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Environmental Life Cycle Assessment of an Airborne Radar System

Master's thesis in Industrial Ecology

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A Cradle-to-Grave Analysis of the Radar System's Environmental Footprint

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SUMMARY

This thesis presents a comprehensive Life Cycle Assessment (LCA) of an airborne radar system developed by Saab Surveillance, conducted in accordance with ISO 14040 and 14044 standards. The study evaluates the environmental impacts of the radar across its entire life cycle, from raw material extraction to end-of-life, focusing on key impact categories including Global Warming Potential (GWP), Acidification, Eutrophication, Mineral Resource Scarcity, and Terrestrial Ecotoxicity.

The assessment identifies the use phase as the predominant contributor to environmental impact, accounting for over 90% of total emissions in most categories, primarily due to fuel combustion associated with airborne operation. However, as this phase lies largely outside the control of Saab Surveillance, a complementary scenario excluding the use and test phases was conducted to better identify actionable environmental hotspots within the company's sphere of influence.

Detailed analysis of the assembly phase revealed that components containing printed circuit boards, especially those with gold-plated finishes, exert a disproportionately high environmental burden per kilogram, driven by the energy-intensive and material-intensive processes associated with gold production. Furthermore, structural components made from iron-nickel-chromium alloys were found to contribute significantly to acidification and resource depletion due to nickel-related emissions.

Recommendations for improving the environmental performance of the radar system include adopting more aerodynamic and lightweight designs, sourcing materials from low-emission suppliers, utilizing alternative plating methods such as nickel-palladium-gold, and exploring bio-based composite materials. Additionally, the study highlights the potential benefits of implementing a formal end-of-life disposal plan and considering take-back systems for high-impact components such as PCBs.

The results provide a strategic foundation for Saab Surveillance to reduce its environmental footprint, enhance supply chain sustainability, and align future product development with ecological and regulatory expectations.

Keywords: Life Cycle Assessment, Environmental Hotspots, Gold-plating.

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Abbreviations

LCA	Life Cycle Assessment
GWP	Global Warming Potential
ISO	International Organization for Standardization
TRM	Transmitter Receiver Module
PCB	Printed Circuit Board
EoL	End of Life
NO_x	Nitrogen Oxides
SO₂	Sulfur Dioxide
Cu-Eq	Copper Equivalents (used in material scarcity category)
DCB-Eq	1,4-Dichlorobenzene Equivalents (used in ecotoxicity category)

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1 Introduction

1.1 The Need for Sustainability in an Evolving Defense Landscape

The current state of the environment is marked by accelerating climate change, resource depletion and widespread pollution which is driven mostly by industrial production and the increasing use of complex materials and technologies (UNEP, 2021). Sectors like aerospace and defense which rely on energy intensive processes, rare earth metals and hazardous substances, carry high environmental burden and must respond proactively to sustainability immediately.

In this context conducting a Life Cycle Assessment (LCA) plays a crucial role as both a diagnostic and a design tool. Mostly used to quantify environmental impacts across a product's life cycle from raw material extraction and manufacturing to end of life disposal. LCA is increasingly used in Environmental Conscious Design (ECD), rather than evaluating impacts it can be integrated early in the design process to guide material selection, improve energy efficiency, reduce emissions and minimise waste across the products lifecycle (Hauschild et al., 2018; International Organization for Standardization [ISO], 2006). This makes it a key driver especially in demanding systems like airborne radar.

The geopolitical landscape in Europe has shifted dramatically in recent years, leading to a significant increase in military expenditure and a surge in defense-related industries. In 2024, European military spending rose by 17% to 693 billion USD ((SIPRI), 2025), marking the steepest rise since the end of the Cold War, largely driven by the ongoing conflict in Ukraine and broader security concerns. As military expenditures rises the defense industry is scaling up production and accelerating technological innovation to meet strategic demands. However this rapid expansion also increases environmental pressures making it essential to evaluate and mitigate ecological impacts associated with the development and deployment of defense systems (Aerospace & of Europe (ASD), 2025).

In this context, LCA serve as a critical tool for ensuring that the pursuit of national security does not come at the expense of environmental responsibility.

1.2 Sustainability at SAAB

Saab is advancing sustainability by integrating environmental, social and governance (ESG) considerations across its operations as part of its long term strategic goals. Their sustainability framework is guided by the vision of contributing to resilient and safe societies. Saab's sustainability framework focuses on climate impact reduction, circularity, responsible sourcing and social responsibility.

By 2025, Saab aims to reduce Scope 1 and 2 ghg emissions by 4.2% annually from a 2020 baseline and scope 3 emissions by 2.5% annually. Its long term objective is to achieve net zero emissions across all scopes by 2050. Saab is actively working to engage 50% of its suppliers in science based climate targets by 2027 (Saab, 2024a).

At the product level, the company is phasing out hazardous substances and implementing substitution programs aligned with EU regulations to improve safety and sustainability across its supply chain (Saab, 2024b). The company is also increasing the quality and coverage of product material declarations by 20% improving transparency and supporting regulatory compliance. In line with its circularity goals, Saab is embedding Environmental conscious design (ECD) into new product development, ensuring that sustainability considerations are incorporated from the design phase (Saab, 2024a, 2024c).

1.3 Technical Overview of the Erieye Radar System

The Erieye is an airborne surveillance radar system developed by Saab, designed to be mounted on an aircraft for long range detection and tracking of airborne and surface targets.

For the purpose of this LCA, the radar system is divided into two main subsystems, structure and electronics. This division is based on internal knowledge provided by Saab experts and is used to track components and assess environmental impacts throughout the life cycle.

The structure subsystem includes the physical components required to mount and support the radar on the host aircraft.

These components include:

- **Composite** housing that encloses and protects the electronics
- **Struts** for mechanical stability and load transfer
- **Cables and installation set** required for integration
- **Fairing** for aerodynamic and structural purposes

The electronics subsystem contains sensing and signal processing elements responsible for the radar's functionality. It includes:

- A **Microwave unit** for generating and processing radar signals
- An **antenna array** for signal transmission and reception
- A **distribution box** for power and integration
- Additional **cabling** for internal connectivity

This division is illustrated in figure 1 and a picture of Erieye mounted on to an aircraft can be seen in figure 2.

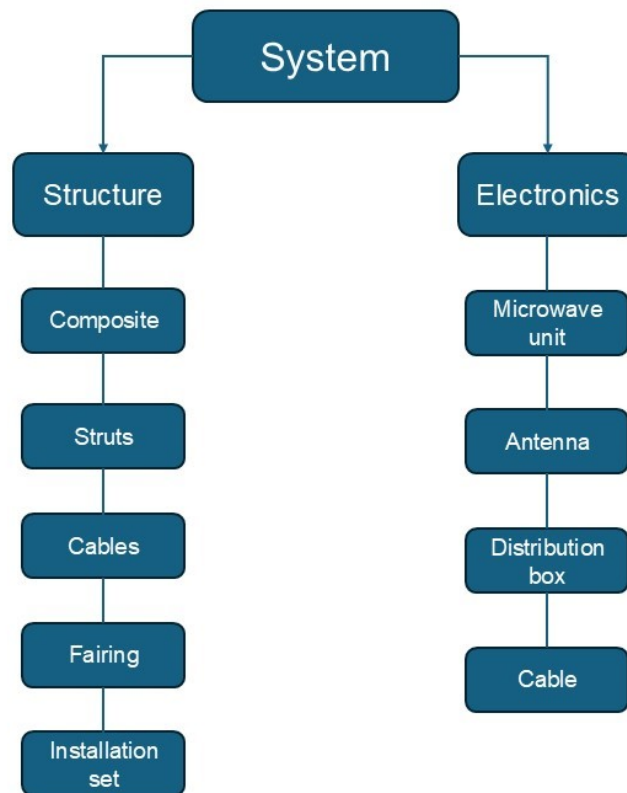


Figure 1: Technical breakdown of the Erieye radar system. The system is divided into two main subsystems: *Structure* and *Electronics*, each consisting of component groups relevant to their respective functions.



Figure 2: The Erieye Radar mounted on SAABs Nextjet 340.

1.4 Aim and Research Questions

The aim of this life cycle assessment (LCA) is to evaluate the environmental impacts associated with Saab's Erieye radar system from cradle to grave. This study seeks to identify environmental hotspots and assess the which components and life cycle stages contribute most significantly to the total impact. Insights gained will support Saab's internal sustainability

efforts and guide product development.

The primary audience for this study is Saab's internal teams that can use the results to make improvements and reduce environmental impacts. In addition the report should be of interest to researchers and professionals working with LCA in the defense sector. Information about the hotspot materials and phases can also help with decision-making when producing similar products outside of the defense sector.

The study addresses the following research questions:

- what are the environmental impacts associated with the radar system?
- which life cycle phase contributes the most to environmental impact?
- how does the impact categories vary across the different lifecycle phases of the radar system?
- what component of the radar system has the highest environmental impact?

2 Life Cycle Assessment Method

This section introduces the life cycle assessment (LCA) method used in this study. LCA is a standardised and widely adopted framework that is used to assess the environmental impact associated with all stages of a product's life from raw material extraction through production, use and end of life management.

The methodology applied in this study is based on the international standards ISO 14040 and ISO 14044, which are the foundational documents used for conducting an LCA.

ISO14040 gives the general principles and framework of LCA. It defines the four phases of an LCA study, goal and scope definition, life cycle inventory analysis, life cycle impact assessment and interpretation. The standard also focuses on fundamental methodological principles such as system boundaries and the avoidance of burden shifting.

In contrast ISO14044 provides the the technical requirements and guidelines that is needed in each phase of an LCA. It includes criteries for defining the functional unit, selecting system boundaries and handling allocation in multi-functional processes. It also outlines how to conduct inventory data collection, apply life cycle impact assessments and perform interpretation activities such as sensitivity analysis, uncertainty evaluation and critical review. The standard also differentiates between types of LCA applications.

By applying both these standards it ensures the studies methodological consistency and scientific robustness throughout the LCA and its adoption enhances the transparency and comparability of the results which can be used to support the use for internal decision making and future sustainability assessments.

2.1 Goal and scope definition

The first phase of the LCA is the goal and scope definition, this phase establishes the context and foundation for the entire study. It ensures that all methodological choices made throughout the assessment are consistent with the intended purpose and application of the results.

In the goal definition, the purpose of the study is clearly described including the reason for conducting the LCA, the intended audience and whether the results will be used internally, externally or for comparative reasons. Establishing a clear goal is essential for determining the appropriate level of detail, data quality requirements and critical review needs (Baumann & Tillman, 2004).

The scope definition supports the goal by outlining the key methodological aspects of the study, including:

- The functional unit, which provides a reference to which all data are normalised and allows for comparability between different systems
- The system boundaries which defines which life cycle stages and processes are included or excluded from the assessment
- The allocation procedure which describe how to handle multi functional processes where inputs and outputs must be divided among different product systems
- Selection of impact categories, assessment methods and assumptions or limitations relevant to the study.

Throughout the LCA, the goal and scope definition must remain flexible. As new information will appear during the life cycle inventory or impact assessment phases, iterative revisions may be necessary to ensure that the study remains consistent and valid (Baumann & Tillman, 2004).

2.2 Life cycle inventory analysis

The second phase of a LCA is the life cycle inventory analysis. As described by Baumann and Tillman, 2004, this phase involves the collection and quantification of all environmental inputs and outputs associated with the product system and the aim is to construct a detailed accounting of the flows of energy, materials, emissions and waste across the system boundaries defined in the previous phase.

LCI is often considered the most time-consuming part of an LCA and this is due to the volume of data required and the complexity of the supply chain. Baumann and Tillmann recommend decomposing the product system into a flowchart of interconnected phases to manage the complexity. For each process data must be collected for:

- Inputs, such as raw materials, auxiliary substances and energy carriers
- Outputs, such as emissions to air, water and soil as well as solid waste and co-products

The inventory includes both foreground data which is data directly related to the studied system and typically collected from the industry, and background data which is generic data collected from databases such as Ecoinvent used for upstream or downstream processes.

In many cases allocation becomes necessary especially when a process yields multiple products or functions. ISO14044 outlines a hierarchical approach for handling multifunctional processes. First, allocation should be avoided, either by dividing the process into sub-processes or by expanding the system boundary to include additional functions. If this is not possible then allocation may be based on physical relationships such as mass or energy content (ISO, 2006)

Another complexity in LCI is dealing with the gaps and uncertainties. Where data cannot be found, estimates may be used. But these estimates must be clearly described and where possible subjected to sensitivity analysis. As the inventory develops it may also be necessary to return to earlier phases such as redefining the system boundaries or revising the assumptions, reinforcing the iterative nature of the LCA process (Hauschild et al., 2018).

In the end, the LCI provides the quantitative basis for the LCIA phase. Its consistency and dependability are crucial for generating significant results and credible conclusions.

2.3 Life cycle impact assessment

The third phase of the LCA is the life cycle impact assessment. The purpose of this phase is to evaluate the significance of the potential environmental impacts associated with the inventory flows identified in the LCA. In other words, LCIA translates the quantitative data collected in the LCI phase such as CO₂ emissions or energy use into environmental impact indicators, such as climate change and acidification.

As described in (Baumann & Tillman, 2004), the LCIA consists of several mandatory and optional step. The mandatory step include:

- Classification: assigning each LCI flow to one or more relevant environmental impact categories. Such as methane emissions may be classified under climate change and human toxicity
- Characterisation: quantifying the contribution of each classified flow using scientifically derived characterisation factors. These factors express the relative contribution of a substance to a specific impact category.

Optional steps which may be included depending on the goal of the study are:

- Normalisation: expressing the results relative to a reference value as this will help contextualise the results and compare the impact of different impact categories

- Weighting: assigning value-based importance to impact categories and aggregating results into single score. This is helpful for decision making however according to the ISO14040 it is not allowed if the product is to be compared to competing products due to this method including value judgements.

There are several LCIA methods available such as ReCiPe, CML and TRACI. Each differing in regional scope and modelling detail. These methods characterize environmental impacts using midpoint indicators. The choice of method should reflect the study's objective and ensure compatibility with the inventory data (Hauschild et al., 2013; Huijbregts et al., 2017).

