can be achieved. The case company should investigate and invest in 3 Level Topology for future products.

For these proposed design changes, an action plan should be followed which is detailed below:

The first step of the action plan is initiation and impact analysis. Change requests must be detailed with all proposed changes and the reasons. Then by applying impact analysis, impact on cost, quality, schedule, and other components need to be studied which evaluates potential risks and benefits of the change.

Then, approval and planning steps should be conducted which starts with review and approval by relevant stakeholders, including engineering, manufacturing, and quality assurance teams. After the approvals, planning to implement the change including updates of documentation, scheduling the change, and allocating resources.

Lastly, implementation by modifying the design, updating manufacturing processes and training personnel must be done. Verification process to ensure it meets the desired outcomes and does not introduce new issues by testing and quality checks must follow.

By following these steps, the proposal aims to significantly reduce the CO₂ footprint throughout the product lifecycle.

The table that summarizes the final proposal is shown below:

Table 23. Final Proposal

Manufacturing Stage Action Plan Goal :Replacing Stainless Steel Frame	Validation/Feedback Additions
•by Using Old UPS Frame (Refurbished UPS)	1) 15 yrs of Product Life vs 25 yrs of Refurbished UPS .Instead of replacing with the new product , keeping the frame installed and change components inside of the frame
•by Recycled steel	1) Consensus on utilize recycled steel .Using scrap metal, initial cost is significantly lower compare to green steel .Supply chain team actions and supplier collaboration are needed
Use Phase Action Plan Goal :Reducing Power Loss --> Improving Product Efficiency	Validation/Feedback Additions
•Silicon Carbide (SiC)	1) Double conversion mode efficiency increase .Main focus to improve overall product efficiency by design change .Already used for the first time in the large/latest product(2 Level) --> Need to investigate/invest on 3 Level Topology .For the upcoming product launches , SiC possibility must be checked

6.4 Summary of final recommendations/action plan

This section presents the outcomes of the proposal validation and highlights further improvements to the initial proposal.

For the manufacturing stage, the refurbished UPS concept and recycled steel are the final recommendations.

By refurbished UPS concept, it's possible to retain the existing product frame and updating internal components to extend the product's life from 15 to 25 years, reducing electronic waste and conserving raw materials.

By utilizing recycled steel, CO₂ footprint impact of stainless-steel frame is prevented.

For the use phase, utilizing Silicon Carbide (SiC) Technology to improve double conversion mode efficiency, with plans to investigate and invest in 3 Level topology for future products is the main proposal.

The final proposal combines these three validated recommendations and aims to reduce the CO₂ footprint throughout the product lifecycle. The action plan includes initiation and impact analysis, approval and planning, and implementation steps to ensure successful execution as detailed in the previous subsection.

In the next section, the executive summary and the conclusion of the study are presented.

7 Discussion & Conclusion

This section wraps up the thesis by presenting the executive summary and offering suggestions for implementing the thesis findings. It also includes an evaluation of the thesis and some final remarks.

7.1 Executive Summary

This thesis focuses on identifying CO₂ footprint sources throughout the product lifecycle and developing recommendations to reduce the CO₂ footprint of the studied product (UPS). The study utilizes a product lifecycle data (PEP ecospasport) to analyze carbon footprint sources in manufacturing, packaging, distribution, use, and end-of-life phases.

The case company operates in a market where sustainability targets are crucial, and product-level actions must be taken accordingly to sustain environmental product declarations. The Finland facility, a center of excellence for UPS since 1962, serves the EMEA market with complete support functions and operational activities.

The business challenge addressed in this thesis is to support corporate sustainability targets, by reducing carbon emissions in the product lifecycle. The objective is to develop recommendations and an action plan for reducing the CO₂ footprint by utilizing data from lifecycle assessments, environmental declarations, and certifications.

The study contains good practices of CO₂ footprint source identification in literature, which were utilized to design a conceptual framework to map CO₂ footprint identification. Based on the conceptual framework, product lifecycle stages are analyzed in the current state analysis to summarize CO₂ sources and weights of the product. After highlighting the main contributors to the CO₂ footprint, an initial proposal was developed and presented to decision-makers and key stakeholders. After receiving feedback, the final proposal was

developed following validated recommendations and action plans, focusing on the manufacturing and use phases.

