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Circular Indicators to Support Decision-Making in the Aerospace Industry

In collaboration with GKN Aerospace Engine Systems

Master's thesis in the Supply Chain Management Master's Programme

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Cover: An airplane is encircled by a leaf and arrows, symbolizing sustainable aviation and circular practices.

Gothenburg, Sweden 2025

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Abstract

The global aerospace industry faces increasing pressure to address the environmental consequences of industrial production, with a particular emphasis on reducing greenhouse gas emissions. In this context, circular economy practices have emerged as a strategic approach to reduce environmental impact and improve resource efficiency. This thesis explores how circularity can be measured, reported, and improved at GKN Aerospace Engine Systems. Through literature review, interviews, and factory observations, the study identifies key functions influencing circularity and examines the information they require to support circular decision-making. A set of circular indicators are proposed, emphasizing material efficiency, use of recycled materials, and waste purity, and aligned with frameworks like ISO 59020:2024. Additionally, the business implications of circularity are analyzed, showing potential for reduced supplier dependency, cost savings, and new revenue streams through expanded repair services. The findings contribute both practical recommendations for the aerospace industry and insights into how CE practices can be implemented and evaluated in high-precision industries.

Keywords: Sustainability, Circular Economy, Reduce, Repair, Recycle, Circular Business Models, Circular Indicators, Aerospace, Aviation Sector, GKN Aerospace Engine Systems

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Carl Eriksson & Emma Olivegren,
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List of Abbreviations

Below is the list of abbreviations that have been used throughout this thesis listed in alphabetical order.

AM	Additive Manufacturing
CBM	Circular Business Model
CE	Circular Economy
CSRD	Corporate Sustainability Reporting Directive
EU	European Union
GHG	Greenhouse Gas
GKN	GKN Aerospace Engine Systems
IAEG	International Aerospace Environmental Group
ISO	International Organization for Standardization
KPI	Key Performance Indicator
MRO	Maintenance and Repair Operations
OEM	Original Equipment Manufacturer
PSS	Product-Service Systems
RRSP	Risk and Revenue Sharing Partnership
SDG	Sustainable Development Goal
UN	United Nations

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1
Introduction

The following chapter provides the background and problem definition of the subject, outlines the aim, presents the research questions, and specifies the limitations of this study. Conducted in collaboration with GKN Aerospace Engine Systems (hereafter referred to as GKN), this thesis aims to gain a deep understanding of the challenges and issues related to circularity in aerospace engine manufacturing. The circular approach is focused on reduce, repair, and recycle of material. GKN is a leading global producer of various aerospace components [5] and their headquarters is located in Trollhättan, Sweden, where the master thesis is being conducted.

1.1 Background

In recent decades, the pressure on manufacturing industries has increased to address environmental impacts due to their production, especially to decrease greenhouse gas (GHG) emissions. The aerospace industry, with its complex production processes, expensive materials and energy-intensive operations [6], is no exception. The aviation sector alone contributes to approximately 2-3% [7] of global carbon dioxide (CO2) emissions, which are expected to increase alongside income levels, as increased wealth enables more people to afford to fly more [8]. Furthermore, as concerns about alarming climate change, raw material scarcity, and geopolitical instability grow, the adoption of more sustainable production models has become not only an environmental necessity but also a strategic business priority.

In response to these environmental impacts, the aerospace industry has launched several initiatives, for example, to reach net-zero by 2050, focusing on improvements in fuel efficiency, lightweight design, and new sustainable fuels [7]. However, these approaches may not be sufficient to address the urgency and scale of environmental challenges. One concept that could help address these challenges of climate action and resource scarcity is circular economy (CE) [9]. Unlike the traditional linear consumption model of extract, make, and dispose, which most of the world lives by [10], CE is based on three core principles: eliminate waste and pollution, circulate products and materials, and regenerate nature [11]. This means a shift in mindset of consumption to one of preservation, focusing on maximizing product lifespan, and keeping materials and products in circulation for as long as possible. Thus, CE is a systematic approach to increase sustainable development, designed to benefit businesses, society, and the environment.

In the aerospace industry, especially with regard to engines, where materials are expensive, technically advanced, and have a lifespan of decades, the benefits that circularity can offer are particularly relevant. By reducing the need for virgin materials by recycling and reusing components and incorporating circular practices such as repair, CE strategies can significantly lower embedded emissions and improve resource efficiency. In addition, circularity also addresses the procurement challenge.

For example, conflict and critical materials, such as titanium and nickel, are a challenge for the aerospace industry [12]. Conflict materials originate from countries experiencing conflict, such as Russia and the Democratic Republic of Congo. The term critical refers to materials that are essential and face risks related to their supply [12]. This can result from several factors, including scarcity in the Earth's crust, difficulties in producing or processing the material, and limited availability due to dependence on a few suppliers. These conditions can lead to increased prices and monopolistic supply chains, which means that one or a few actors controls the whole supply chain. A longer product lifespan reduces the need for new raw materials, thus decreasing dependence on conflicting countries and suppliers [13]. In addition, it also reduces the risks of supply shortages, both short- and long-term, as well as fostering economic development by creating a circular loop of materials.

Despite the potential benefits CE can have in the aerospace industry to address environmental challenges, it is still rarely at the center of sustainability discussions. Although CO2 reduction is widely discussed and supported by road maps and regulations [7], progress towards circular practices remains unfocused, and tools to measure and evaluate their impact are underdeveloped. As a result, an important approach to environmental and economic performance is being underutilized.

GKN is a global, tier one, supplier to the aerospace engines market, including structural engineered components, parts repair, commercial and aftermarket contracts [14]. GKN is positioned between upstream raw material producers and downstream original equipment manufacturers (OEMs) such as Rolls-Royce and Pratt & Whitney. Some of the components GKN develops are turbine cases, rotating structures, shafts, intermediate compressors, static frames, and fan cases to civil and military engine programs [5]. An example of an intermediate case within an engine can be seen in Figure 1.1, which is a part of a civil aircraft engine. GKN's products require high manufacturing precision due to high safety and quality requirements within the industry, which is done by utilizing technologies such as laser welding [6]. The products are made from lightweight or heat resistant materials, such as titanium and nickel-based alloys, which are essential to ensure fuel efficiency and mechanical reliability in jet engines [5]. Although GKN manufactures and delivers these components, the ownership of the final engine typically remains with the OEMs or the customers of the OEMs. GKN does not produce complete engines for the civil market or operate aircrafts, but its role is essential to ensure the performance and longevity of the engine's subsystems. Contracts between GKN and OEMs are typically long-term, spanning several decades in alignment with the extended life cycles of aircraft engines.

Figure 1.1: An intermediate case from GKN

Since 2018, GKN Aerospace has been fully owned by Melrose Industries PLC, a UK-based investment firm [15]. Under Melrose, GKN has focused on operational efficiency and financial performance while also increasingly incorporating sustainability into its strategic priorities. GKN's sustainability mission, *"to be the most trusted and sustainable partner in the sky"*, is supported by global initiatives aligned with the EU Green Deal, and the Sustainable Development Goals (SDGs) [16]. A key component of GKN's circular approach is its growing Maintenance, Repair and Overhaul (MRO) business. Through its MRO services, GKN restores worn or damaged engine components to serviceable condition. They restore not only their own components, but also components that they are certified to repair from the OEM. This leads to extended product lifespan and reducing the need for new material production. These repair operations require deep technical expertise, including advanced welding, coating, and additive manufacturing (AM) processes.

GKN has a focus on sustainability, with specific goals targeting emissions reduction, water usage, and diversion of waste from landfill [16]. As part of its commitment, GKN is transitioning from a linear to a circular economic model by embedding sustainability into core business processes such as product development and supplier selection [17]. In addition, initiatives such as life cycle assessments (LCAs), implementation of material-efficient manufacturing, and innovations in AM demonstrate the company's ambition to reduce their environmental impact throughout the product life cycle. However, despite these efforts, GKN, like many aerospace manufacturers, still lacks standardized metrics to evaluate the progress and impact of circularity within its operations. Although waste and landfill reduction is a key circular goal, more circularity targets are needed. GKN's current sustainability approach includes focusing on three key areas, repair, circular materials, and circular operations, aimed at developing circular solutions[1]. However, without suitable metrics, it is difficult for GKN to evaluate progress, compare its performance over time, or align efforts across departments. Metrics are also important due to the Corporate Sustainability Reporting Directive (CSRD) under the EU Green Deal, which

[1]Internal document, 2024

requires companies to report on their social and environmental risks, as well as how their activities impact stakeholders and the environment [18]. Therefore, this thesis is conducted in collaboration with GKN to gain a deep understanding of the challenges and opportunities related to circularity in aerospace engine manufacturing.

1.2 Aim

GKN has several circular activities, such as MRO and an active interest in reducing material usage, but there is a lack of circular indicators that allow the measurement of circularity, in terms of reduce, repair, and recycle. The thesis will therefore aim to help GKN find new ways to measure circularity in their material stream in an appropriate and sustainable way.