The LCIA does not produce absolute measures of damage, but rather relative indicators that highlight potential EI. These results support the interpretation phase where their relevance is assessed in the context of the goal and scope (ISO, 2006).

2.4 Interpretation

The final phase of the LCA is the interpretation phase and it serves to analyse the results in light of the study's objectives and methodological choices (ISO, 2006). The interpretation phase involves reviewing the results of the inventory and impact assessment to determine which processes, materials or life cycle stages have the most significant influence on the overall environmental impact (Baumann & Tillman, 2004).

To evaluate the reliability of the results, methods such as sensitivity and uncertainty analysis are often used. This help assess how variations in the input data or assumptions could affect the overall conclusions (Hauschild et al., 2018). When results are intended for external use or decision making, ISO recommends that the study undergoes a critical review by an independent party to confirm methodological consistency and data quality.

3 Goal and Scope

In this chapter, the purpose and scope of the LCA is described to establish a methodological foundation for the study. The sections that follow define how the system is modeled including its functional unit, system boundaries, type of LCA, and impact categories.

3.1 Goal of the Study

The goal of this study is to fulfill the aim and answer the research questions presented in Section above.

3.2 Functional Unit

The functional unit of the study is defined as one unit of Saab's Erieye radar system over a 25-year lifespan. The radar unit itself is not mobile as it is designed to be integrated to a host aircraft. As such the environmental impact associated with life cycle of the aircraft are excluded from the system boundaries. However, the environmental impacts resulting from operating the aircraft such as fuel consumption during flight are included in the assessment.

The operational profile of the radar is based on an assumed usage of 1000 hours per year, distributed across 240 flight cycles annually with each cycle being approximately 6 hours.

3.3 Type of LCA

This study is based on a conventional attributional LCA, where conventional refers to the evaluation of an existing technology under present day conditions using average data. The assessment focuses on the Saab Erieye radar system as it is currently designed and operated. An attributional approach is used to quantify the environmental impact associated with the direct material and energy flows entering and leaving the product system over its life cycle (Baumann & Tillman, 2004; Finnveden et al., 2009).

3.4 Impact Categories

The environmental impact in this study is assessed using the ReCiPe 2016 midpoint (H) method, which is one of the most widely used and scientifically robust LCIA methods available. ReCiPe translates the LCI results into environmental impact indicators into two levels, midpoint and endpoint. In this study midpoint indicators are used as they provide a better understanding of the contribution of emissions and resource use to distinct environmental problems (Huijbregts et al., 2017).

ReCiPe 2016 includes 18 midpoint impact categories which can be grouped under three broader endpoint areas of protection: human health, ecosystems, and resource availability. These relationships are illustrated in Fig. 3, which shows how individual environmental mechanisms link to long-term environmental damage pathways.

For our study, we will focus on the most relevant aspects of the radar system. The following midpoint categories are selected for detailed evaluation.

- Climate Change
- Terrestrial Acidification
- Terrestrial Ecotoxicity
- Mineral Resource Scarcity
- Freshwater Eutrophication

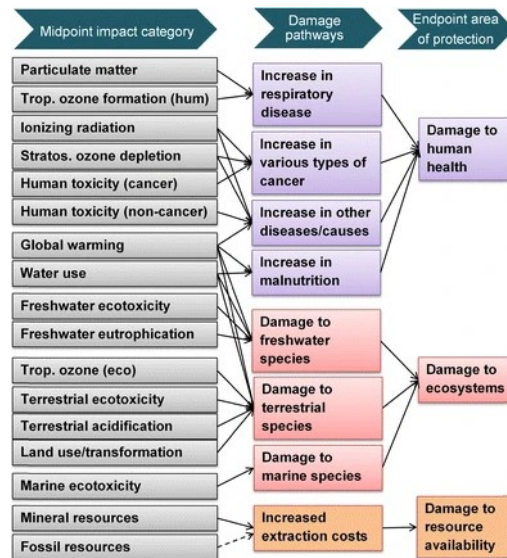


Figure 3: Relationship between ReCiPe 2016 midpoint impact categories, damage pathways, and endpoint areas of protection.

3.5 System boundary

Defining the system boundaries is an important step in LCA, as it establishes the scope of the analysis and determines which life cycle stages, processes and flows are included in this study (Baumann & Tillman, 2004; ISO, 2006).

This section defines the system boundaries applied in the present assessment, including the system under study, the geographical and temporal scope, the boundaries within the technical system and the allocation procedure used to handle multifunctional processes. Together, these elements ensure that the study remains consistent with the defined goal and scope and that the modeling choices are transparent and consistent.

3.5.1 The System Under Study

This study focuses on the Saab Erieye airborne radar system, assessing its environmental impacts over a 25 year operational lifetime. The system is modeled from a cradle to grave perspective including upstream, operational and EoL processes.

The system is divided into two main systems, background and foreground system. The foreground system includes processes under Saab's direct control or influence. These comprise the assembly, verification and testing, use phase, maintenance and transportation by Saab. Product specific data has been collected for these steps where available.

The background system consists of upstream processes such as raw material extraction, material production and processing, transportation not controlled by Saab and EoL treatment. Also electricity and fuel production is taken into account. Data for these processes are sourced from LCA databases or through our own literature research and represent market averages, incorporating both primary and secondary materials. Material production is modelled to include the environmental burdens of raw material extraction and transformation into usable inputs.

For the EoL stage, a combination of landfill, incineration and recycling is assumed. Here a literature study is done, in order to replicate a real-world scenario as close as possible. Following the cut off approach to open loop recycling (Ekvall & Tillman, 1997), any downstream benefits from recycled materials are excluded from the system boundaries. As a result, environmental credits for recycled outputs are not assigned to the radar system.

A flowchart of the product system and associated life cycle stages is presented in fig 4.

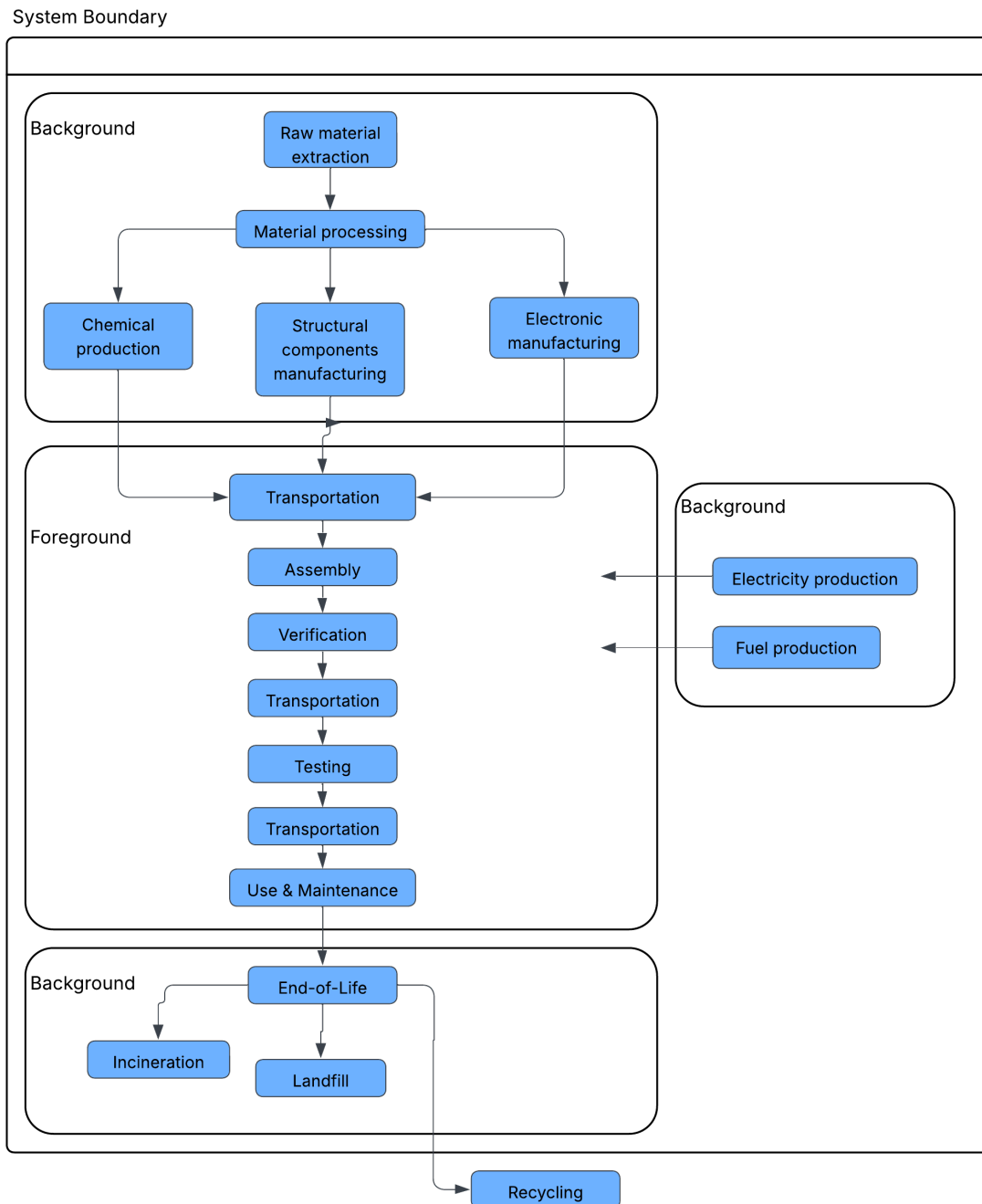


Figure 4: Overview of the life cycle stages and system boundaries of the Erieye radar system. The diagram distinguishes between foreground and background systems and indicates external flows such as electricity production, fuel production, and open-loop recycling. (Source: Author)

3.5.2 Geographical Boundary

The geographical boundary of this study is defined based on the locations of production, use, and EoL treatment relevant to the Erieye radar system. The manufacturing and assembly of the system are modelled on the basis of conditions in Sweden, where Saab's production facilities are located. This includes Sweden's energy mix.

The use phase is modelled with a global perspective as the radar system is deployed in various regions. Since the aircraft may operate under different energy conditions, the modelling assumes a global average.

For the EoL stages the data will be based on global averages, once again, since the radars disposal takes place at SAABs end-customers which are located all around the world.

3.5.3 Temporal Boundary

This study represents a current LCA, meaning that the product system modeled reflects the Erieye radar system as it exists at the present time (Arvidsson et al., 2018). The assessment is based on the most recent available data and does not include any changes to the product system. The radar is assumed to have an operational lifetime of 25 years which is consistent with internal expectations for similar system in service.

Primary data were collected from internal sources at Saab using IFS, covering the period from 1996 (when it was first launched) until today with supplementary data obtained through internal interviews with experts which was conducted in spring 2025. These sources were used to guide the modeling of component materials, energy use, maintenance schedule and production processes. As the system is not mass produced but rather custom made for individual customers, with this in mind, the study is based on the most recent production of the Erieye system which took place in 2022. Any updates made on not-yet released systems will not be included.

The background data used in this study, such as material production and electricity supply, are drawn from the Ecoinvent 3.11.1 database, which reflects present day conditions.

3.5.4 Allocation

Allocation was applied at two points in the life cycle, during the use phase and the EoL stage. In accordance with ISO 14044, allocation was only used when necessary and based on a physical relationship between the flows, as recommended when allocation cannot be avoided (ISO 2006b).

In the use phase, the Erieye radar system contributes to the overall consumption of the host aircraft. Since the aircraft serves multiple functions, only a portion of the total fuel use was assigned to the radar system. This was done using mass based allocation, in where the environmental burden associated with fuel combustion were distributed based on the radar system's share of the aircraft total mass (Baumann & Tillman, 2004).

At the EoL stage the study applies the cut off approach. In this approach materials leaving the system for recycling are not assigned any environmental credit for future reuse and the burden of materials production are instead fully borne by the first product system. This means that while recycled materials are modeled as outputs, the benefits of their reuse will be outside the system boundary and will not be accounted for (Baumann & Tillman, 2004).

4 Inventory Analysis

The inventory analysis was the most time-consuming part of this thesis, primarily due to the inconsistent, incomplete, and varied quality of available data. Also, the radar is a big and complex product made up of countless big and small parts. This necessitated a multi-step and adaptive approach to data collection and validation.

4.1 Material Composition and Data Collection

4.1.1 Primary Data: IFS Excel Sheet

Our primary source of material data was obtained in collaboration with domain experts at Saab, using their internal IT system, *IFS* (Industrial and Financial System). Through this platform, we extracted a comprehensive Excel sheet. This report organized the radar's components into a multi-level hierarchy of subassemblies and included details such as part quantities, mass, volume, and surface area.

The initial Excel sheet included data for approximately **14,000 parts**, but only provided reliable information for **60–70%** of these. The remaining data was either missing or faulty, and could not be used directly.

4.1.2 Secondary Data: Manual IFS Retrieval and Material Declarations

To address data gaps, we conducted manual searches in IFS using part numbers. This allowed us to retrieve **Material Declaration Sheets** either from SAAB or their suppliers. From these documents, we obtained essential material properties—such as density, thickness, or application method—in order to calculate missing values for mass, volume, or area. Another approach in the manual search was to examine the product through radar design and mechanical design in CAD. A CAD-program which showed us a visual view of some of the components was used, this helped us retrieve data such as lengths, areas and heights, but also to deepen our understanding about the radar.

4.1.3 Expert Estimations

In cases where neither the Excel Sheet nor the material declarations or CAD provided sufficient data, we consulted SAAB experts with deep knowledge of the radar system. These individuals worked either in radar construction or in CAD-based design and had extensive product experience. Their input was considered highly reliable and their estimations filled the remaining data gaps.

4.1.4 Aggregated Component Mass

After compiling data from the IFS QuickReport, material declarations, and expert estimates, the total material mass was aggregated at a component level. Each major part of the radar system was broken down into its components, and their material weights were summarised. This aggregation gives a high level view of the material composition of the radar and helps understand system wide material use.