By following these recommendations, the study aims to significantly reduce the CO₂ footprint throughout the product lifecycle. The study contributes to a broad understanding of CO₂ footprint reduction and provides an overview for future development and best practice sharing within the company.

7.2 Practical next step recommendations

This study has developed a proposal to reduce the CO₂ footprint in the product lifecycle. The final proposal includes validated recommendations and action plans, focusing on both the manufacturing and use phases.

For the manufacturing stage, the proposal includes the refurbished UPS concept, which retains the existing product frame and updates internal components to extend the product's life, reducing electronic waste and conserving raw materials. Additionally, using recycled steel instead of stainless steel is recommended.

For the use phase, incorporating Silicon Carbide (SiC) technology is suggested to improve double conversion mode efficiency. The case company should investigate and invest in 3 Level Topology for future products.

To implement the changes based on the proposal, the following steps are recommended for the case company:

- I. **Initiate and Conduct Impact Analysis:** Detail the change request and evaluate its impact on cost, quality, schedule, and other components.
- II. **Approval and Planning:** Review and approval from relevant stakeholders, including engineering, manufacturing, and quality assurance teams. Plan

the implementation, update documentation, schedule the change, and allocate resources.

- III. Implementation: Modify the design, update manufacturing processes, train personnel, and conduct verification processes to ensure desired outcomes and identify any new issues through testing and quality checks.
- IV. Communicate and Involve Stakeholders: Ensure steady communication of the implementation process to all stakeholders, encourage initiatives.
- V. Collect Feedback and Improve Continuously: Gather feedback at all stages of implementation to continuously develop and improve the quality of the CO₂ reduction process.

The actions listed above present the steps to prepare for the implementation phase of the proposal.

7.3 Self-evaluation of thesis project credibility

This thesis objective was developing recommendations for reducing the CO₂ footprint in product lifecycle within the case company. The goal was to provide concrete recommendations, and the research approach was suitable for achieving this objective. The decision makers validated the proposal and the approach of the study.

As using qualitative methods, the credibility of a study relies on research preparation. Research approach by using rigorous techniques and methods as collecting high-quality data must be assured (Patton, 1999).

By combining multiple observers, theories, methods, and data sources, researchers can hope to overcome the intrinsic bias that comes from single-method, single-observer, single-theory studies. (Denzin, 1970:315)

Rigorous techniques and methods were utilized in the study, including the use of R&D, global product stewardship CO2 related databases, as well as PEP Eco passport (environmental declaration according to ISO standards). Interviews and CO2 weight calculations were used as data sources which incorporate both qualitative and quantitative data.

As mentioned above, multiple data sources were utilized that ensures a comprehensive data plan of the thesis. On the other hand, the study is highly based on raw data, including CO2 figures and impact calculations.

As a self-evaluation for the study, the exclusion of the End-of-Life (EOL) stage based on the current state analysis and lower figures compared to the Use phase and manufacturing could have been reconsidered. After receiving feedback from stakeholders, it became evident that by utilizing circular economy principles, both manufacturing and EOL CO2 footprints can be reduced.

Additionally, more frequent interviews and reviews could have been conducted. This approach would have generated some new ideas, such as refurbished UPS, to be analysed at an earlier stage. Furthermore, the service team could have been added to the interview list, potentially leading to more concrete recommendations for the EOL and manufacturing stages.

7.4 Closing Words

In conclusion, this thesis has identified CO2 footprint sources throughout the product lifecycle and developed actionable recommendations to reduce the CO2 footprint within the case company. By analysing carbon footprint sources in manufacturing, packaging, distribution, use, and end-of-life phases, the study provides a comprehensive understanding of the environmental impact.

The study's outcome supports the high-level sustainability goals of the case company and the industry by proposing practical solutions.

Lastly, it's rewarding to work on this sustainability topic, which becomes more crucial each year for businesses, countries, and the whole world, as can be seen from the global sustainability targets and the need for the carbon reduction.

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