1.2.1 Research Questions

This thesis has been guided by the following research questions, which focus on circularity measurement, the use of circular indicators, their application within the aerospace industry, and the role of circularity from a business perspective.

1. What functions at GKN make decisions about its circularity?
2. What information do these functions need to improve GKN's circularity?
3. In the identified functions where circularity can be improved, what are the appropriate ways to measure, report, and improve the results?
4. How can an improvement in circularity at GKN affect its business?

1.2.2 Limitations

Since GKN is a security-protected site, photography and unauthorized recording are not permitted and therefore not allowed to be used in this thesis.

As of writing, there are many regulations and trends in the area of circularity in the making. Since the topic is still in development, the work will focus on current and near-future circularity trends and measurements.

GKN is a company that works towards both the military and civil aerospace engine market. Due to the complications of security classifications and classified information towards the military market, the thesis will only focus on the material flow and materials in the civil market at GKN.

2

Theoretical Framework

This chapter explores sustainability in relation to CE, highlighting the R framework, closed- and open-loop systems, and the financial effect CE has. It also discusses how to measure circularity using various indicators, frameworks, and ISO standards. Finally, relevant business models to the aerospace industry are presented.

2.1 Sustainability

The world is facing a large deal of challenges related to resource consumptions, climate change, and economic development. Sustainability, according to the United Nations Brundtland Commission, can be defined as *"meeting the needs of the present without compromising the ability of future generations to meet their own needs."* [19]. This means that the quality of life should be high for the current people living and for the generations to come. To achieve this quality of life and to address the global challenges the world faces, the UN developed several sustainable development goals (SDG). These goals can be grouped into the three pillars (also called the triple bottom line) of sustainability: economic, environmental, and social sustainability [20]. Economic prosperity considers the economic parts that an organization has control over, which could be paying livable wages, sourcing ethically, and workplace safety. Although some actors may perceive economic prosperity to be about the financial performance of a company, in terms of the triple bottom line, this is only a small part of it. It means that business practices should be in line with the Brundtland Commission's definition [21]. The second pillar is environmental sustainability, which considers the relationship between an organization and the environment. This pillar focuses on how to stop the harmful damage we are creating to the environment in terms of resource extraction, pollution, and emissions. This means that the needs and demands of the organization and customers have to balance the environmental effects it creates. To increase environmental sustainability, new policies can be implemented, companies can take action to reduce their emission and resource extraction, and new environmentally friendly based investments can be made [20]. The last pillar of sustainability is the social aspect. This pillar takes all stakeholders into consideration, which should not be confused with shareholders in this scenario. Stakeholders are all affected by the actions of an organization [21]. This can be actors in the supply chain, customers, people within the company, people in the surrounding environment, and even future generations. In order to work sustainably with society, human resources need to be managed well. This means that safety and sustainable growth should be of high priority and that communal growth and reducing poverty should be prioritized.

There are some problems concerning the three pillars. It is designed to cover all problems that arise in society, and the UN's SDGs are there to help society reach sustainable development [22]. But an increase in one or two of the pillars tends to have a negative effect on the last one. For example, by increasing the production of food, more economic prosperity can be brought forward and poverty can be reduced while also decreasing starvation. However, it can have an effect on the environment by cultivating inappropriate land fields or by using artificial fertilizer that harms other parts of the environment.

2.1.1 Circular Economy

Most of the world lives by a linear consumption model, materials are extracted from the Earth, products are created by these materials, and finally the products are thrown away as waste [10]. Instead of continuing to extract new materials and throwing them away, a CE encourages the extension of material and product use in order to tackle climate change and other global challenges.

There are several definitions regarding CE. The European Parliament [9] describes that CE is a model of production and consumption. However, it involves many subcategories such as sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products as long as possible. In short, it reduces the waste to a minimum. When the product reaches the end of its life, the materials of the product are kept in the economy with the use of repairing, recycling, and other reuse measures. This process can be repeated multiple times, creating more value without extracting new materials.

Another definition, used in this thesis, is given by the Ellen MacArthur Foundation [11] which mentions three core principles that a CE must do: **Eliminate** waste and pollution, **circulate** products and materials, and **regenerate** nature. In order to move from a linear economy to a circular one, redesigning the economy using circular principles is a must. By designing infrastructure, products, and materials to return to the economy after their use, waste and pollution can be eliminated. Thus, by designing from a circular point of view, waste can be prevented. In addition, by maintaining, reusing, and recycling products and materials, they can be circulated. The outcome is longer product life cycles, and the linear process is no longer at the forefront.

2.1.2 “R” Framework

Regardless of how CE is defined, many authors agree on the same general structure or framework of CE, often the “R” framework [23]. The framework is based on different core principles, combined in different ways. The R-strategies are a helpful tool to use as a guide on how circular design and manufacturing can maximize resource efficiency and minimize waste [1]. The tool effectively visualizes and clarifies the various stages of resource utilization and waste management within a circular economy and their definition can be seen in Table 2.1.

Table 2.1: The "R" Framework of CE and their definition [1]

Principles	Definition
Refuse	Avoid the use of unnecessary or harmful products by making conscious design and consumption choices from the start.
Rethink	Redesign products, services, or systems to enable smarter use, such as shared access or dematerialization.
Reduce	Minimize energy and material consumption throughout a product's life cycle by improving efficiency and using fewer natural resources.
Reuse	Extend product lifespan by reusing items for the same purpose without significant modification or processing.
Repair	Develop and maintain products that are easy to repair, extending their lifespan by restoring their original function instead of replacing them.
Refurbish	Improve and modernize used products, often cosmetically and functionally, to prepare them for resale or continued use.
Remanufacture	Rebuild products by combining reused, repaired, and new components to restore them to a like-new condition with the same functionality.
Repurpose	Use products or parts for a new function other than originally intended, extending their usability.
Recycle	Design products with recyclable materials and ensure they can be processed into new materials of the same or lower quality at the end of their lifespan.
Recover	Extract useful energy or materials from waste through processes like incineration or anaerobic digestion when other options aren't viable.

The R-strategies have different focus points that create different lengths of the waste loop each strategy represents [1]. With shorter loops indicating more sustainable solutions, as they require fewer resources and less energy as can be seen in Figure 2.1. For example, Reduce creates the shortest loops by emphasizing smarter product use and manufacturing. Repair focuses on life extension strategies, resulting in medium-length loops. Lastly, Recycle involves creative material application, leading to the longest loops.

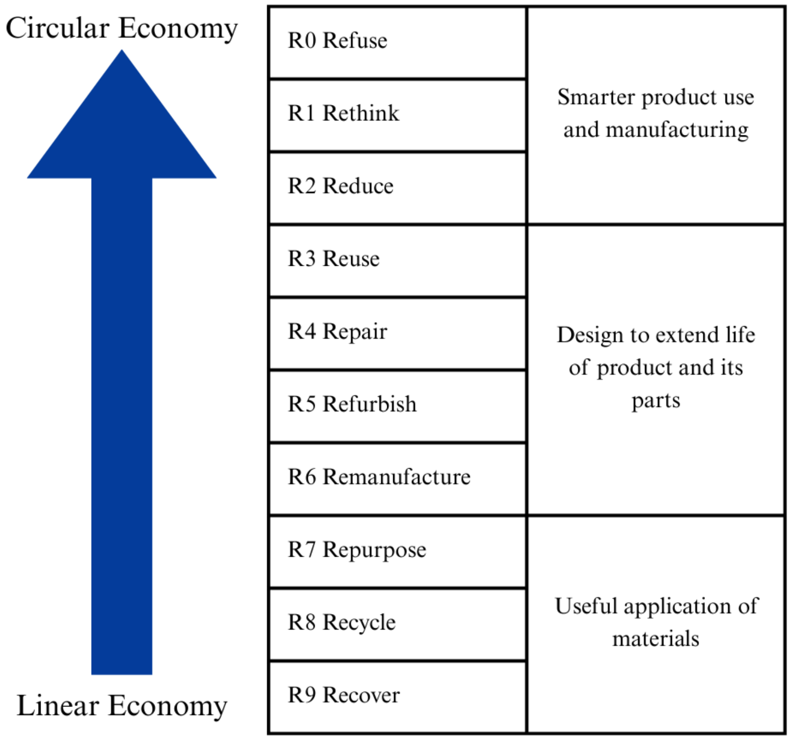

Figure 2.1: The "R" Framework of CE [1]

2.1.3 Closed-Loop and Open-loop systems

When designing a CE system, two main approaches can be used in material recycling: the open-loop system or the closed-loop system [24]. An open-loop system means that once the product or material is used, it is sent for recycling, reuse, or similar to an external actor. Examples of this can be second-hand markets or recycling stations. An overview of the process can be seen in Figure 2.2. When a product in an open-loop system reaches its end of life stage, it is typically recycled with materials from other waste streams [2]. Once recycled product material is deemed to no longer meet quality requirements, it is disposed of in the form of energy recovery, e.g. incineration, or landfill.