The results are presented in figure 5, which lists the aggregated total mass for each component of the radar system.

4.1.5 Inventory coverage summary

To evaluate the completeness of our data collection, we calculated the percentage of the system mass that each type of data covered. Figure 6 summarises this breakdown.

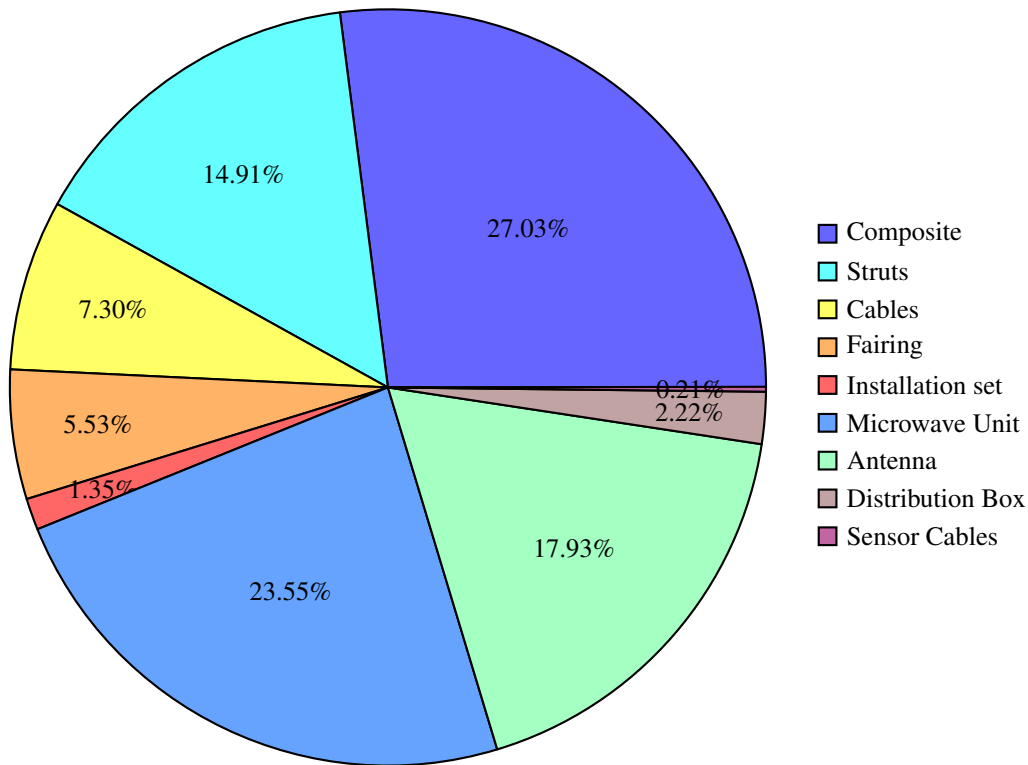


Figure 5: Mass breakdown of Erieye's components in percentage

4.1.6 Data Confidence Level

To evaluate the quality of data, we classified the data we obtained into three confidence levels:

- **High confidence:** Direct measurements or well-documented IFS data.
- **Medium confidence:** Estimates based on Material Declarations or expert opinions.
- **Low confidence:** Approximations based on proxy data or assumptions where no documentation was available.

The majority of the systems mass that was derived from high or medium confidence is around 80% ensuring the reliability of the data.

4.1.7 Example Component Breakdown

To illustrate the level of complexity and the methodology used in the data collection process, Table 1 shows detailed material breakdown for one component **Installation set**. This component was chosen because it includes a mix of materials and substances such as metals, coatings and plastics.

4.1.8 Mass-Based Allocation Approach

As previously described in Section 3.5.4 mass-based allocation was used to assign a share of aircraft-level fuel consumption to the radar system during the **test phase** and **use phase**. This approach is justified because these are the only stages in which the radar is mounted on the aircraft and contributes to its total operational load.

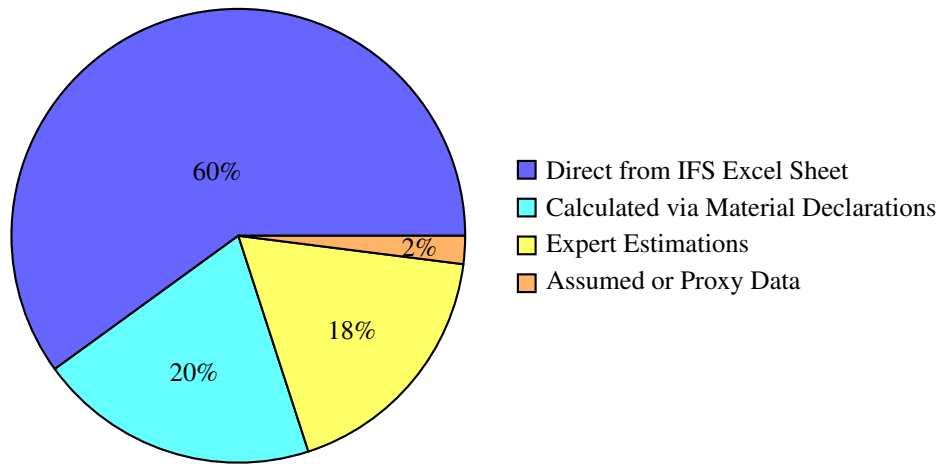


Figure 6: Estimated coverage of total system mass by data source

The environmental burdens associated with fuel combustion were allocated proportionally based on the radar system's share of the total system mass. This follows the method outlined by Baumann and Tillman, 2004. To preserve confidentiality, the actual weights are not disclosed. However the resulting allocation factor is:

- Mass allocation factor (radar / total system): **3.7%**

This factor was applied consistently to fuel use across both phases to ensure a fair representation of the radar's impact within the overall aircraft system boundary.

Installation Set	Share of total mass (%)
Aluminium Alloy	23.738
Polyester Label	0.143
Chromate coating	0.004
Primer (bisphenol A epoxy based vinyl ester resin)	0.004
Polyurethane topcoat	2.729
Polyester Label	0.286
Finishing lacquer	0.001
n-butyl acetate	0.109
Xylene	0.043
Butyl-alcohol	0.043
Acrylic varnish	0.001
Sodium hydroxide, caustic soda	0.043
Manganese dioxide	0.043
Polysulfide	0.043
Phthalic anhydride	0.043
Lead	0.017
Connector adapter	0.176
Lead	0.017
Adapter jack stainless steel	1.710
Mounting flange stainless steel	0.018
LD Polyeten	0.174
PVC	0.181
Nickel-chromium stainless steel	0.041
Stainless steel washer	0.020
2x16 power divider	70.432

Table 1: Material Quantities in Percentage

4.2 Process Data Collection

4.2.1 Transportation Phase

Throughout the radar system life cycle it undergoes several transport stages, these include inbound transport from suppliers, internal transport between Saab facilities and outbound delivery to customers for the foreground system. Transport is also included in the background system via the Ecoinvent database.

Transportation	Flow type	Unit	Amount
Supplier to Saab site A	Airplane	km	635.00
Saab site A to Saab site B	Truck	km	274.00
Saab site A to Customer	Airplane	km	5607.50

Table 2: Transport distances and modes for Erieve radar system

The transport distances presented in table 2 are based on average values. The distances from the suppliers to Saab site A represents the mean distance calculated from several key suppliers, while the customer delivery distance reflects the average distance based on the actual shipments from the radar system to the customers.

4.2.2 Assembly Phase

The assembly of the radar system is divided into mechanical and electrical assembly and both are carried out in Saab facilities. Energy consumption during these processes was estimated based on an old LCA conducted at Saab on a similar radar system in 2015 (Gustafsson and Rönnblom, 2015). Given the technical similarities between the systems, the values reported in the study were considered representative for the current analysis. The duration for each assembly part has been taken with the help of Saab engineers that work with assembly. In the assembly phase all the materials that are used in the radar and their upstream processes are also included. Products, materials or substances are all taken into account as shown earlier in Table 1.

Process	Duration	Power Draw	Amount	Unit
Mechanical Assembly	230 hours	0.048 kW	11.40	kWh
Electrical Assembly	40 hours	0.72 kW	28.80	kWh

Table 3: Energy use during radar assembly phase

As shown in Table 3, the mechanical assembly involved a lower power draw (0.048 kW) sustained over a longer duration, resulting in 11.40 kWh of electricity use. Whilst electrical assembly required significantly more power (0.72 kW) but was completed in just 40 hours, resulting in a higher total energy use of 28.80 kWh.

4.2.3 Verification Phase

The verification phase is an important part of the radars production cycle and is divided into two activities, burn-in and characterisation. Burn-in testing is done to identify potential early life failures by running the radar continuously under standard operating conditions. Whilst the characterisation phase involves high intensity testing to measure the system's performance under varying electrical and environmental conditions.

Process	Duration	Power Draw	Amount	Unit
Verification: Burn-in	90 hours	3.8 kW	342.00	kWh
Verification: Characterisation	150 hours	48 kW	7200.00	kWh

Table 4: Energy use during radar verification phase

Table 4 shows the resulting energy use for each of these activities. Data for the power draw has been taken from Saab's internal energy budget for the radar and the duration for each activity is taken from expert estimations.

4.2.4 Test Phase

The test phase is the last phase before delivery to customer and in this phase the full system is evaluated. During this phase the radar is operated under realistic conditions to verify functionality and integration with the host plane. This phase generates significant energy demand from both radar operation and fuel consumption.

Table 5 presents the electricity use for radar operation and the Jet A-1 fuel consumed by the aircraft during the test phase.

Test Phase Process	Duration / Cycles	Total Use	Rate / Assumption
Radar electricity use	648 hours	33,700 kWh	-
Jet A-1 fuel use	108 flight cycles	40,389 kg	374 kg per cycle

Table 5: Energy and fuel use during radar system test phase

4.2.5 Use Phase

The use phase represents the most energy intensive part of the radar life cycle. It includes both the electricity consumption and the fuel consumption under operation. It is important to note that radar usage can vary significantly depending on the customer with this in mind we selected the most likely scenario based on expert input whilst acknowledging that this phase over which Saab has limited control. The 25 year lifetime is also a rough estimate as no radar system has reached the end of their life cycle and have also had a longer lifetime than 25 years.

Table 6 presents the key parameters used to model the use phase. To protect performance-sensitive information, specific power ratings, durations, and cycle-level consumption values have been withheld.

Parameter	Value	Description
System lifespan	25 years	Expected operational life of the radar system
Operational hours per year	1000 hours	Estimated annual usage duration
Flight cycles over lifespan	6000 cycles	Estimated number of operational cycles
Fuel consumption per cycle	Confidential	Average Jet A-1 fuel allocated to radar use per cycle
Fuel density	0.8 kg/L	Used for converting fuel mass to volume

Table 6: Operational parameters and energy use during radar system use phase

The total calculated electricity use and fuel use for the radar across its life time are shown in Table 7. These values were derived from estimates and reviewed internally.

Use Phase Activity	Resource	Unit	Total Use
Radar electricity use	Electricity	kWh	1,300,000
Jet A-1 fuel use	Jet A-1	kg	2,243,884

Table 7: Total electricity and fuel use during the radar system use phase

4.2.6 Maintenance Phase

Maintenance of the radar system occurs periodically throughout its operational lifetime and involves the replacement of key components. Due to limited data on the average number of parts replaced during the lifetime of the radar, we only focused on one key component which is the transmitter/receiver modules (TRMs). We chose the TRMs because it was the only part where we had data on the number of replacements, all other parts only had data on how often they should be inspected. Also, via expert consultation, we learned that the TRMs is the parts that are most often replaced in the radar.

This does not take into account the repaired TRMs which is handled internally by Saab so the repaired TRMs were excluded from the assessment, as no data was available regarding their reparation frequency.

It is roughly estimated that around three TRMs may require replacement each year leading to a total of approximately 75 replacements over a 25 year lifetime. This estimate is not based on empirical failure data but was developed in collaboration with Saab personnel familiar with the system. As such it should be viewed as a worst case scenario used to ensure that the maintenance phase is not excluded.

It is important to remember that the actual maintenance frequency can vary significantly depending on the customers usage patterns and the operational environments.

The environmental impact of replacements was modelled in OpenLCA by replicating the production and transport processes for each unit replaced. This makes sure that the material and process contributions of maintenance are captured in the life cycle model.

4.3 End-of-Life Assumptions

Saab has minimal influence over the radar's EoL treatment, as disposal is entirely up to the customer. Furthermore, no radar systems sold by Saab have yet reached the end of their life cycle, leaving no empirical data to draw upon.

We therefore made assumptions based on global average treatment practices, supported by literature review, see Table 8. Materials were categorized by their expected EoL treatment (for Training et al., 2024 for Economic Co-operation and (OECD), 2022 Monitor, 2024 Institute, 2024).

Material	Share of total mass (%)	Waste Flow
Steel	11	85% recycled, 15% landfill
Aluminium	33	75% recycled, 25% landfill
Plastics & Composites	29	9% recycled, 19% incinerated, 72% landfill
Coatings & Surface treatments	2	Average of steel, aluminium, and plastics. Applied on these materials.
Cables, Connectors and Electronics	24	22% recycled, 78% landfill
Sealants, Lubricants & Miscellaneous	1	Average of steel, aluminium, and plastics. Applied on these materials.

Table 8: Material percentages and corresponding waste flow distribution

Where necessary, components were grouped by expected joint behaviour during disposal. For example, lubricants applied to plastic, steel, or aluminium components were considered to be part of the same waste stream.

4.4 Data Entry and Quality in OpenLCA

Following the data collection phase, all information was compiled and entered into **OpenLCA**. In most cases, we were able to find *exact matches* for materials, substances, or process flows. However, in some cases where exact matches were unavailable, we used the most similar available flow. These substitutions affected only a small number of data entries.

This process was covered not only for material data but other process flows associated with each life cycle stage. The following sections detail the criteria used to justify these proxy flows.

4.5 Proxy Flow Justification

In cases where no exact matches were found for materials, processes or flows in OpenLCA, proxy flows were selected based on the following criteria:

- **Matching material type:** For example if a specific alloy wasn't available, a similar material was used such as aluminium.

- **Similar life cycle stage:** The proxy flow needed to be from the same life cycle stage to minimise variation in environmental impact.

These substitutions affected only a small amount of the total flows, making sure that the overall impact of the radar system was carefully assessed to avoid variations in the final results.

4.5.1 Data Quality and Limitations

The inventory analysis was based on internal documents, expert input, and external databases such as Ecoinvent 3.11.1. The primary data from the IFS QuickReport was considered reliable, although 30-40% of the entries were incomplete. For these cases, expert judgment and material declarations were used to estimate missing values, which introduces a degree of subjectivity to the data. On top of that, some material and process flow had no exact equivalents, in such a case closest matching flows were used instead. These proxy flows may affect the precision of the result in some phases of the life cycle.

4.5.2 Ethical/Confidentiality Constraints

Certain data was withheld due to confidentiality agreements with Saab. These restrictions limit full transparency in some part of the analysis.

While the lack of data impacts the reproducibility of this analysis, the methodology is transparent and consistent. The data used in the LCA has been validated internally by experts, and all assumptions have been documented to provide the most transparency given the constraints.

5 Impact Assessment

The environmental performance of the system's components was quantified. The focus was on five key impact categories: acidification potential (kg SO₂-eq), global warming potential (GWP, kg CO₂-eq), eutrophication potential (kg P-eq), material resource use (kg Cu-eq) and Terrestrial Ecotoxicity (kg 1,4 DCB-Eq). Both total impact and normalized impact per kilogram of component mass were analyzed for some scenarios. We decided to divide them into four different scenarios:

- Full Lifecycle of the radar
- Full Lifecycle of the radar without Test- or Use Phase
- Only counting the Assembly Phase, basically all the materials in the radar and their manufacturing
- Only counting the Structure part of the Assembly Phase

5.1 Full Lifecycle

5.1.1 Acidification Potential

Acidification, measured in **kg SO₂-equivalents** and illustrated in figure 7, was overwhelmingly dominated by the *Use phase*, contributing **56,411 kg SO₂-eq**, which accounts for the vast majority of the total impact. The next most significant contributors were the *Test phase* with **1,018 kg SO₂-eq** and *Assembly* at **419 kg SO₂-eq**. Other phases, including *Transportation* (**317 kg SO₂-eq**), *Maintenance* (**69 kg SO₂-eq**), *Verification* (**0.93 kg SO₂-eq**), and *EoL* (**0.05 kg SO₂-eq**) had comparatively negligible contributions.

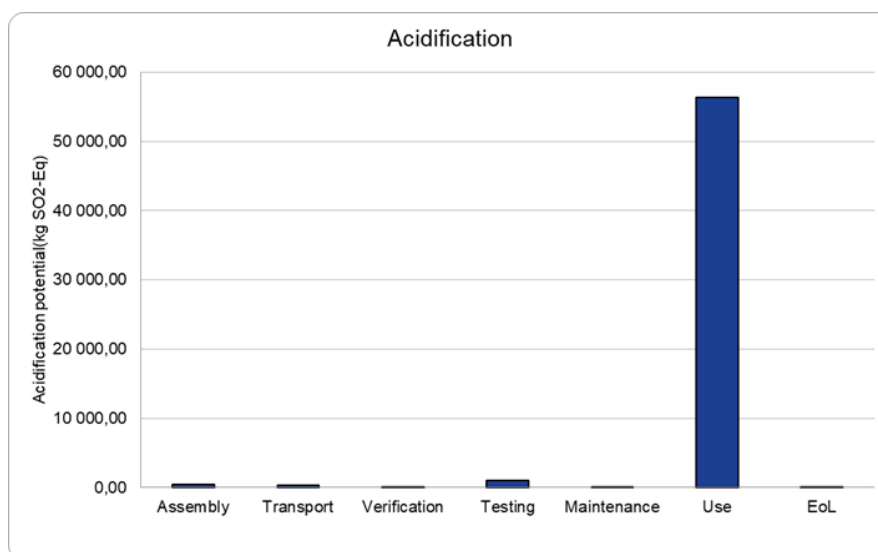


Figure 7: Total Acidification Potential of the different phases.

5.1.2 Global Warming Potential (GWP)

Global Warming Potential (GWP), expressed in **kg CO₂-equivalents** and depicted in figure 8, was also dominated by the *Use phase*, which accounted for **13,120,054 kg CO₂-eq**. This far exceeded all other life cycle stages. The next most impactful phases were *Test phase* with **236,615 kg CO₂-eq**, *Transportation* (**133,192 kg CO₂-eq**), and *Assembly* (**82,636 kg CO₂-eq**). Contributions from *Maintenance* (**14,678 kg CO₂-eq**), *EoL* (**424 kg CO₂-eq**), and *Verification* (**280 kg CO₂-eq**) were comparatively minor. These results further underscore the dominant climate impact of the *Use phase* in the system's life cycle.

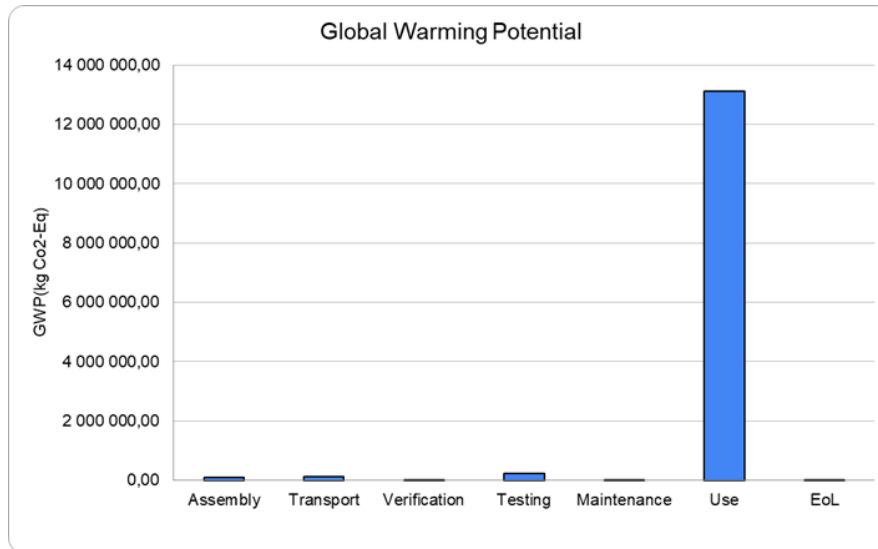


Figure 8: Total Global Warming Potential of the different phases.

5.1.3 Freshwater Eutrophication

Freshwater eutrophication, measured in **kg P-equivalents** and presented in figure 9, was predominantly caused by the *Use-phase*, which contributed **1,861.00 kg P-eq**, accounting for the majority of the total impact. Other contributing phases included *Assembly* with **97.00 kg P-eq**, *Testing* (**33.86 kg P-eq**), and *Maintenance* (**21.34 kg P-eq**). The remaining phases—*Transport* (**1.83 kg P-eq**), *Verification* (**0.11 kg P-eq**), and *EoL* (**0.01 kg P-eq**)—contributed marginally. These results highlight the significant burden of the *use-phase* on eutrophication potential over the product's life cycle.

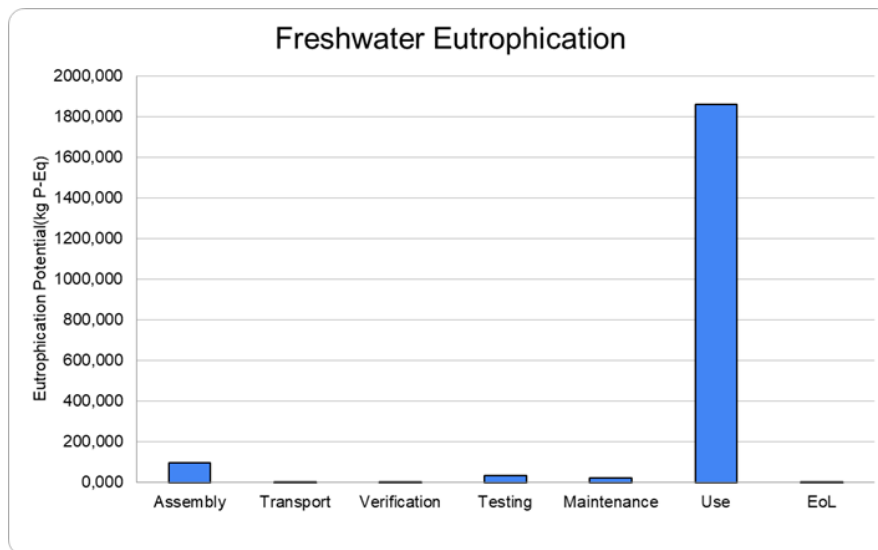


Figure 9: Total Eutrophication Potential of the different phases.

5.1.4 Mineral Resource Scarcity

Mineral resource scarcity, expressed in **kg Cu-equivalents** and shown in figure 10, was primarily driven by the *Use-phase*, which accounted for **418,171.00 kg Cu-eq**, representing nearly the entire total impact. The *Test-phase* was the next most significant contributor with **7,549.64 kg Cu-eq**, followed by *Assembly* (**2,947.99 kg Cu-eq**). Other life cycle phases, such as *Maintenance* (**620.00 kg Cu-eq**), *Transport* (**588.30 kg Cu-eq**), *Verification* (**9.54 kg Cu-eq**), and *EoL* (**2.10 kg Cu-eq**) had marginal contributions. Once again these results emphasize the dominant role of the *use-phase*, this time in contributing to potential mineral resource depletion.

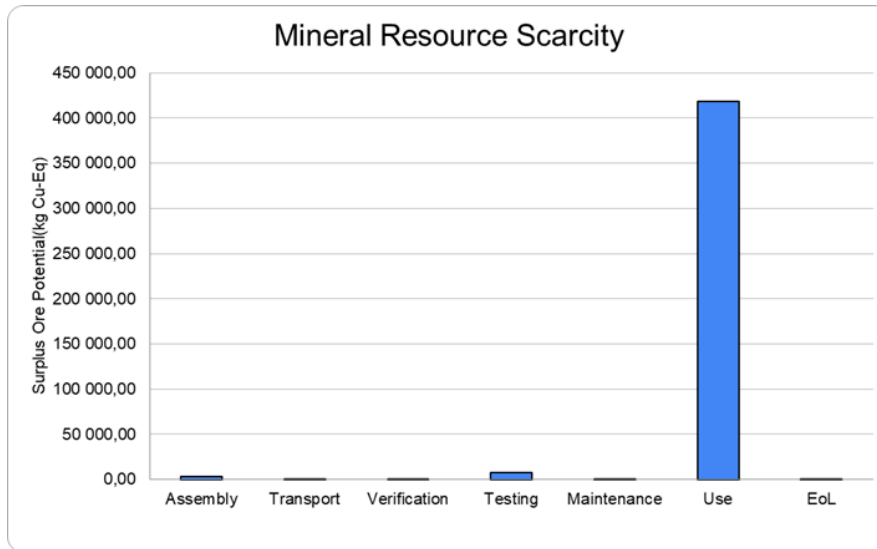


Figure 10: Total Surplus Ore Potential of the different phases.

5.1.5 Terrestrial Ecotoxicity

Terrestrial ecotoxicity, reported in **kg 1,4 DCB-equivalents** and visualized in figure 11, was also dominated by the *Use-phase*, contributing a substantial **49,376,390.00 kg 1,4 DCB-eq** out of the total **51,183,420.88 kg 1,4 DCB-eq**. Other noteworthy contributors included the *Testing-phase* with **908,579.00 kg 1,4 DCB-eq** and *Assembly* at **852,281.00 kg 1,4 DCB-eq**. The *Transport* and *Maintenance* phases added smaller impacts of **27,580.00 kg** and **14,363.00 kg** respectively. Minimal contributions came from *Verification* (**3,315.88 kg**) and *EoL* (**912.00 kg**). These results clearly identify the *use-phase* as the critical driver of terrestrial ecotoxicity within the product life cycle.

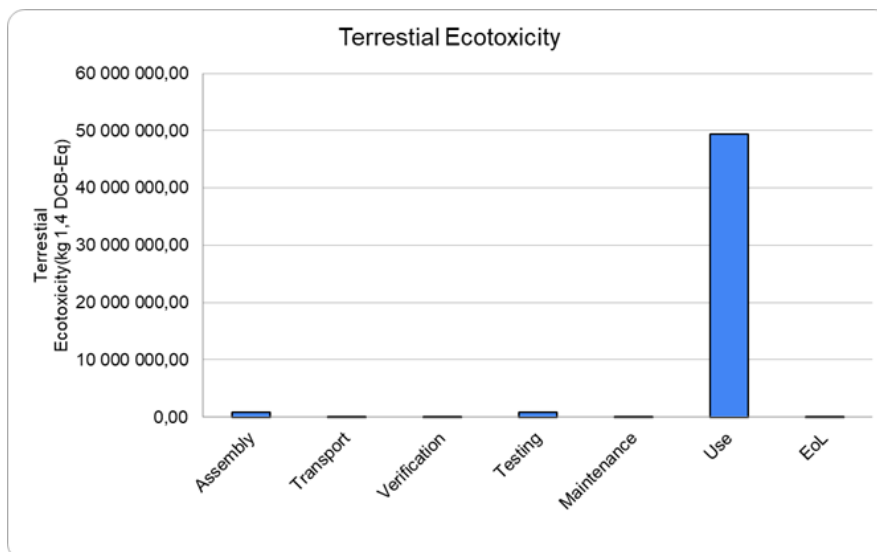


Figure 11: Total Terrestrial Ecotoxicity of the different phases.

5.1.6 Comparison between Categories & Phases

To provide a clearer comparison across impact categories and highlight overall trends, all life cycle phases were aggregated and their respective contributions to the total environmental impact were analyzed. As illustrated in Figure 12, the *use phase* consistently dominates across all impact categories, contributing more than **95%** of the total impact in each case. The only notable deviation from this pattern is observed in the *eutrophication* category, where the *assembly phase* contributes approximately **5%** of the total impact, representing the most significant non-use-phase contribution across all categories.