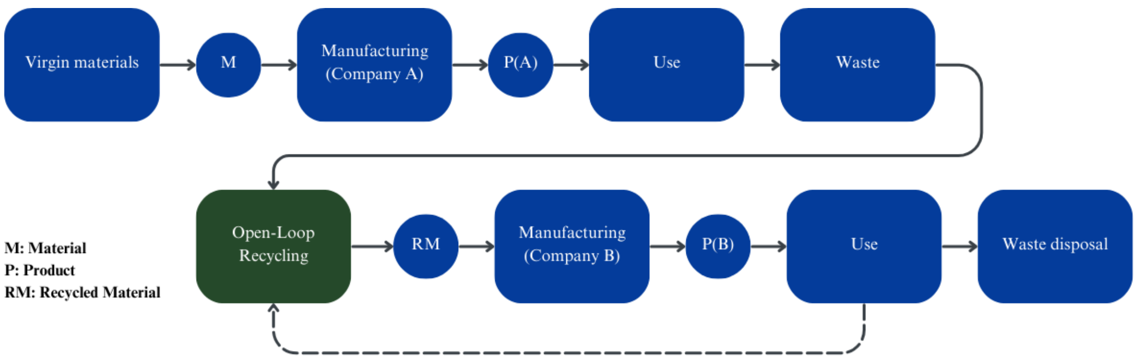

Figure 2.2: Flow of Open-loop as depicted by Abubara et al. [2]

The other type of loop in a CE is the closed-loop system. With this type of system, an investment in a well-functioning reverse logistics system is needed [2]. As mentioned in several interviews, there are multiple ways to achieve a closed-loop system, but researchers agree that the best way to do it is by making sure that the ownership of the product returns to or stays with the manufacturer. A clear example of this is Sweden's glass bottle deposit system. Consumers purchase a glass bottle and pay a deposit, which is refunded when they return the bottle to the same manufacturer. The returned bottles are then washed, recapped, and resold, creating a continuous reuse cycle that minimizes waste. The closed-loop system can also include recycling, remanufacturing, and other ways of reusing materials. As mentioned by Fedkin [24] the material should not deteriorate or lose quality as it is being recovered, the recycling loop should be clear of contaminants, and the material should be able to manufacture more than one product. In theory, a perfect closed-loop system should not have any landfill deposition during and after the use phase, since everything is being reused in the loop. An overview of a closed-loop system can be seen in Figure 2.3.

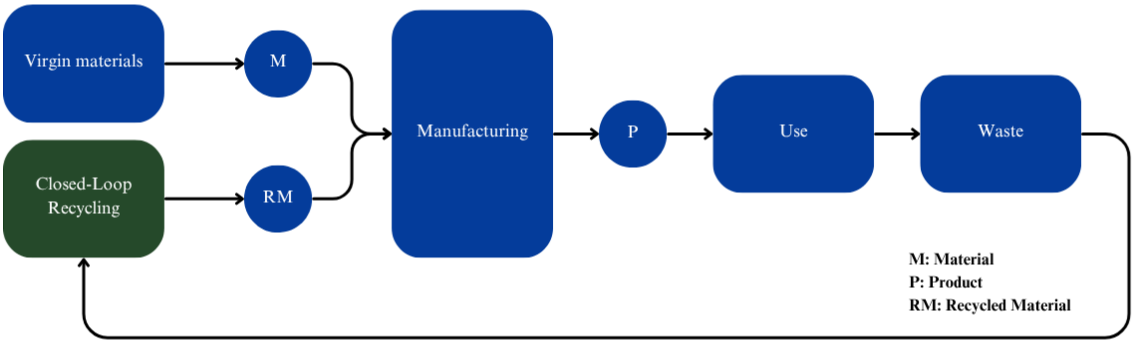

Figure 2.3: Flow of Closed-loop Abubara et al. [2]

2.1.4 Financial Effects

The shift to CE has significant implications for the financial performance of businesses and industries [9, 25]. By changing from traditional linear economic models, CE promotes resource efficiency, innovation, and sustainable growth, all of which influence financial outcomes at both micro- and macroeconomic levels.

Adopting CE principles can lead to improved financial performance for businesses by reducing costs, improving resource efficiency, and opening new revenue streams [26]. Research has found a positive correlation between circular strategies and financial performance, as Palea et al.[26] mention that with their econometric estimations indicate that CE initiatives contribute to better financial performance in terms of profitability and market value. Furthermore, some actors who have initiated green initiatives, such as Green Marketing, have increased their market share as a result [27]. Green marketing involves promoting products and processes that meet customer needs while reducing environmental impact, such as changes to the production process, modifying advertising, and communication.

Furthermore, CE fosters resilience by reducing the dependency on virgin raw materials, which are often subject to price volatility and supply chain disruptions [9].

By focusing on material reuse, remanufacturing, and recycling, companies can mitigate the risks associated with raw material shortages and geopolitical uncertainties. These factors contribute to financial stability and long-term competitiveness.

On a larger scale, CE can drive economic resilience and job creation. According to the European Parliament [9], the change to a CE could generate approximately 700,000 new jobs in the EU by 2030. The financial benefits extend beyond businesses, impacting consumers by offering more durable and cost-efficient products, which in turn sustain economic growth. In addition, Palea et al.[26] highlight that the circular economy can serve as a means to promote not only environmental sustainability, but also economic development. They suggest that policy measures aimed at influencing market demand and amplifying the reach of circular practices could yield advantages for both the environment and the broader economy.

The DuPont model can be used to analyze a company's return on assets, a profitability ratio to the companys total assets, by breaking it down into various subcomponents [28]. An overview of the breakdown can be seen in Equation 2.1. The goal of the DuPont model is therefore to maximize the return on assets, which can be done by both increasing the profit margin or the total asset turnover.

$$\begin{aligned} \text{Profit Margin } &= \tfrac{\text{Revenue}}{\text{Costs}} \\ \text{Asset Turnover } &= \tfrac{\text{Revenue}}{\text{Total Assets}} \\ \text{Return on Assets } &= \text{Profit Margin} * \text{Asset Turnover} \end{aligned} \tag{2.1}$$

As mentioned by Palea et al. [26], a manufacturing company that utilizes a CE approach has a high chance to perform better financially, which can be explained by the DuPont model. First, the total asset turnover can be increased if the company reduces the amounts of assets they are using, for example, by creating the same value with less resources. They could also reduce the amount of scrap they are using and recycle it with their suppliers, to use less material overall. Secondly, the profit margin can be heavily impacted by opting in to use a CE approach. The costs, which affects the results of the company, may be reduced by purchasing a recycled material. On the other hand, the revenue might be increased if customers are interested in purchasing products labeled as circular in order to promote sustainability. The revenue can also be increased by better managing waste, and selling it to recycling companies or back to the supplier.

2.2 How To Measure Circularity

In order to get an understanding of how circular an organization, function, or product is, measurements are needed. Without measurements to support the claims regarding circularity, they lack a proper foundation to support them. Furthermore, a measurement is needed to not only report circularity, but also measure improvement progress and deviations. However, how to measure circularity is a challenge, which is explained in this section.

2.2.1 Circular Indicators

As mentioned above, CE is crucial for transitioning toward a more sustainable society. In an interview with one of the researchers, it was mentioned that with increasing demands for circularity from governments, organizations, and society, measurement methods are needed not only to report circularity but also to find ways to improve and control it [29]. These measurement methods are called circular indicators and are used in various ways to measure circularity. In the literature, three main target levels for circularity can be found [30, 31, 32, 33]:

- Micro: Focus on an organization as a whole or particular products and processes.
- Meso: Focuses on the relationship between companies, consumers, and producers.
- Macro: The main focus is on large geographical areas and international organizations.

With these three levels in mind, the goals in a CE are traditionally set with a top-down approach [31]. Meaning goals are set at the macro level, such as national or international policies [34], and then adjusted to micro level goals. With relevant indicators at each level, progress can be measured and areas of improvement can be identified. The purpose of these indicators is then to report circularity to other stakeholders to ensure that goals are reached, to find areas for improvement within the organization, and to gather more data for which decisions can be made.

As mentioned by Saidini et al. [31] and Moraga et al. [30], there are currently many different circular indicators published. In their work, they present a compilation of about 70 circular indicators, one of which is the Material Circularity Indicator made by the Ellen Macarthur Foundation [35]. The reason for so many indicators was the lack of standardization in both creation and usage. In 2024 however, the ISO foundation released a standard on how to create and use them [3]. Before this standard was developed, it was difficult to know where to draw limits on measurement levels, how to properly measure, and how to report the results. While goals on a macro or meso level might be clear, micro level reportings may have been formulated in inconsistent ways and lead to a difficult comparison.

2.2.2 Frameworks and ISO Standard

To develop an effective circular indicator, it is highly recommended to use a pull approach. [36, 37], which means that the design of a circular indicator starts with identifying the function that needs to make a decision. Only after this has been done can the information needed for the function be explored and collected. Lastly, the indicator will be created. There are multiple benefits in creating circular indicators in this manner, as mentioned by Landström et al. [37]. For example, creating too many indicators could result in a loss of priority which could be minimized by ensuring that they are based on accurate and relevant data and are clearly defined. From a CE perspective, circular indicators will be able to help in decision making in various ways by providing more data and a better foundation, as mentioned by Cayzer et al. [32]. Since CE needs to cover the entire life cycle of a product, various functions need to be informed and have information if an improvement in circularity is of interest.

When designing circular indicators, it is important to know their purpose to ensure that all stakeholders has the same interpretation and understanding [36]. In general, there are three key purposes that can be seen in Table 2.2. However, an indicator might have more than one purpose:

Table 2.2: Key Purposes When Designing Indicators

Purpose	Definition
Reporting	Indicators that are used to report information to reports, stakeholders or others.
Controlling	Indicators to make sure a value stays within limits.
Improving	Indicators that are used to improve a function.

An organization that works with setting standards for various purposes is the International Organization for Standardization (ISO). Due to the many different ways of reporting and measuring circularity [31, 3], ISO developed a couple standards in 2024, the 59000 series, not only to define what a CE means, but also to determine how it can be measured. [3]. The standard corresponds to previous literature on how to measure circularity in various steps but agrees in the complexity of the subject. Since circularity in a manufacturing context is a complex subject, some examples of areas of circular measurements are provided by the standard ISO 59020:2024 and can be seen in Table 2.3.

Table 2.3: Examples of circular indicators related to materials from ISO 59020:2024 [3]

Material Flows	Circular Indicators
Resource inflows	• Reused content • Recycled content • Virgin, renewable content • Virgin, non-renewable content

Material Flows	Circular Indicators
Resource outflows	• Components and products that are reused • Per cent recycled material derived from outflow • Products and materials for renewable recirculation

Another important thing mentioned by the ISO foundation in its 59020:2024 standard is that circularity could also be measured in terms of product lifetime [3]. They describe it as follows:

> *"The "average lifetime of product or material relative to industry average" circularity indicator identifies the degree to which a resource outflow (e.g. a product or material) is able to retain its value over time compared to the industry average for that resource when available. This can be used to represent the slowing of a resource flow. This circular indicator can be particularly relevant when the system in focus produces products or materials that are then provided to a user to fulfill a function."*

This is important to discuss when dealing with products with a long lifespan, such as aerospace engine components. Since engines have a very long lifespan, a component that does not need replacement until the end-of-life (EOL) of the engine would have a higher average lifetime of product ratio compared to those that need to be replaced or repaired.

The ISO standard 59020:2024 also mentions several economic (or business) indicators that are not used specifically to measure circularity but are aimed at supporting the transition to circularity [3]. They describe it as follows:

> *"The application of economic-related circularity indicators is of high importance for an organization to provide transparency and demonstrate that circular strategies and actions are economically feasible. The measurement and evaluation of economic viability can be based on the way economic value can be created and captured and how the realization of related actions affects such value."*

Some examples of business indicators proposed in ISO standard 59020:2024 [3] can be seen in Table 2.4:

Table 2.4: Examples Business Indicators

Business Indicator	Definition
Net value added	Measures the value of a product minus negative economic factor costs. These negative economic costs are usually taxes, deprecation or similar, but can be extended to include circular strategy costs such as additional labor and resource costs. [3]
Value per mass	Provides an estimation of the resource use efficiency. An increased value per mass shows an increased amount of circularity. [3]
Resource productivity	Can be compared to the value per mass, but is extended to the regional system by using the GDP instead of revenue as a measuring unit. Allows a region, country or geographical area to track progress towards a circular economy. [3]
Genuine progress indicator	An indicators that is suited to higher system levels. This indicator is often used as an alternative to GDP and includes negative economic effects. This indicator is not directly related to circularity, but can include circular activities to make sure that it is a relevant circular indicator. [3]

When deciding how to measure circular performance, the ISO standard 59020:2024 describes how the measurement boundaries should be established [3]. The boundaries should be set with a life cycle perspective. Secondly, the boundaries should be made with relevant spatial scale. On a product level, this means that all stages across the value chain are taken into consideration. Since these stages may take place in different locations, the spatial scale can be cross territorial and even international. Lastly, the temporal scale needs to be considered, as it refers to the time span that the measurements cover. The framework for measuring and assessing circularity performance according to the ISO foundation can therefore be seen in Figure 2.4.

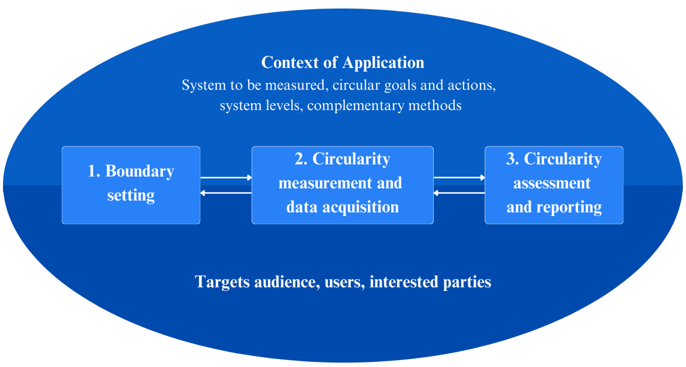

Figure 2.4: ISO Framework on how to measure and assess circularity [3]

After the boundaries has been set, information has been collected and measured, circularity is ready to be assessed and reported [3]. This process can be divided into four steps. First, the measurement results must be reviewed. This involves reflecting on the purpose of the measurements and evaluating whether the chosen boundaries were effective or need adjustment. It also includes assessing how the circularity indicators can be measured and applied, how they provide results and support decision-making, and finally identifying any gaps in information or data. This could be seen as the ISO standards take a bottom-up approach compared to the guide provided by Almström et al. [36] which uses a top-down approach. There are benefits to both approaches, but the goal and scope of the measurement could be more clear with the top-down approach recommended by Almström et al. [36].

The second part of the assessment is to assess the value and impact of the measurements [3]. The sustainability impacts should follow the triple bottom line, i.e. social, environmental, and economic aspects. Although some decisions may lead to an improvement in one area, it is often that they have contradictory goals, this could be compared to the sub-optimzation as mentioned by Almström et al. [36]. The economic value of the assessment is also critical and can be evaluated by examining the total cost of ownership, along with other positive or negative impacts expressed in monetary terms.

The third part includes consulting interested parties, users and target audiences [3]. These can be grouped into internal and external parties. The internal parties could be seen to have an interest in decision making and how circular actions will affect them in terms of the triple bottom line. The external parties could be users, suppliers, customers, external organizations, and others that might have an interest in the results of indicators. This falls in line with the three types of indicators mentioned in Table 2.2.

Lastly, after consulting with the interested parties, the final part is to document and report the outcome of the circularity measurement [3]. Important things to take into consideration here are the target audience and transparency. The report should be able to be received by the correct audience, and they should be presented with what is interesting to them. This also means that transparency is of high importance. All information found and reported must contain everything necessary to support correct decision-making and correct information.

However, as ISO mentions, and as can be seen in Figure 2.4, the three steps are not isolated to each other [3]. It is an iterative process that requires the analysis to go back and fourth between the different stages.

2.3 Business models

This section presents important business models in the aerospace industry and circular business models. Since the aerospace industry uses several circular concepts, the aspects of circular business models are important to discuss.

2.3.1 Risk and Revenue Sharing Partnership

A risk and revenue sharing partnership (RRSP) is a kind of collaboration between multiple actors and an OEM that are developing a product [4]. In the aerospace industry, this is a typical partnership to enter when developing an engine. An owner share of 5% would therefore correspond to earning 5% of the revenue that the engine generates. This method of developing an engine reduces the economic risk a single actor takes, for example, the PW1000G GTF cost approximately 10 billion USD to develop [4]. In a traditional engine RRSP, the partners who work together with the OEM owns less than 50%. This is to make sure that the OEM still retains ownership and maintains overall decision power.

In addition, the time it takes to develop the engines is very long [4], approximately up to 15 years, since it may not only be the product itself that is being developed, but also the underlying technologies. For some actors, revenue might start to generate once the engine starts selling to customers, but for others, the majority of the revenue might start to generate once the aftermarket services start taking place. An example of such an actor is GKN [4].

2.3.2 Circular Business Models

A business model describes how a company creates, delivers, and captures value [38]. It defines what customers want, how the business meets those needs and how it generates revenue and profits in the process. Essentially, it reflects the company's strategy for providing value while ensuring financial sustainability. However, a CBM instead focuses on minimizing resource use, waste, and emissions by improving the way materials and energy are managed within an organization [39]. Antikainen et al. [38] describe five types of CBMs:

1. Circular supply:
   Using renewable, bio-based, or recycled materials instead of traditional inputs.

2. Product life extension:
   Designing products to last longer by making them easier to reuse, repair, refurbish, remanufacture, and recycle, ensuring materials stay in circulation for as long as possible.