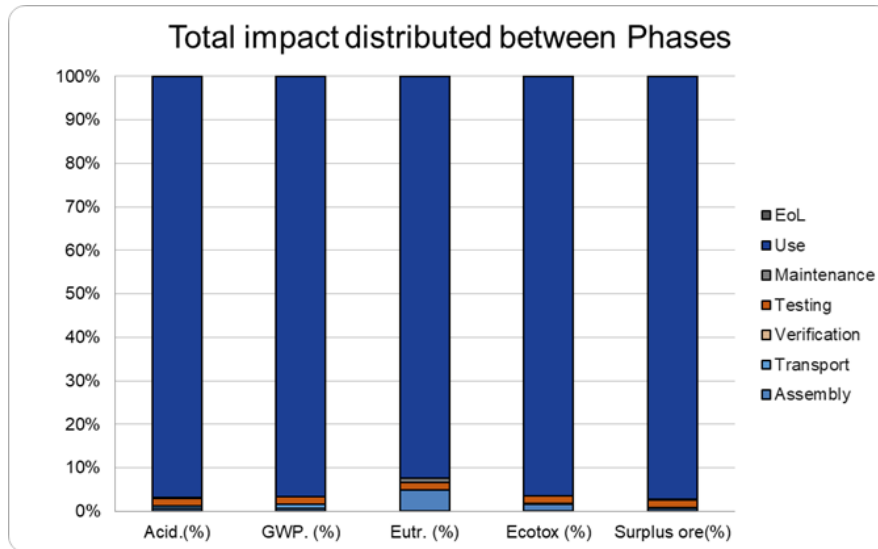


Figure 12: Contribution of the different phases across all Impact Categories.

5.2 Full Lifecycle without Use- or Test Phase

The *use* and *test* phases were identified as dominant contributors to the total life cycle impact of the radar system. However, these phases are largely managed by **SAAB Aeronautics**, which is responsible for the aircraft and its operation, and therefore fall outside the direct control of **SAAB Surveillance**. To enable a more focused analysis of the phases under SAAB Surveillance's influence, we conducted a separate scenario with a comparison of the environmental impact excluding the *use* and *test* phases. This approach allows for a clearer visualization of environmental hotspots among the remaining phases and supports the development of more actionable and relevant sustainability recommendations specifically for SAAB Surveillance.

5.2.1 Comparison between Categories & Phases

Figure 13 illustrates the relative contribution of each life cycle phase excluding the use and test phases, to the total impact across five environmental categories. The *assembly phase* is the most significant contributor in all categories except *global warming*. It is particularly dominant in *terrestrial ecotoxicity* and *freshwater eutrophication*, where it accounts for more than 80% of the impact. The *transportation phase* also shows notable contributions, especially in *global warming* and *terrestrial acidification*. *Maintenance*, *verification*, and *end-of-life (EoL)* phases generally contribute minimally but *Maintenance* is noteworthy in categories such as *mineral resource scarcity* and *freshwater eutrophication*. These results highlight the assembly and transport phases as primary focus areas for impact reduction efforts within SAAB Surveillance's control.

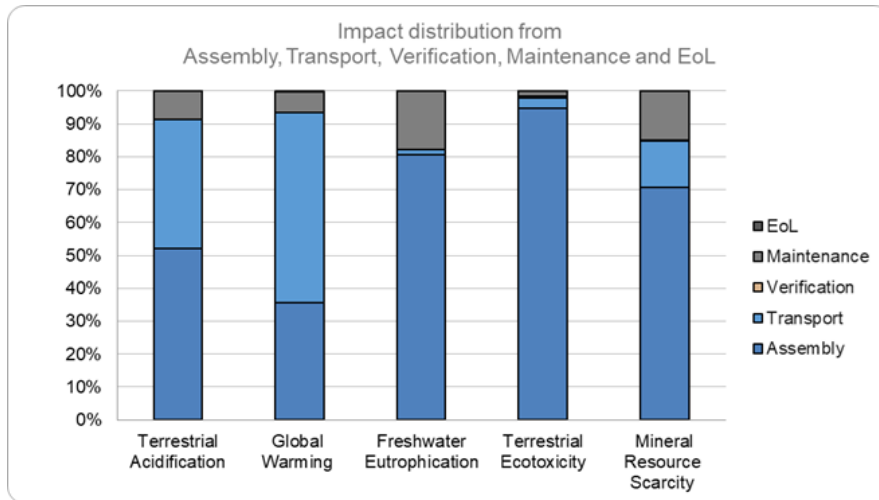


Figure 13: Contribution of the different phases across all Impact Categories without the Use- or Test phase.

5.3 Assembly Phase

Here we present the results for just the *assembly phase*. This is important because this is the phase that **SAAB Surveillance** has most control over. Also, it is fully focused on the materials in the radar and their production, while also including the energy used in the assembling of the materials.

5.3.1 Acidification Potential

The highest total contribution to acidification was recorded for the *Microwave Unit*, at **178 kg SO₂-eq**, followed by the *Antenna* with **71.93 kg SO₂-eq**, and the *Installation Set* with **50 kg SO₂-eq**. These values reflect the combined effect of component mass and material composition, see figure 14.

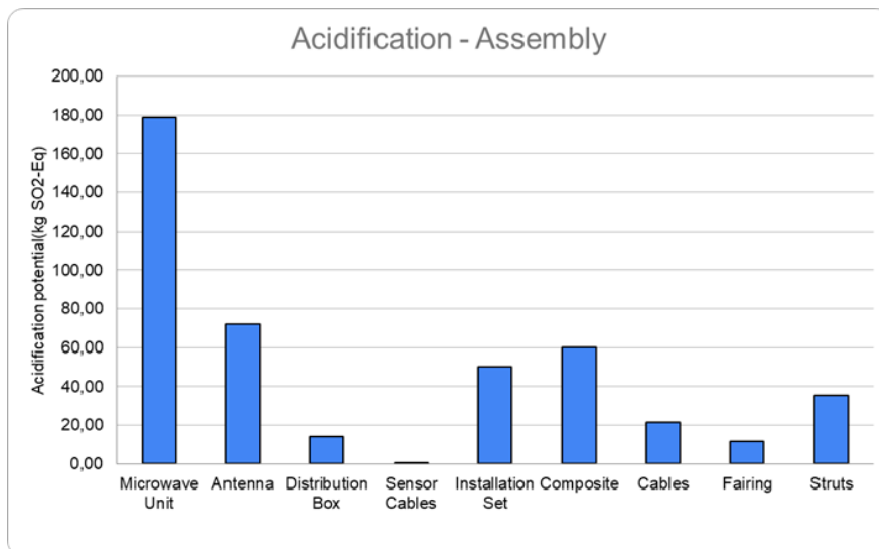


Figure 14: Total Acidification Potential of the different components.

When normalized by weight, the *Installation Set* exhibited the highest acidification intensity at **3.59 kg SO₂-eq/kg**, followed by the *Microwave Unit* (**0.73 kg SO₂-eq/kg**) and the *Distribution Box* (**0.61 kg SO₂-eq/kg**). See figure 15.

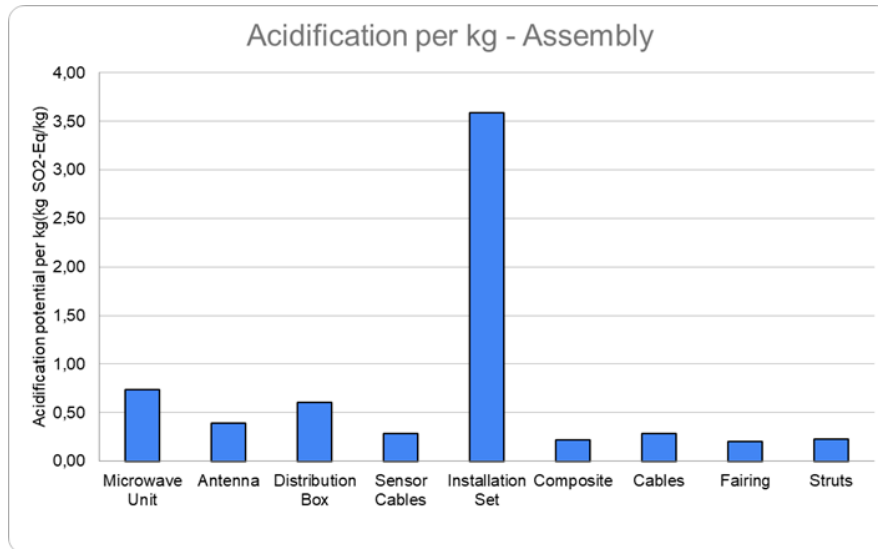


Figure 15: Total Acidification Potential of the different components per kg of component.

5.3.2 Global Warming Potential (GWP)

The *Microwave Unit* also had the highest total **GWP**, reaching **37,640 kg CO₂-eq**, more than double that of the *Antenna* (**15,211 kg CO₂-eq**). The *Installation Set* and *Distribution Box* followed with **12,510 kg CO₂-eq** and **2,933 kg CO₂-eq**, respectively.

Normalized by weight, the *Installation Set* again had the highest impact at **895 kg CO₂-eq/kg**, followed by the *Microwave Unit* (**154.36 kg CO₂-eq/kg**) and *Distribution Box* (**127 kg CO₂-eq/kg**).

Both these results can be seen in figure 16 and 17 respectively.

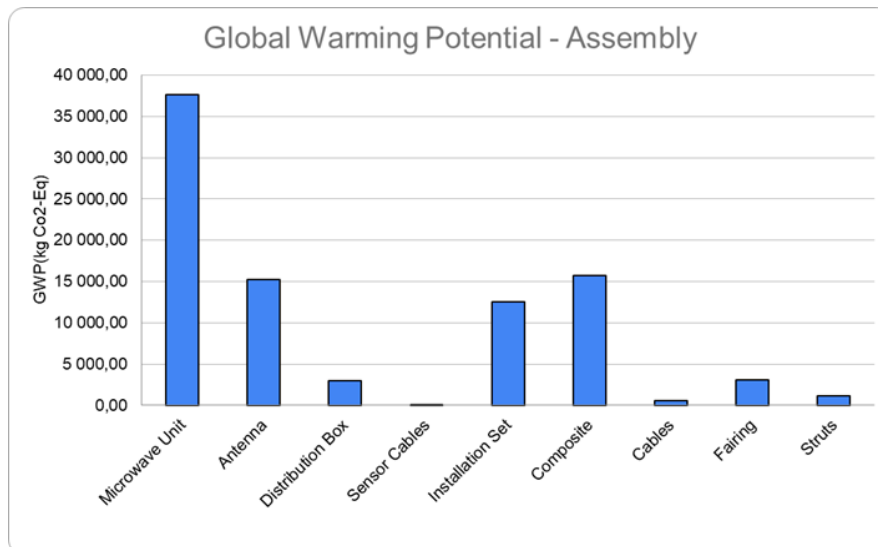


Figure 16: Total Global Warming Potential of the different components.

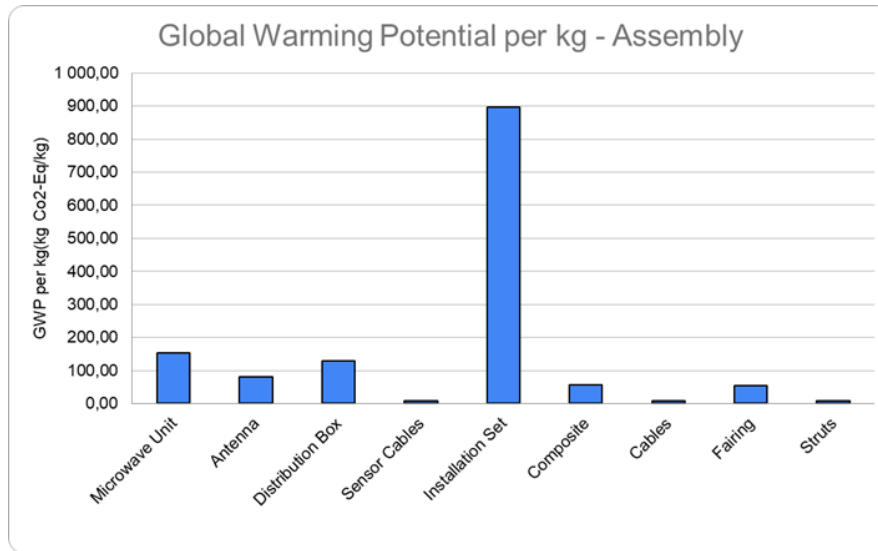


Figure 17: Total Global Warming Potential of the different components per kg of component.

5.3.3 Freshwater Eutrophication

Eutrophication potential was assessed using the freshwater eutrophication indicator, measured in **kg P-eq**. The *Microwave Unit* showed the highest total contribution with **8.13 kg P-eq**, followed by the *Antenna* (**3.18 kg P-eq**) and the *Installation Set* (**2.50 kg P-eq**). Other components such as the *Distribution Box* and *Sensor Cables* had lower total values of **0.63 kg P-eq** and **0.003 kg P-eq**, respectively, see figure 18.

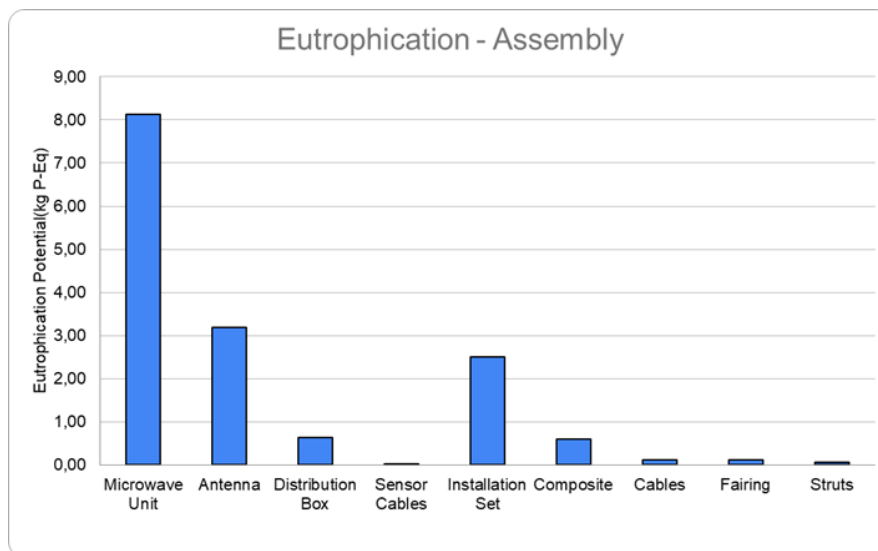


Figure 18: Total Eutrophication Potential of the different components.