3. Sharing:
   Maximizing the use of underused products by allowing multiple people to share them instead of each person owning their own.

4. Resource recovery:
   Turn waste into valuable materials by recycling and recovering resources, to ensure that materials are reused instead of discarded.

5. Product-service systems (PSS):
   Instead of selling a product, companies offer access to its function as a service while still retaining ownership over it. There are also three different types of PSS:

- Product-oriented services:
  The customer buys and owns the product, but the company offers additional services to extend its lifespan.
- User-oriented services:
  The company maintains ownership of the product, and customers pay to use it temporarily. The company is therefore responsible for its maintenance and disposal.
- Result-oriented services:
  The customer pays for a specific outcome rather than a product itself. The company provides whatever is needed to deliver that result.

3
Methodology

During the thesis, several methods were used, which can be seen in Figure 3.1. First, data was collected through a literature review, interviews, and observations to get a well established background on the subject.

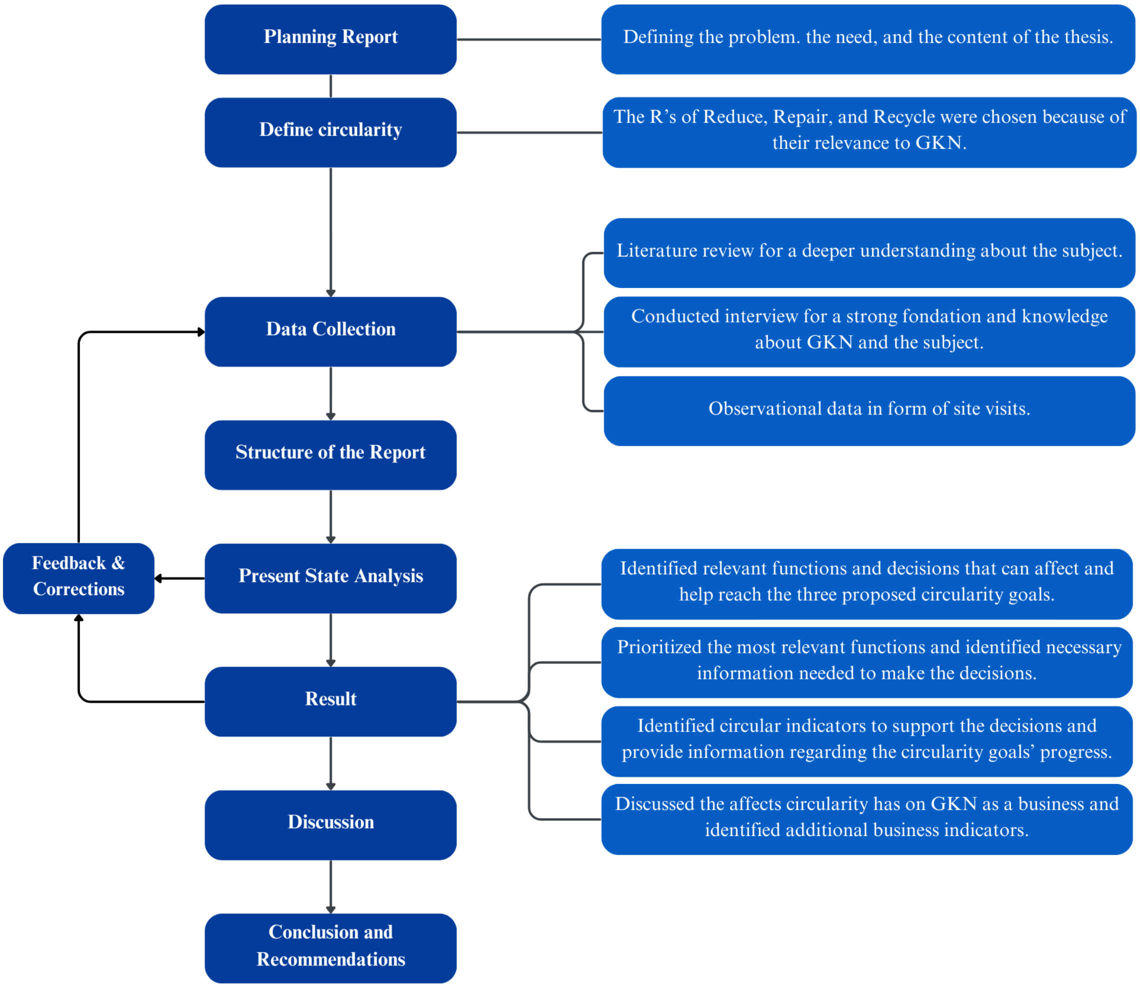

Figure 3.1: Flow chart of the methodology

The literature review aimed not only to explore and define topics related to circularity but also to identify potential applications within the aerospace development industry. From the literature review, the work of Almström et al. [36] was analyzed, which outlines an appropriate approach to develop relevant indicators. This approach also shaped the structure of the thesis, as reflected in the guiding research questions. The first step in developing indicators is to define circularity goals to reach and who or what function at GKN makes decisions about these goals. Thereafter, it is necessary to know what information is needed to make these decisions with a good foundation. After these two steps, circular indicators could be developed and connected to the decisions and proposed circularity goals. After the literature review was completed, a series of semi-structured interviews were conducted with circularity experts and personnel from GKN. For additional data collection, several unstructured interviews were conducted with supervisors and observations were made in the form of three visits to the factories. Then, a present state analysis of the company and its situation was conducted. After data collection and a present state analysis was completed, the result was created and discussed. The result and present state analysis was regularly discussed with the supervisors and other relevant interviewees which created a loop of feedback, corrections, and verifications. Finally, a conclusion and recommendations to GKN and academia were presented.

3.1 Literature Review

Articles related to the subject have been analyzed, summarized, and explored to support the thesis. According to Knopf [40] a literature review has two main components, the first being to summarize the findings of previous research on the subject. Therefore, it was important to find relevant articles on the subject in the early phases of the thesis. Secondly, the literature review was supposed to find how accurate the current literature was on the subject and what needed further research. Therefore, the literature review was important not only to find the most recent findings on the subject but also to support other methods to find new and relevant findings that can be used in the thesis. Furthermore, Knopf [40] also mentions that the literature review should start with a more general approach before narrowing to more specific topics. The review in the thesis was started by utilizing keywords and phrases in literature databases to find relevant articles. Keywords used were the following:

- Circular indicators
- Circularity in aerospace
- Circularity frameworks
- Circular business models
- Risk and Revenue Sharing Partnership

3.2 Semi-Structured Interviews

The thesis conducted semi-structured interviews with engineers, manufacturing personnel, technology developers, and other relevant employees at GKN. Interviews were also conducted with circularity researchers and external people within the aerospace industry. Since the subject is in an exploratory stage and research is being conducted as of writing, semi-structured interviews were an appropriate way to gather information, as follow-up questions were allowed [41]. Follow-up questions that might arise during the interview are crucial as they may not be covered by the literature.

The interviews were important in order to grasp the current development of circularity in the aerospace industry. Therefore, the main objective of the interviews was to understand which functions were important for circularity, what information would be needed in the functions to create measurements, and how circular indicators could be used in various different stages of product and business design. The idea of the interviews was therefore to start wide before narrowing down the focus with key people. The list of the people interviewed and their occupations can be seen in Table 3.1.

Table 3.1: All semi-structure interviews

Interview	Occupation	Date
A	Professor Emeritus, Environmental Systems Analysis	Feb 11, 2025
B	Site environmental lead at GKN	Feb 13, 2025
C	Expert Procurement Method and Means at GKN	Feb 14, 2025
D	Postdoc, Environmental Systems Analysis	Feb 18, 2025
E	Research Engineer-Materials & Processes at GKN	Feb 18, 2025
F	Sustainability Expert at GKN	Feb 21, 2025
G	Project Manager at GKN	Feb 21, 2025
H	Research Engineer at GKN	Feb 21, 2025
I	Global Commodity Manager at GKN	Feb 26, 2025
J	Principal Research Engineer Design at GKN	Mar 5, 2025
K	Strategy & Sustainability Director at GKN	Mar 18, 2025
L	Associate Professor, Supply and Operations Management	Mar 21, 2025
M	Head of Circular Economy working group at International Aviation Environmental Group (IAEG)	Mar 21, 2025

To keep the interviews on track, an interview guide was developed with questions for each interviewee that contained relevant questions [42], which can be seen in Appendix A. As mentioned by Wildemuth [42], the order and formulation of the questions could and would vary between different interviewees. The questions were designed to be open ended due to the fact that the area is unexplored, and this allowed for follow-up questions. The questions were split into three categories: (1) general questions about the background of the interviewee and the area, (2) specific questions for people at GKN, and lastly (3) questions for researchers and external people. The interviewees were selected with the help of GKN to ensure that the right person was contacted for the right function and area. With consent, the interviewees were recorded and asked if it was okay to refer to them in the thesis.