When normalized by weight, the *Installation Set* showed the highest impact per kilogram at **0.18 kg P-eq/kg**, significantly exceeding all other components. The *Microwave Unit* and *Distribution Box* followed with normalized values of **0.03 kg P-eq/kg** and **0.02 kg P-eq/kg**, respectively, see figure 19.

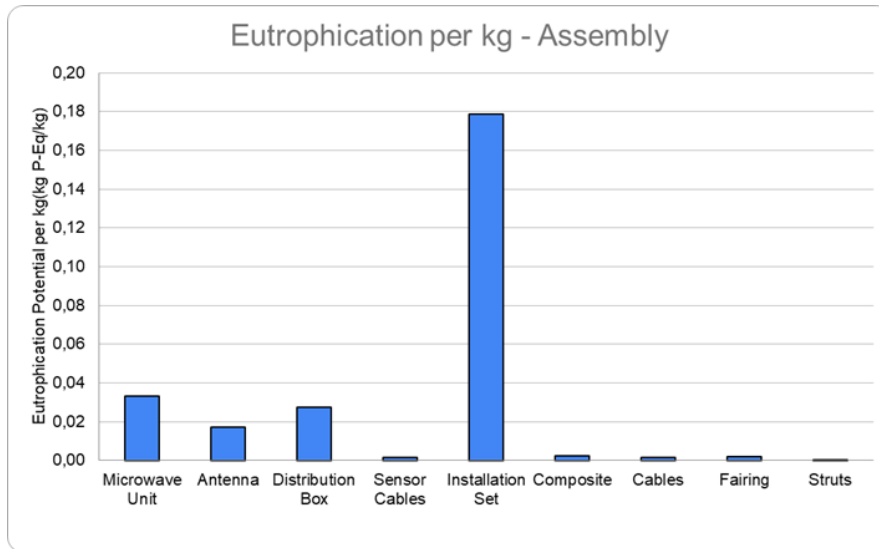


Figure 19: Total Eutrophication Potential of the different components per kg of component.

5.3.4 Material Resource Use

Material resource use, measured in **kg Cu-equivalents** and seen in figure 20 was highest for the *Microwave Unit* at **1,591 kg Cu-eq**, followed by the *Antenna* (**629 kg Cu-eq**) and the *Installation Set* (**428 kg Cu-eq**).

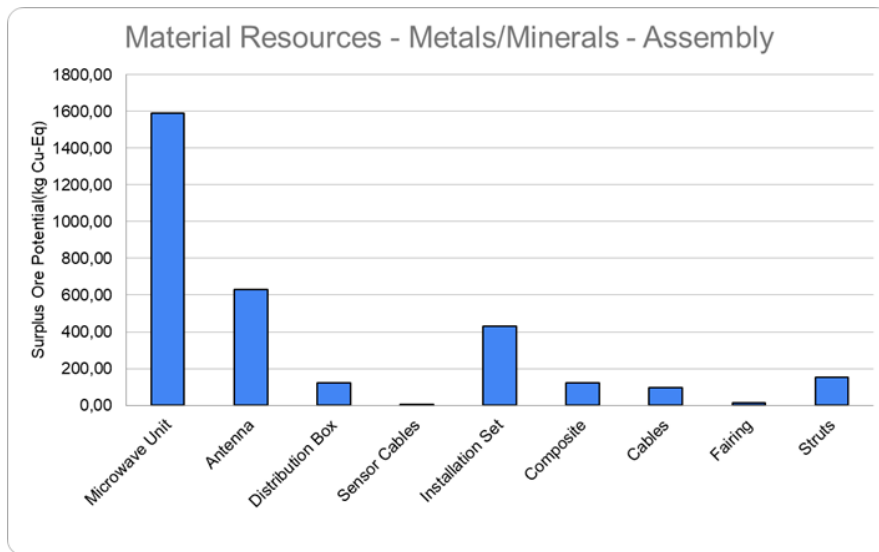


Figure 20: Total Surplus Ore Potential of the different components.

When normalized per kilogram, as seen in figure 21, the *Installation Set* had the highest intensity at **30.7 kg Cu-eq/kg**. Followed by the *Microwave Unit* (**6.53 kg Cu-eq/kg**) and the *Distribution Box* (**5.38 kg Cu-eq/kg**).

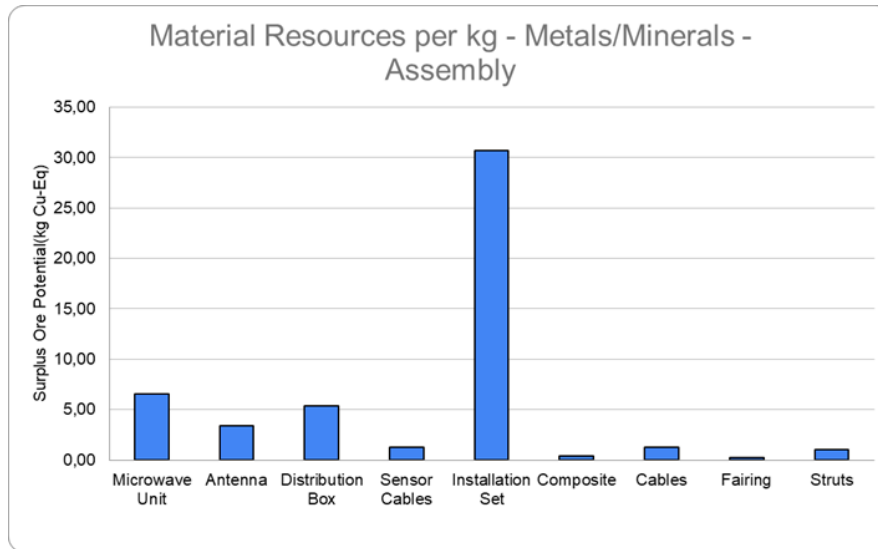


Figure 21: Total Surplus Ore Potential of the different components per kg of component.

5.3.5 Terrestrial Ecotoxicity

Terrestrial ecotoxicity, measured in **kg 1,4 DCB-equivalents** and illustrated in figure 22, was highest for the *Microwave Unit* at **368,272 kg 1,4 DCB-eq**, followed by the *Antenna* and the *Composite*, each with **144,973 kg 1,4 DCB-eq**. The *Distribution Box* (**28,551 kg 1,4 DCB-eq**) and the *Struts* (**69,290 kg 1,4 DCB-eq**) also contributed significantly.

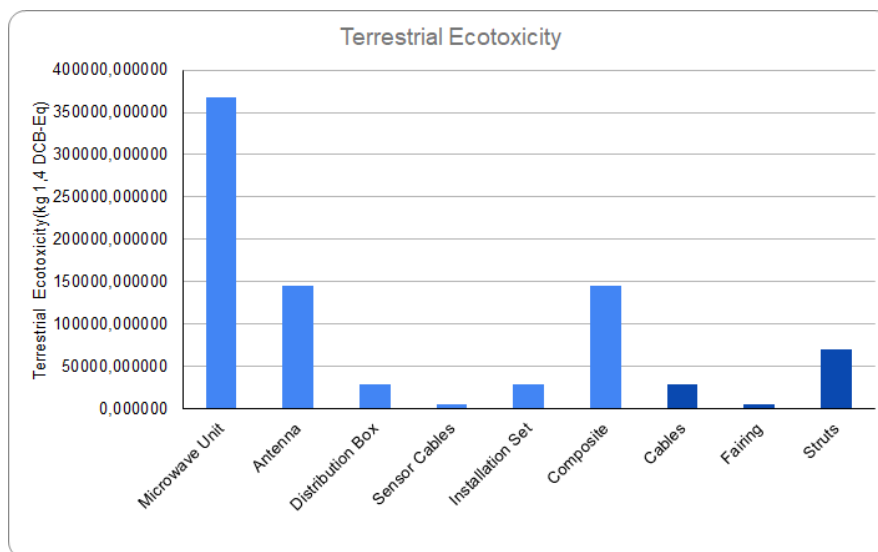


Figure 22: Total Terrestrial Ecotoxicity of the different components.

When normalized per kilogram of component weight, as seen in figure 23, the *Sensor Cables* had the highest terrestrial ecotoxicity intensity at **2,324 kg 1,4 DCB-eq/kg**, followed by the *Installation Set* (**2,050 kg 1,4 DCB-eq/kg**) and the *Distribution Box* (**1,245 kg 1,4 DCB-eq/kg**). Despite its high total impact, the *Microwave Unit* ranked fourth in intensity with **1,510 kg 1,4 DCB-eq/kg**.

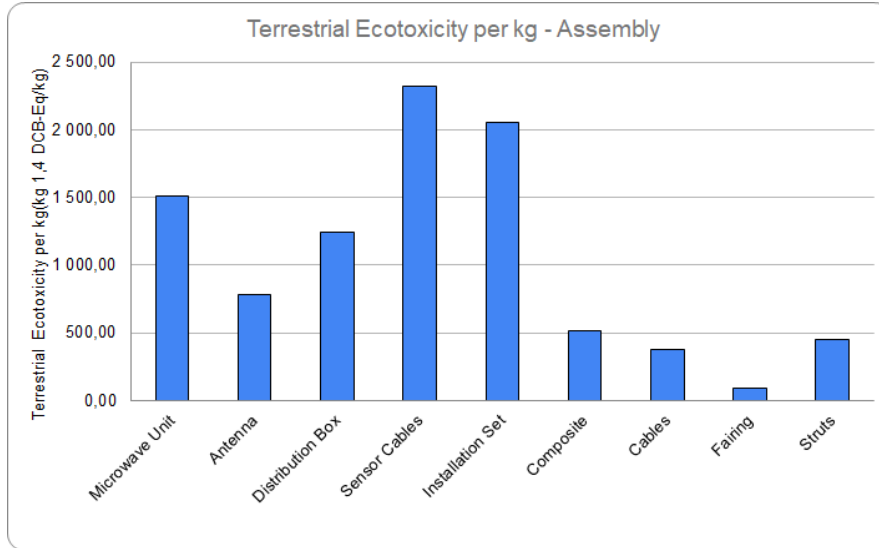


Figure 23: Total Terrestrial Ecotoxicity of the different components per kg of component.

5.4 Structure

A big part of the environmental impact in the assembly phase came from the *Electronics* side of our system. To be able to draw more conclusions from the *Structure* side we also created a scenario where we only look at the impacts from the *Structure*.

5.4.1 Comparison between Categories & Phases

Figure 24 presents the distribution of environmental impacts among the structural components across five impact categories. Here, the results are a bit more diverse and different components have big impacts in different categories. The *installation set* has its biggest contribution in *freshwater eutrophication*, *Global Warming* and *Material Resource Use*. *Struts* shows the biggest impact in *terrestrial ecotoxicity* while *Composite* shows its biggest contribution in the *Global Warming* category. *Cables* contribute notably in *terrestrial ecotoxicity* and *Acidification* while the *Fairing* has a comparatively minor impact across all categories. These results gives insight into which components that affect which categories.

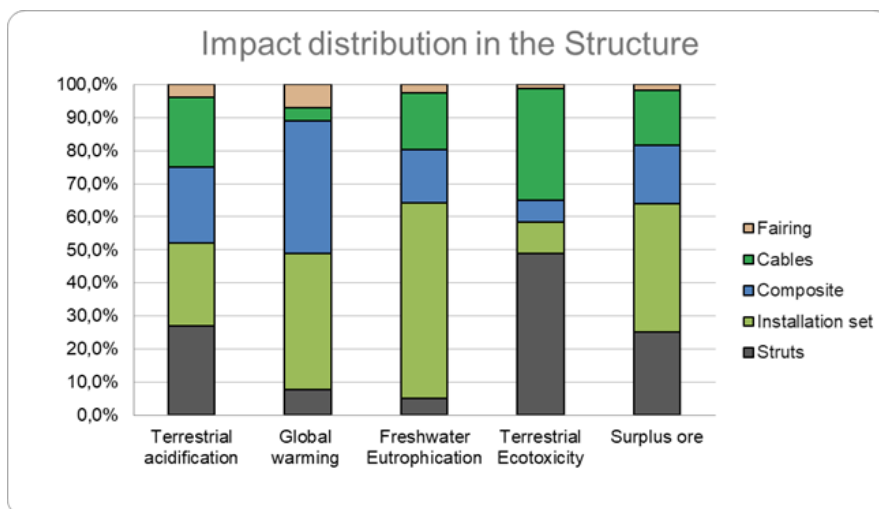


Figure 24: Contribution from the different components across all Impact Categories.

6 Interpretation

In the interpretation chapter that follows we will review the results from our inventory analysis and impact assessment. We want to get answers to our research questions and analyze any other interesting findings. Some reiteration back to the earlier phases will also be done to create different scenarios in which we can analyze what and how we can lower the radars environmental impact in the most efficient way. An uncertainty analysis will also be performed to analyze the potential affect from the variation on the data and processes in the data collection.

6.1 Interpretation of the different scenarios

In the following sections we will present our interpretation of the results from the *impact assessment*, for all four scenarios under study as well as Impact per kilogram in the Assembly scenario.

6.1.1 Full Lifecycle

The *use-phase* clearly dominates the environmental impact across all assessed categories, contributing over **90%** of the total impact in every category. Upon closer analysis, the primary cause of this substantial contribution is the combustion of **Jet A-1 aviation fuel** (see Figure 25), which is used by the Global 6000 aircraft (Bombardier Defense, 2025). Carbon dioxide emissions from fuel combustion are the main contributor to the *Global Warming Potential (GWP)*, while emissions of nitrogen oxides (NO_x) significantly affect the *Acidification Potential* category (European Environment Agency, 2001; NOAA Climate.gov, 2023).

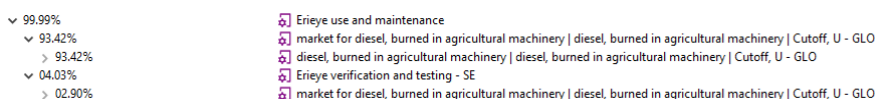


Figure 25: Excerpt from OpenLCA, showing the big contribution from the burning of fuel on the use-phase. "Diesel, burned in agricultural machinery" is a proxy flow for the burning of Jet Fuel. Jet Fuel and Diesel has nearly identical emissions of CO₂ and NO_x per kg of fuel.

In the case of *Mineral Resource Scarcity*, the use-phase also shows the highest relative contribution. This impact is primarily attributed to the materials and infrastructure associated with fuel extraction, refining, and distribution processes, including ships and vehicles involved in fuel logistics (Wang et al., 2024).

These findings are consistent with previous life cycle assessments of radar systems conducted at SAAB, where the use phase was found to account for approximately **80–90%** of the total impact across all categories (Gustafsson and Rönnblom, 2015; Johansson and Schmidt, 2023). However, the current study reveals an even higher share, ranging from **90–95%**, indicating a more pronounced environmental burden during operation for airborne systems compared to ground-based systems.

Not just the share, but also the total environmental impact from the use phase of the airborne radar system is significantly higher than that of previously studied ground-based systems, such as the *Arthur radar* studied by Johansson and Schmidt, 2023. For example, the total GWP for the Arthur system is approximately **1.7 million kg CO₂-eq.** while for the Erieye radar, it is around **13 million kg CO₂-eq.** This difference is logical, considering that the average fuel consumption of a military aircraft is considerably higher than that of a ground-based military vehicle because of fundamental physical and operational factors.

Unfortunately, no previous LCA studies on airborne radar systems, neither at SAAB nor in the broader academic literature, are currently available for direct comparison. This study therefore provides a novel and valuable contribution to understanding the environmental profile of airborne radar technologies.

6.1.2 Full Lifecycle without Use- or Test Phase

In order to better understand the environmental impact of the remaining life cycle phases, a scenario was developed in which the *use* and *test* phases were excluded from the analysis. These two phases were found to dominate the

results across all impact categories, primarily due to the extensive fuel combustion involved. This made it difficult to meaningfully interpret the contributions of the other phases. Furthermore, as previously discussed, these phases fall largely outside the operational control of **SAAB Surveillance**, being managed instead by other departments within SAAB or by the end user.

When excluding the use and test phases, the total environmental impacts across all categories are substantially reduced. Approximately by a factor of **100**.

In this modified scenario, the *assembly* and *transport* phases emerge as the dominant contributors. The transport phase shows the highest impact in the *Global Warming Potential (GWP)* and *Acidification Potential* categories, primarily due to emissions of **carbon dioxide (CO₂)** and **nitrogen oxides (NO_x)** from air and road freight fuel consumption.

The *maintenance* phase is most impactful in categories influenced by the replacement of *Transmitter Receiver Modules (TRMs)* in the component *Microwave Unit*, aluminum casings containing printed circuit boards, see Figure 26. On average, approximately **three TRMs** are replaced annually during the operational lifetime of the system. As mentioned earlier, this phase does not take into account the TRMs that are actually repaired and then re-assembled into the radar, as there were no data on this procedure. Knowing this, the impacts we present might be a bit higher than the actual case.

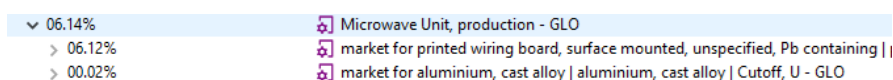


Figure 26: Excerpt from OpenLCA, showing the big proportion that "market for printed wiring board" accounts for in the *Microwave Unit* production.

A more detailed material-level assessment of these environmental impacts is provided in the following scenario.

6.1.3 Assembly Phase

The assembly phase includes all materials used in the radar system as well as the upstream production chains associated with those materials. It excludes other life cycle stages such as transport to and from SAAB, use phase, verification, testing, and end-of-life treatment. Therefore, the results presented here reflect only the embedded environmental impact of material extraction, refinement, component manufacturing and their assembly at Saab.

The results show that the *Microwave Unit* exhibits by far the highest total environmental impact across all examined categories. A more detailed analysis reveals that this is primarily driven by the printed circuit boards (PCBs) embedded in the transmitter modules, as seen earlier in Figure 26.

For the categories *climate change*, *acidification*, *material resource scarcity*, and *eutrophication*, the main contributor is the gold plating used on the PCBs. This result aligns with previous studies in the electronics and aerospace sectors, where the high energy intensity and material scarcity of electronic subsystems often dominate the environmental footprint (Andrae and Andersen, 2010; Deng et al., 2011). The production of PCBs involves energy-intensive processes such as etching, lamination, plating, and soldering, often requiring the use of precious and heavy metals in very small quantities that nonetheless have disproportionate impacts.

Among the most impactful materials identified in the assessment is gold, used predominantly in surface finishes such as electroless nickel immersion gold (ENIG) for improved conductivity and corrosion resistance on contact surfaces and edge connectors.

Gold's exceptionally high environmental burden is a result of:

- **Extremely low ore concentration:** On average, only 1–5 grams of gold are extracted per ton of ore, requiring enormous material throughput (Nuss and Eckelman, 2014).
- **Toxic processing methods:** Gold extraction typically involves cyanide leaching, a process that is both toxic and water-intensive, often contributing to ecotoxicity, human toxicity, and water pollution (UNEP, 2019).
- **High energy demand:** The smelting, refining, and purification stages for gold are exceptionally energy-intensive, contributing significantly to global warming potential (GWP).

In the context of the radar system assessed here, the impact of gold is further amplified by the market context. According to the ecoinvent database and global trade models, the environmental burden attributed to gold is not only due to production but also reflects the high global demand, price volatility, and the supply chain concentration in regions with less strict environmental regulations (ecoinvent Association, 2022; Graedel et al., 2015).

In the *terrestrial ecotoxicity* category, copper becomes the primary contributor. This is due to the high levels of sulfur dioxide (SO₂) emissions associated with copper smelting, which is one of the largest sources of global SO₂ emissions and a key driver of ecotoxicity (Andrews et al., 2025; CarbonChain, 2023).

In the subcomponent *Cables*, copper in the wires is again the dominant contributor across most categories. In the *Antenna* subcomponent, gold plating, this time used on the radar waveguides, is once more identified as the material with the greatest environmental burden.

These findings highlight the significant environmental impacts associated with precious and conductive metals, particularly gold and copper, and underline the importance of careful material selection and recycling strategies in the design of high-tech components.

6.1.4 Impact per Kilogram of components in the Assembly Phase

To better understand the relative environmental burden of each subcomponent in the assembly phase, we normalized the results by the mass of each subcomponent, calculating the environmental impact per kilogram.

The component with by far the highest impact per kilogram is the *Installation Set*. This can be attributed to its high share of electronic content, over 70% of its total mass consists of power dividers, connectors, and adapters, see Figure 1 in the inventory analysis. As in previous analyses, the printed circuit boards (PCBs) within the power dividers are the main contributor to the elevated impact. Within these PCBs, it is once again the upstream production chain of gold that is responsible for the majority of the environmental burden.

These results underscore the need for careful consideration of high-impact electronic components in early design phases and support the case for improving material traceability and selecting more sustainable alternatives where feasible.

6.1.5 Structure

When isolating the *structure* components of the radar system within the assembly phase, we observe notable environmental impacts, particularly in the *Global Warming Potential (GWP)* and *Acidification Potential* categories. In addition to the previously discussed *Installation Set*, which showed high impact due to its electronic content, two other structural subcomponents emerge with significant contributions.

The *Composite* subcomponent shows a particularly high GWP. This is primarily due to the use of *prepreg* materials, which are composed of carbon fiber or aramide fiber embedded in epoxy resins and subsequently cured to form a strong and functional structure. The production of carbon fiber involves a high-temperature pyrolysis process that is very energy-intensive, also it is fully fossil-based. aramide fiber shares similar production characteristics, relying on fossil resources and requiring high thermal input, both of which contribute substantially to greenhouse gas emissions (Hosseinzadeh et al., 2024).

The *Struts* show the highest impact in the *Acidification Potential* category. This is mainly attributed to the substantial use of an *iron-nickel-chromium alloy* in their composition. Among these metals, *nickel* is the most significant contributor. The extraction and smelting of nickel ore release large quantities of sulfur dioxide (SO₂) and nitrogen oxides (NO_x), both of which are key drivers of acidification (European Environment Agency, 2019).

Additionally, many of the world's primary nickel mining operations are located in countries such as Indonesia and the Philippines, where electricity grids are heavily reliant on coal-based energy. These regions often also have comparatively weaker environmental regulations, which further exacerbates the emissions associated with nickel production (Fachrudin and Barrow, 2024).

These findings highlight the importance of material choices in structural components and point to potential impact reduction opportunities through improved sourcing practices, material substitution, process optimization or recycling.

6.1.6 Uncertainty Analysis

In order to investigate the robustness of our results, we performed a Monte Carlo simulation with 100 iterations on the calculation for the structure only. This allowed us to capture uncertainties in the background data, such as variations in material production and processes. Here we present three environmental impact categories where we examine the uncertainty.

First, we look at Material Resource Use, most of the simulations fall between 550 and 600 although there is some spread, see Figure 27. This variation is primarily due to uncertainties in the extraction data for nickel, titanium, and copper.

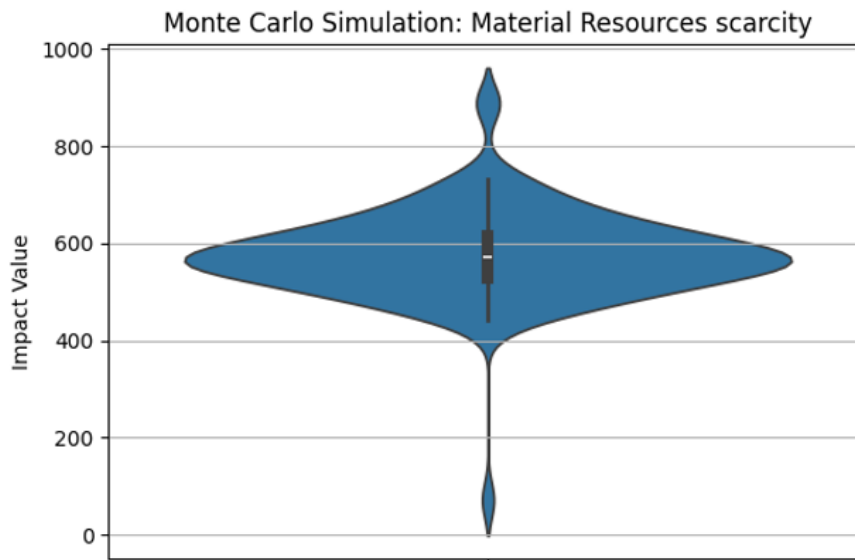


Figure 27: Monte Carlo simulation for the structure in the impact category Material Resource Use.

Next, we see a clear example of greater uncertainty in the case of Terrestrial Ecotoxicity, see Figure 28. The spread is large and skewed, with some simulations reaching up to 400,000. This reflects the sensitivity of the data regarding nickel and copper refining, where emission levels can vary dramatically depending on the mining and refining methods used.

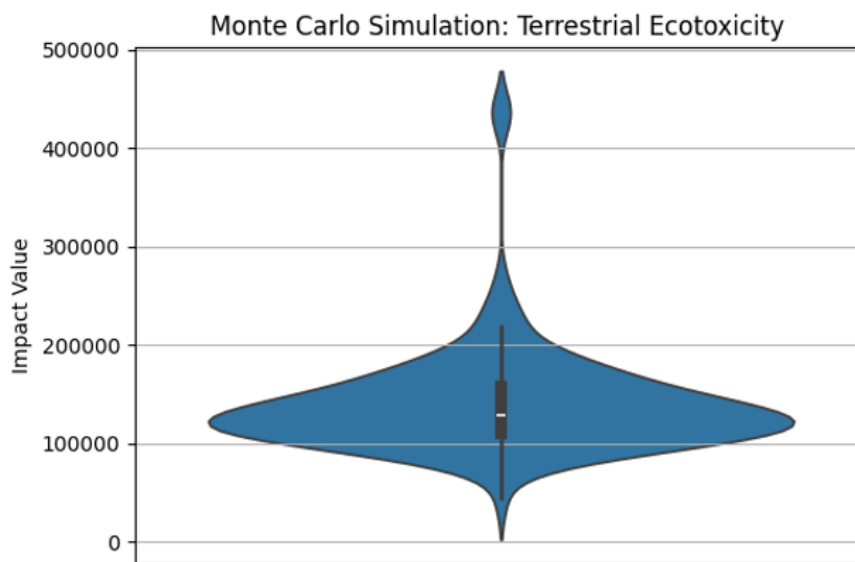


Figure 28: Monte Carlo simulation for the structure in the impact category Terrestrial Ecotoxicity.

Finally, for Climate Impact, the uncertainty is moderate. Most values range between 12,000 and 17,000, see Figure 29. Here, assumptions related to the production of carbon fiber and alloys containing iron, nickel, and chromium influence

the results. Despite the variation, the peak value remains consistent, which reinforces our conclusions about structural hotspots such as the composite material and the overall structure.