3.3 Unstructured Interviews

The second type of interview used was unstructured interviews. This method was chosen to strike conversations, meetings, and spontaneous interviews with relevant people. The main difference between an unstructured and a semi-structured interview is that in the unstructured kind, no predetermined questions were prepared [42]. The selected group of interviewees included individuals from supervision meetings, those working in GKN offices, and factories as can be seen in Table 3.2. This enables more spontaneous conversations to get a deeper understanding of the subject. Since the unstructured interview is based on a normal conversation, Wildemuth [42] mentions that good ways to start these interviews are with questions similar to "How do you feel about the...?".

Table 3.2: All unstructured interviews

Interview	Occupation
N	Sustainability Expert at GKN
O	Business Analyst at GKN
P	Associate Professor, Supply and Operations Management
Q	Site personnel at GKN
R	Manufacturing Engineer at GKN

However, something to note is that although an interview may be unstructured, it is always a controlled conversation [42]. The goal of the conversation should always be to reach the interviewer's research interests, and this occurs when both sides of the conversation are allowed to participate. A difficult task during an unstructured interview is to take notes and document everything, since this might disrupt the conversation. To counteract this, two people attended each unstructured interview to ensure that all relevant information could be documented.

3.4 Direct Observational Data Collection

Observational data were collected through site visits to GKN in Trollhättan. These visits were crucial to get an in person perspective on GKN's situation accurately and then comparing it to interviews and literature. The purpose of the site visits was also to see the material flow and where possible improvements could be made in terms of circularity.

Wildemuth [42] points out that direct observations are needed to "see it for yourself". People who exist in the setting may overlook or take certain things for granted that would be missed without an observation. Furthermore, through observational data collection, more precise data, e.g. sequence, frequency, timing, and duration, can be collected. The primary purpose of this sort of data collection is to notice behavioral patterns in a certain settings. Through site visits to GKN, non-participation observations were made.

3.5 Empirical Analysis

After interviews and site visits were conducted and the literature on the subject had been read, a current state analysis of GKN was performed together with a material flow analysis. Important functions for circularity and decisions within them were identified. After this had been done, the functions would be analyzed and possible circularity improvements were discussed.

3.5.1 Relevant R

The circularity framework in this report is based on three of the ten R's in circular economy principles: Reduce, Repair, and Recycle. These were selected for their relevance and applicability to GKN, as identified in the empirical analysis and introduction as proposed circularity goals. Reduce was considered relevant due to GKN's focus on minimizing material usage in production, as well as reducing waste, contamination, and other inefficiencies. Repair is a core aspect of GKN's business, as the company specializes in servicing and repairing engine parts. Although some repair processes resemble remanufacturing, the definition used in this thesis (based on the theoretical framework) classifies these activities as repair as the components, rather than being returned to their original manufacturer, are sent to GKN for restoration. Recycle is of significant interest to GKN due to the high cost of materials. Diverting scrap from landfill not only reduces waste disposal costs but also provides a potential revenue stream through material recovery. In addition, the three Rs each represent different lengths of a loop, short, medium, and long, as described in Chapter 2.1.1.

The other R's were considered to be irrelevant. Refuse would not be relevant since it would directly go against GKN's goals and objectives, and would need a complete remodel of their business model. Rethink was also not relevant, since the components are mounted on a single engine and use intensity would be up to the customer/OEM. Reuse of components could be applicable on the second-hand market of aerospace engines, but from a first-tier supplier such as GKN, the products need to live up to strict regulations and have well-made documentation. Since GKN work mostly with static parts, refurbishing would not be relevant since it would most likely be repaired instead. Repurposing GKN's components is also very impractical if not impossible in a useful way. The products are designed to be used with a specific engine, and finding a new useful application would be difficult if not impossible. Recover mainly insinuate energy recovery by incineration. However, the materials used in the aerospace industry are of high value, and most engine components are made of metal. In this context, recycling is far more appropriate than incineration. Therefore, recover was not deemed relevant.

For GKN, the most relevant R's are Reduce, Repair, and Recycle, as these align with their business model, regulatory constraints, and material recovery strategies. The other R's are less applicable due to strict safety regulations, high material value, and the specialized nature of aerospace components.

3.6 Research Quality of the Thesis

In order to maintain a high quality of the research, several aspects were taken into account when designing the methodology and data collection. This was based on the five criteria presented by Korstjens and Moser [43]. First of all, the research should have a high degree of credibility by drawing plausible information from the original data source, which in this thesis are the interviews. Since the data is collected from original sources, and from multiple organizations, the data is credible and gives multiple perspectives to the problems faced. Secondly, the research should be transferable to other context or settings. This was a goal for the thesis, since the creation of indicators was one of the goals, and this thesis shows how they can be created in areas where they may not be as developed or have unclear definitions. Third, the dependability of the findings over time needs to be addressed. This has been supported by multiple interviews over the thesis time period and multiple feedback sessions from supervisors, and shows that the right areas were of focus. Fourth, conformability was needed to make sure that the right data was collected and interpreted in the correct way. This was done in two ways, one by conducting multiple interviews with researchers to confirm findings and discuss new potential areas of research. And the other by conducting a literature review for the discussion to see how the research holds up to others. Lastly, the reflexivity had to be taken into account. This describes how the critical self reflection during the writing of the thesis was performed. This was done by proof reading the thesis multiple times, but also by having the supervisors review the thesis as it was being written.

3.6.1 Use of AI

In line with current recommendations for transparency in academic research [44], this thesis utilized the AI tool ChatGPT, developed by OpenAI, exclusively for language refinement and translation support. The tool was used to enhance clarity, correct grammatical inconsistencies, and improve the overall readability of the text. Importantly, no content was generated by the tool, all conceptual, analytical, and written work remains the product of the authors. The authors take full responsibility for verifying the accuracy and integrity of all content and outputs resulting from the use of AI support.

4

Present State at GKN

The following chapter will provide an in-depth background to GKN as a company, their business model, and a map of the material flows in the production. This is to give the reader a better understanding of the current state at GKN. All information presented in this chapter is derived from interviews, site visits, and GKN's website.

4.1 GKN Today

GKN Aerospace Engine Systems is a supplier to various actors in the aerospace industry [5]. They not only design, develop, and manufacture components for engines in the civil industry, but also repair them and provide after-market services [45]. To provide the best service and products possible, they are currently present in multiple countries with several manufacturing locations. A focus of their business is to provide low turnaround times in repairs for their global partners and Original Equipment Manufacturers (OEM), such as General Electric and Pratt & Whitney [46].

GKN primarily develops static components for the civil aerospace market. These parts are typically sold directly to customers, who are usually OEMs [4]. One common scenario is when the OEM chooses to purchase a component from GKN without involving GKN in a risk and reward sharing partnership (RRSP). Alternatively, GKN can participate in an RRSP, which qualifies them as a strategic partner in the engine program, this business model is described in more detail below. The components GKN supplies to OEM customers are often titanium- or nickel-based alloys, and some examples of products are the following [4]:

- Rear engine mount structures
- Forward engine mount structures
- Rotating components
- Fan cases
- Turbine cases
- Shafts

Since GKN is developing aerospace engine components for OEMs, they are qualified as partners in RRSPs. This ensures that GKN is trying to make the best parts possible within RRSPs in terms of weight, strength, cost, and efficiency. By being part of this program, GKN can also take on the role of maintaining MRO services for the engine. This includes parts manufactured by GKN and others within the RRSPs. As of writing, GKN currently has three large centers for engine MRO, one in San Diego, US, one in Johor, Malaysia, and one in Trollhättan, Sweden [47]. This enables the company to offer repair solutions close to their customers, and also send out on-site service teams for immediate support.

To stay on top with new technologies and solutions, GKN is investing heavily into R&D practices [48]. By having a location dedicated to advancing current and new technologies, GKN is working actively, both independently and in collaboration with its customers, to improve not only the products it manufactures, but also the overall sustainability of the industry [16].

Although it is mandatory to report emissions in today's environmental reports [49], regulations regarding recycled materials and circularity within a company are not as developed. GKN could therefore be in need of measuring its circularity to be able to publish it in its environmental reports in the near future.

4.2 Business Model

GKN's products undergo a long development cycle, which can be followed by MRO until they reach their EOL. GKN's production process spans an extended period before products reach the market and begin to generate revenue. The specifics of this model will be discussed in detail in Sections 4.2.1 and 4.2.2. Figure 4.1 illustrates GKN's cash flow during a product's life cycle.