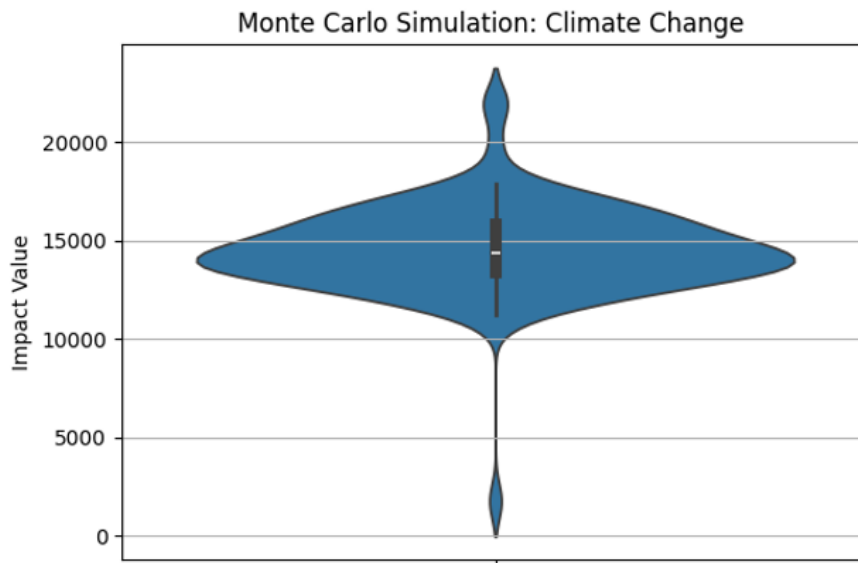


Figure 29: Monte Carlo simulation for the structure in the impact category Climate Change.

In summary, while some environmental impact categories, particularly ecotoxicity, exhibit greater spread, our conclusions remain robust. The key contributing materials, such as nickel, copper, gold, and carbon fiber, are clearly identified as hotspots regardless of data variations.

6.2 Answers to our Research Questions

This section provides structured answers to the research questions posed at the outset of the study. The responses are based on the comprehensive life cycle assessment (LCA) conducted on the radar system, encompassing both quantitative results and qualitative interpretation.

6.2.1 What Are the Environmental Impacts Associated with the Radar System?

The environmental impacts associated with the radar system are presented below for each Impact Category:

- **Climate Change: 13,587,880 kg CO₂-eq.**
- **Acidification Potential: 58,236 kg SO₂-eq.**
- **Freshwater Eutrophication: 2,015 kg P-eq.**
- **Material Resource Use: 429,888 kg Cu-eq.**
- **Terrestrial Ecotoxicity: 51,183,420 kg 1,4 DCB-eq.**

These impacts arise from various processes across the radar's life cycle, including the extraction and processing of raw materials, the production of complex electronic components, transportation logistics, and most notably, the operational use of the radar system aboard aircraft. The combustion of aviation fuel during the operational phase stands out as the dominant source of environmental burden.

6.2.2 Which Life Cycle Phase Contributes the Most to Environmental Impact?

The *Use Phase* contributes the most significantly to the overall environmental impact of the radar system. In every impact category analyzed, the Use Phase accounts for over 90% of the total impact. This overwhelming contribution is primarily due to the extensive consumption of Jet A-1 fuel during airborne operations, which results in high emissions of carbon dioxide (CO₂) and nitrogen oxides (NO_x). These emissions heavily influence the GWP and Acidification Potential categories. This finding is consistent with previous LCAs of radar systems, where fuel usage during operation typically dominates the environmental profile.

6.2.3 How Do the Impact Categories Vary Across Different Phases of the Radar System?

The variation in impact categories across different life cycle phases reveals unique environmental hotspots. As stated, the Use Phase is the predominant contributor in all categories, but when it is excluded for analytical clarity, other phases show differentiated patterns:

- **Assembly Phase:** High contributions in Mineral Resource Scarcity and Terrestrial Ecotoxicity, driven by the production of electronics containing gold and copper.
- **Transport Phase:** Notable impacts in GWP and Acidification, primarily due to fossil fuel combustion in logistics.
- **Maintenance Phase:** Moderate impact across categories, with recurring material replacement (e.g., TRMs) contributing steadily over the radar's lifetime.

This variation underscores the need for a phase-specific sustainability strategy.

6.2.4 What Component of the Radar System Has the Highest Environmental Impact?

The *Microwave Unit* is identified as the component with the highest overall environmental impact, particularly within the Assembly Phase. This is due to the presence of numerous transmitter-receiver modules (TRMs), each incorporating multiple printed circuit boards (PCBs) with gold and copper content. The upstream processes for these materials, especially the energy-intensive production and low ore yield of gold, result in significant impacts in GWP, Mineral Resource Scarcity, and Terrestrial Ecotoxicity. When normalizing for component weight, the *Installation Set* also shows a high impact per kilogram due to its dense inclusion of electronic parts.

7 Conclusion & Recommendations

In this section we plan to draw a conclusion from our Life Cycle Assessment and give recommendations to decrease the environmental impact from the radar Erieye.

7.1 Recommendations

Although Saab Surveillance has limited control over the operational phase of the radar system, this phase accounts for over 90% of the total environmental impact across all impact categories. As such, even minor design optimizations can result in meaningful environmental benefits. One area under Saab Surveillance's influence is the physical design of the Erieye radar. Improving aerodynamic integration, such as reducing the radar's drag through streamlined design, and minimizing weight by optimizing material selection could help reduce fuel consumption during airborne operation, thereby lowering lifecycle emissions.

Furthermore, it is recommended that Saab reduce reliance on materials associated with high environmental or ethical risks. Critical raw materials such as gold, nickel, and copper should be sourced with traceability and sustainability in mind. Saab can, for example, require suppliers to disclose the country of origin and production methods for these materials in key components. Requiring the use of recycled gold or "conflict-free gold" (as defined by the World Gold Council) (World Gold Council, 2024) in electronics procurement can reduce contributions to geopolitical conflict and environmental degradation.

In addition, Saab should prioritize suppliers that utilize low-carbon sources of nickel. One example is nickel production in Newfoundland, Canada, where renewable energy sources reduce emissions to one-third of the global average (Mining Magazine, 2023; Wikipedia contributors, 2024). Saab may also consider investigating alternative plating techniques to reduce reliance on pure gold coatings. Nickel-palladium-gold plating, for example, offers comparable performance at lower environmental and financial cost. These coatings use significantly thinner layers of gold and introduce nanoscale layers of palladium to reduce total material consumption (Duggirala and Moore, 2014).

Another promising approach is the adoption of bio-based composites. Materials such as flax fiber or basalt, combined with bio-based epoxy resins, have shown strong thermal resistance and vibration damping characteristics. These composites have already been tested in high-performance sectors such as motorsports, aircraft interiors, and ballistic protection, and could serve as feasible structural alternatives for certain radar components (Veerappan et al., 2024; Vijayakumar et al., 2024). Flax fibre also has low dielectric constant and very low conductivity which is important for the radar waves to be able to be transmitted through the material.

Nickel used in iron-nickel-chromium alloys contributes notably to Acidification Potential and Resource Scarcity, particularly due to production in coal-intensive regions with limited environmental regulation. Saab should investigate whether components such as struts can be manufactured using alternative materials, such as high-strength aluminum (Kumar et al., 2024) or advanced composites (Mandal et al., 2024), which could offer similar mechanical performance with a reduced environmental footprint.

It may also be beneficial to conduct a cost-benefit analysis on the feasibility of recovering printed circuit boards (PCBs) from customers at end-of-life. The significant environmental burden and material value, especially from gold—associated with PCBs, justify evaluating reverse logistics solutions.

Lastly, the absence of a formal disposal plan for the Erieye system should be addressed. Developing such a plan would not only enhance the accuracy of life cycle data, particularly for the end-of-life phase, but also provide customers with clearer guidance on responsible decommissioning practices.

7.2 Conclusion

This study set out to assess the environmental performance of the airborne radar system Erieye using life cycle assessment (LCA) methodology. The analysis spanned the full product life cycle—from raw material extraction and component manufacturing to operation, maintenance, and end-of-life. A range of environmental impact categories were evaluated, including Global Warming Potential (GWP), Acidification Potential, Terrestrial Ecotoxicity, Eutrophication, and Mineral Resource Scarcity.

The results clearly indicate that the *Use Phase* of the radar system dominates all impact categories, accounting for more than 90% of the total environmental burden. This outcome is primarily driven by the substantial emissions associated with the combustion of Jet A-1 fuel during airborne operations. Although Saab Surveillance has limited control over this phase, the results underline the importance of design decisions, such as aerodynamic optimization and lightweight material selection, that could indirectly reduce fuel consumption and operational emissions. These factors are all under the control of Saab Aeronautics.

When the Use and Test Phases are excluded from the analysis, the Assembly and Transport Phases emerge as the most environmentally impactful. The environmental burden in these phases is largely attributable to the production of electronic components and the transport logistics involved. Specifically, the Microwave Unit and Installation Set were identified as critical components due to their high material intensity and reliance on resource-intensive metals like gold, nickel, and copper.

The study further highlights the role of material selection in shaping the system's environmental profile. Precious and base metals used in PCBs and structural alloys are major contributors to categories such as Mineral Resource Scarcity and Acidification Potential. These insights suggest that targeted improvements, such as sourcing recycled or low-impact materials, or substituting with bio-based or lower-emission alternatives, can offer meaningful environmental benefits.

This is the first LCA of an airborne radar system, therefore a comparative LCA on the same system or a similar system in the future would be interesting both for academia and Saab to see improvements in environmental performance.

This systems lifetime was set to 25 years by Saab but in-house experts predicts that the system could live a lot longer than that. Therefore, choosing a functional unit that incorporates the time-aspect could be useful. Another reason for doing that could be to take into account the remanufacturing or repairing of parts in the radar. This is something that Saab is doing on a small scale, but no accurate data is yet available to make valuable calculations on these flows.

In conclusion, this work provides Saab Surveillance with a data-driven understanding of the environmental hotspots across the radar system's life cycle. It also presents actionable strategies for impact reduction within the domains that Saab directly influences. These findings support ongoing efforts to align product development with broader sustainability goals and to prepare for future environmental regulations and customer expectations.

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A Appendix

Bill of Materials (BOM) Breakdown

This section provides a breakdown of materials used in the radar, presented in percentage for each component. Due to confidentiality reasons the exact mass has been omitted.

Composite	Share of total mass (%)
Titanium	8.50
Primer	1.25
Stainless steel	3.09
Hardener	0.31
Aluminum	3.29
Polyester	0.01
Epoxy	2.77
Adhesive	2.00
Iron	0.02
Polyurethane	1.40
Polyamid	15.77
Edge sealant	0.01
Nickel alloy	0.01
Glue	0.01
Carbon fiber	58.10
Silicone rubber	2.24
Glass fabric	0.24
Thinner	0.06
Polymethacrylamide	0.41
Copper	0.01
Polyimide	0.02
Paint	0.59
Total	100.00

Table A1: Material Quantities in Percentage for Composite

Material	Share of total mass (%)
Stainless steel	11.76
Polyester	0.01
Edge sealant (xylene)	0.03
Titanium	1.68
Primer	0.001
Adhesive	1.11
Silicone	0.35
Lubricant (aeroshell grease)	0.05
Glue	0.02
Aluminum	36.73
Nickel-Chromium alloy	43.08
Hardener	0.003
Polyurethane	0.02
Nitrogen steel	4.89
Cadmium plated steel	0.10
Epoxy	0.02
Nitric acid	0.14

Table A2: Material Quantities in Percentage for Struts

Material	Share of total mass (%)
Stainless steel	5.86
Aluminium	7.71
Titanium	1.93
Silicone	1.17
Epoxy	0.19
Nylon 6	2.00
Anodizing agent	0.01
Conductor cable	2.69
Connector cable	78.11
Vinyl polyester label	0.32
Ethylene glycol	0.00
Rust preventing agent	0.01

Table A3: Material Quantities in Percentage for Cables

Material	Share of total mass (%)
Aluminum	4.13
Glass fabric	5.20
Cables	0.28
Stainless steel	1.90
Chrome steel	0.30
Cadmium plated steel	0.03
Polyester	0.004
Glue	0.14
Primer	1.87
Adhesive	3.69
Titanium	0.20
Methanol	0.01
Polydimethylsiloxane	0.005
Epoxy	4.78
Hardener	1.77
Prepreg	60.39
PMI	3.98
Polyamide	11.31

Table A4: Material Quantities in Percentage for Fairing

Material	Share of total mass (%)
Aluminium	51.34
PCB	48.66

Table A5: Material Quantities in Percentage for MWU

Material	Share of total mass (%)
PCB	25.04
Chromate	12.47
Aluminum	62.48
Carbon fibre	0.01

Table A6: Material Quantities in Percentage for Antenna

Material	Share of total mass (%)
Aluminum	61.00
PCB	39.00

Table A7: Material Quantities in Percentage for DBB

Material	Share of total mass (%)
Cables	100

Table A8: Material Quantities in Percentage for Sensor Cables

Impact Assessment Results

Table A9 provides the result of the Impact Assessment for **all** 16 Impact Categories.

Impact Category	Impact Result
Acidification (kg SO ₂ -Eq)	58,236.28
GWP (kg CO ₂ -Eq)	13,587,880.45
Freshwater Ecotoxicity (kg 1,4 DCB-Eq)	645,188.00
Marine Ecotoxicity (kg 1,4 DCB-Eq)	845,623.00
Terrestrial Ecotoxicity (kg 1,4 DCB-Eq)	51,183,420.88
Energy Resources Non-Renewable (kg oil-Eq)	3,765,132.00
Freshwater Eutrophication (kg P-Eq)	2,015.15
Marine Eutrophication (kg N-Eq)	395.29
Human Toxicity Carcinogenic (kg 1,4 DCB-Eq)	1,077,418.00
Human Toxicity Non-Carcinogenic (kg 1,4 DCB-Eq)	49,666,143.00
Ionising Radiation (kBq Co-60-Eq)	614,220.00
Land Use (m ² -a crop-Eq)	1,128,056.00
Material Resources – Metals/Minerals (kg Cu-Eq)	429,888.57
Ozone Depletion (kg CFC-11-Eq)	4.5563
Particulate Matter (kg PM2.5-Eq)	32,111.63
Photochemical Ozone Formation Human Health (kg NO _x -Eq)	105,066.44
Photochemical Ozone Formation Terrestrial (kg NO _x -Eq)	107,832.51
Water Use (m ³)	35,746.00

Table A9: Summary of environmental impact scores by category

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