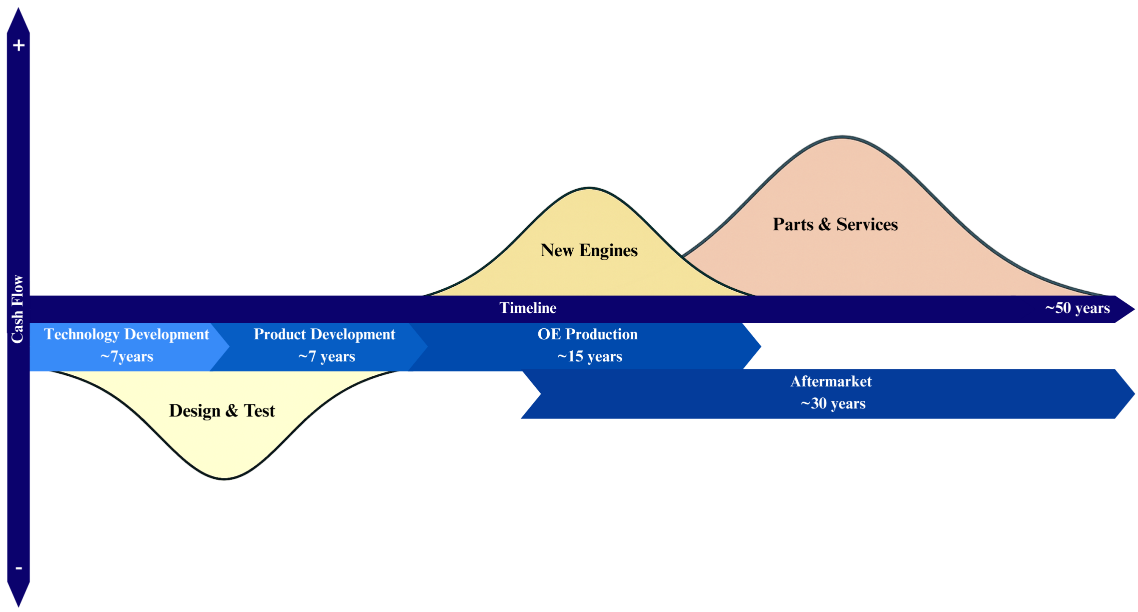

Figure 4.1: Time line and cash flow of product's life cycle [4]

In Figure 4.1, it can be seen that the largest investments are made during the development stages of the technology and the product, as it has negative cash flow. Since these stages are very long and it is not uncommon for them to take up to 15 years, a positive cash flow is not realized until many years later, which is explained in more detail in Section 4.2.1.

4.2.1 Risk and Revenue Sharing Partnership

The aerospace industry usually works with a RRSP [50]. The same works for some of GKN's products, where they own a share of the whole engine. The share is based on how much of the engine is made from GKN's parts. The OEM contract results in a power-by-the-hour or a cycle-based business model, where one cycle would be equal to a flight from point a to point b. This means that the engine only generates revenue when it is in use. GKN's share of the revenue is the same as its share of the ownership of the engine. As can be seen in Figure 4.1, all positive cash flow from this business model is generated during the aftermarket phase. As a result, the industry has high entry barriers, making it difficult for new players to commit the long-term investments of capital, resources, and time required.

The high risk requires high trust between the many partners since they lose revenue if some part of the engine breaks down. In addition, the MRO contract expires after a certain number of years, which in turn results in the end of revenue generated for GKN on that specific engine if no additional MRO services are procured. Even if the engine is later determined to have reached its EOL, this does not mean that the part produced by GKN is no longer viable or as good as new. This could be a potential loss of a reliable part for GKN.

Since GKN also takes on the role of repairing and performing engine service, a large portion of the positive cash flow is generated in these operations. It is therefore critical that the company has the capacity and materials to repair parts, such as turbine blades and manufacture spare parts.

4.2.2 Circular Business Model

Given GKN's involvement in not only the design and manufacture of engine parts, but also the repair and servicing of engines, circularity is a core aspect of its business. In addition, GKN focuses on manufacturing products with a long lifespan, designed to last the entire lifetime of the engine.

The materials that GKN uses in its products are very expensive. This gives high incentives not only to recycle the material as much as possible, but also to minimize the amount of material needed. GKN currently has two different types of recycling activities. Firstly, it makes sure that its material waste in production is being managed by a recycling company. When material is sold to an external recycling company, the quality of the waste is of great importance. The price difference between the contaminated material and the pure material is large. For example, for the alloy TI 6-4, the pure metal has a 132% higher price compared to the contaminated counterpart [1]. In order to maximize profits from these metal scraps, efforts have been made to collect as much scrap as possible. However, making sure that it is not contaminated with other metals is one of the larger challenges. Secondly, GKN works with its suppliers to return excess material from its production to increase

[1] Internal Document, 2024

recycling. This type of collaboration sends back material that was purchased from that specific supplier, creating a loop of materials.

4.3 Material Flow

After conducting several interviews with the relevant people working at GKN and visiting the factories, a general material flow was created, as can be seen in Figure 4.2. In order to create the flow of the materials, a sample product was first selected and analyzed, and then adjusted to make it more general for all of GKN products.

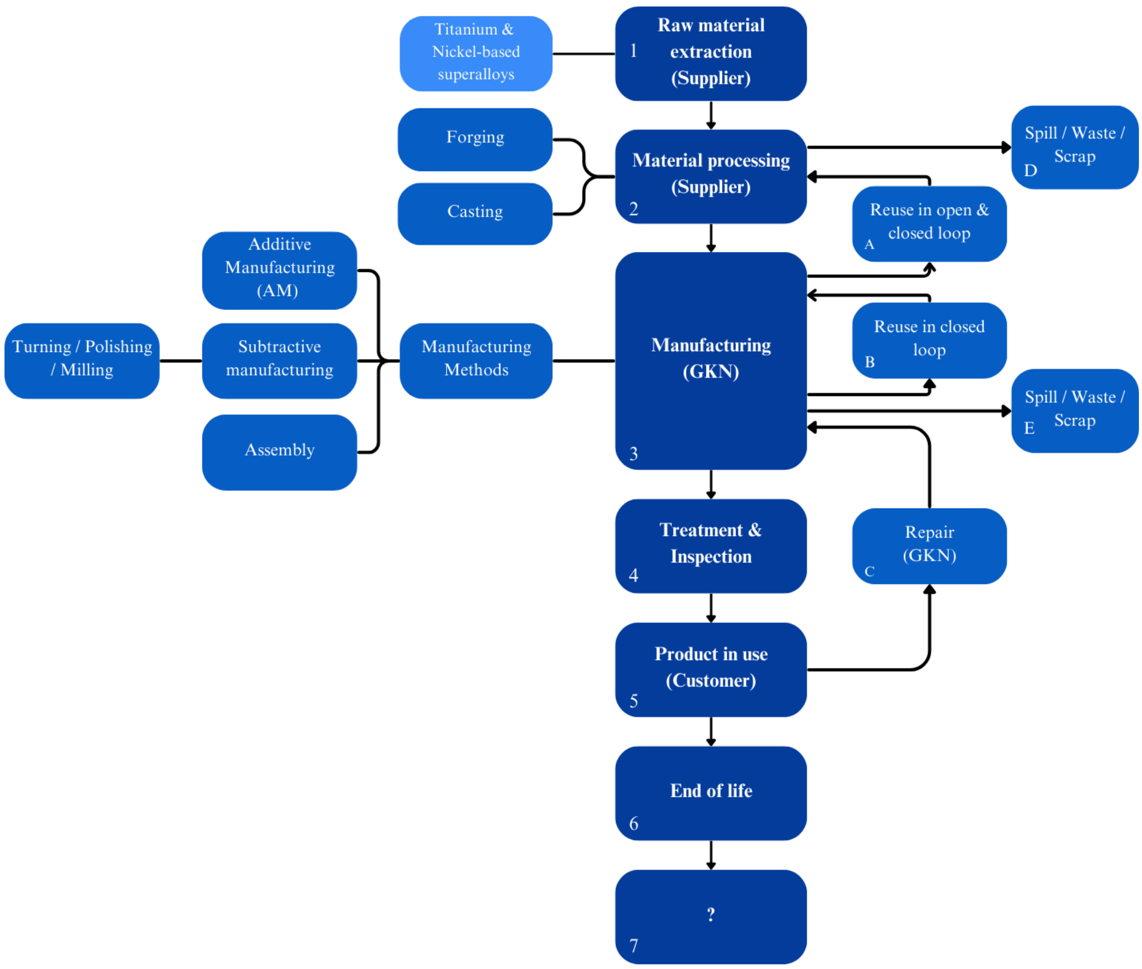

Figure 4.2: General material flow at GKN

The material flow is analyzed from the perspective of GKN and how it handles ingoing and outgoing material flows. First, the raw material is acquired by its supplier (1). GKN primarily uses two types of metal-based alloys: titanium-based and nickel-based superalloys. GKN uses titanium for components that need to be lightweight and nickel-based when they need to withstand high temperatures. These materials are then processed in various ways, including melting and casting into products, creating bars or pellets, forging parts for later machining, or forming sheet metal. Regardless of the form in which the raw materials are procured, they will undergo further processing (2). During this stage, some material waste and scrap is generated (D), which is most often handled by an external recycling company to be recycled and sold.

When the processed material reaches GKN's manufacturing facilities (3), further processing is carried out on-site, involving techniques such as additive manufacturing (AM), subtractive manufacturing, and assembly. Many of these processes involve material removal, leading to additional waste and scrap generation (E). However, in some cases, the supplier will collaborate with GKN to reuse material (A), creating a closed or open loop, depending on whether the excess material is returned to GKN or not. In addition, some leftover material is reused internally within GKN's processes (B), if the process allows it. An example of such a process could be the reuse of material from AM processes.

Following manufacturing and final processing, the components are treated and inspected, including quality control (4). Afterwards, they are delivered to customers for use (5). Over time, these components require maintenance or repair. When such needs arise, parts are sent back to GKN (C) for service, allowing for repairs to extend product life and reduce waste. These repairs are for products manufactured by GKN and components manufactured by others. This cycle continues until the service contract of the engine runs out. Finally, the engine has reached its EOL and is out of service (6). At this point, the final fate of the engine components remains uncertain, as this is decided by the final owner (7). Possible scenarios include recycling valuable materials, reusing functional parts for other engines, repairing specific components, or, in some cases, disposal if no further reuse is feasible.

5

Proposed Circularity Goals

GKN's current sustainability approach focuses on establishing circular solutions of repair, circular materials, and circular operations. In Figure 5.1 the connection between circular indicators, decisions, and circularity goals can be seen. According to Almström et al. [36] a pull approach is appropriate when designing suitable indicators. Therefore, as seen in Figure 5.1, the circularity goals should be established first, then decisions affecting these goals, and finally circular indicators can be developed to support decisions and communicate progress.

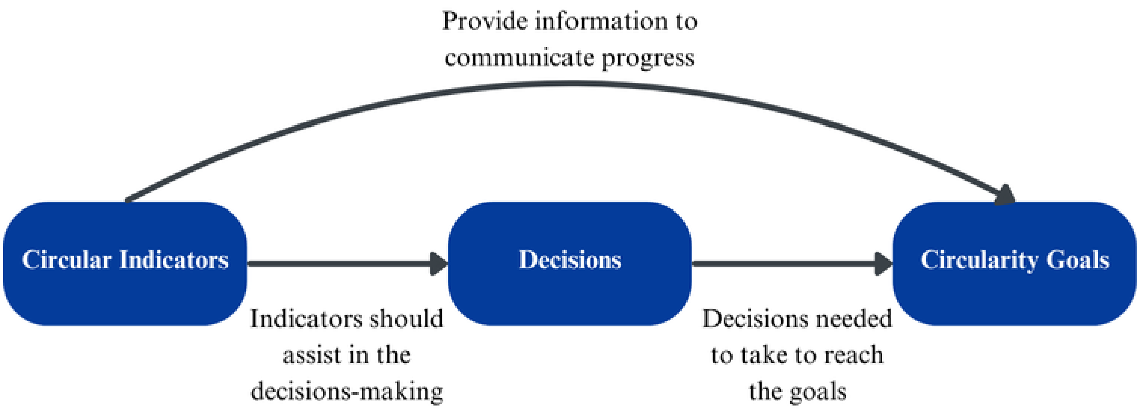

Figure 5.1: How circular indicators, decisions, and circularity goals affect each other

Since indicators should have something to strive towards and something to communicate progress about, this thesis proposes that GKN establishes its circular solutions as goals to follow the pull approach of creating circular indicators. These proposed goals would therefore be formulated as follows:

- **Goal 1:** Reduce material usage
- **Goal 2:** Increase recycling of material
- **Goal 3:** Grow repair business

These goals also mirror the three R's, Reduce, Recycle, and Repair, and reflect areas where GKN sees a strong potential to strengthen circular practices.

6 Identified Functions

The following chapter presents and discusses the identified functions that have an affect on GKN's circularity and how they relate to the three R's, Reduce, Repair, and Recycle. All identified functions, except EOL Management, are currently organizational units at GKN and their definition can be seen in Table 6.1. This chapter will also discuss the decisions that exist within the different functions that need to be taken to achieve the three proposed circularity goals. All information presented in this chapter is derived from interviews. Any additional sources are appropriately referenced.

Table 6.1: All functions and their definition

Functions	Definition
Strategy	Organizational unit at GKN that handles business models and decisions for enabling circular solutions. This includes managing circularity with regard to economic prosperity. This function also handles market analyses, merger and acquisitions, business analysis, and more related to the strategic decisions within the company.
Commercial	Organizational unit at GKN that engages with clients to understand their needs, provide technical support, manage service agreements, and ensure long-term partnerships. In addition, manages business operations related to sales, pricing, and contracts.
Technology Development	Organizational unit at GKN that develops new materials, manufacturing technologies, and repair methods. It is driven by market requirements, the integration of new methods and materials, airframe compatibility, and evolving engine specifications.
Design	Organizational unit at GKN that cover decisions taken during the design phase of the product. For example, determines material selection and manufacturing feasibility during the product development phase.
Procurement	Organizational unit at GKN that evaluates, negotiates, and contracts suppliers, for example based on cost, quality, lead time, and adherence to industry standards.
Manufacturing	Organizational unit at GKN that handles selection of manufacturing methods for products, considering waste generated both prior to and during production.

Functions	Definition
Product Quality Assurance	Organizational unit at GKN that ensures product quality by evaluating components after manufacturing, before repair decisions, and conducting final inspections after repairs to authorize their return to the customer.
Waste Management	Organizational unit at GKN that establishes procedures for handling, segregating, recycling, and disposing of waste materials from manufacturing and maintenance operations.
Engine Maintenance	Organizational unit at GKN that conducts inspections, repairs, and overhauls on engines to maintain performance and compliance with customer requirements.
EOL Management	How the engine and its components are handled after its operational use. As of writing, this is not yet an organizational unit at GKN, but it is proposed that one be established to improve and manage circularity at EOL.

In order to understand how the functions are important with regard to circularity at GKN, they have been placed in relation to the three R's that align with the proposed circularity goals. An overview of these relations can be seen in Table 6.2. For example, the strategy function has an impact on both repair and recycle to build a foundation for circularity at GKN.

Table 6.2: Summary of all functions relating to the three proposed circularity goals connected to the three R's.

Functions	Goal 1: Reduce	Goal 2: Recycle	Goal 3: Repair
Strategy	■	■	■
Commercial		■	■
Technology Development	■		■
Design	■	■	■
Procurement		■	
Manufacturing	■	■	
Product Quality Assurance			■
Waste Management		■	
Engine Maintenance			■
EOL Management		■	

Many of these functions are interconnected and influence each other. For example, waste management is directly influenced by material selection, which is determined during the design phase. To better understand the root causes behind various decisions, a mapping of these functional relationships has been conducted. The results are presented in more detail in Appendix B, which illustrates the connection between the influencing and the influenced function. In addition, while strategy may not have a direct effect on waste management, it indirectly influences it by shaping design choices, for example, designing products to have a long lifespan. To avoid redundancy, decisions are discussed only within the function in which they are made. This approach, combined with Appendix B, helps to clearly identify both direct and indirect influences between functions.

6.1 Strategy

Reduce & Recycle
The strategy function at GKN is highly relevant to both reducing material usage and increasing the use of recycled materials, as it defines the company's long-term direction and objectives. By setting measurable circularity goals, such as targets for material efficiency, reduction in virgin material use, or a target for recycled ingoing material, the strategy function directly influences how the company prioritizes and integrates resource-saving measures across its operations. In addition, GKN's business model, as shaped by the strategy function, includes circular aspects such as product repair services, extended product ownership, and responsibility for components at EOL. These elements support material reduction by extending the life of products and components, minimizing the need for new raw materials.

Repair
As mentioned above, a part of GKN that sets the prerequisites for the entire business is the strategy function. The strategy function sets the foundation for who owns the product and the business model, what they are actually giving to the commercial function to sell, and what should be repaired and manufactured at the company. Furthermore, GKN repairs not only the components they design but also those produced by others, which increases the circularity and extends the lifespan of the components in the aerospace industry.

Decisions
The strategy function is setting the foundation for a lot of decisions in other functions and is therefore very important for circularity. The decisions that impact the three proposed circularity goals can be seen in Table 6.3.

Table 6.3: Decisions in the strategy function connected to the circularity goals

Name	Decision	Goal
Str1	What the long-term goals of the company strategy are. This includes measurable circularity goals.	Goal 1, 2, 3
Str2	How the business model of the company involves circular aspects, such as the repair of products, ownership, and responsibility at EOL.	Goal 1, 2, 3

Name	Decision	Goal
Str3	Determine how and when to expand GKN's repair portfolio by identifying and certifying additional components for repair.	Goal 3

6.2 Commercial

Recycle
The restrictions on what GKN can sell are strict, as it is set by the material specifications. Therefore, through the commercial function, it is important to have a discussion with customers and OEMs about what an acceptable amount of recycled material is without risking safety and quality risks.

Repair
Repairing plays an important role in GKN's customer relationships, as the company offers not only components but also repair services. In order for the repair of the components to be functional, the communication between the commercial function and partners would have to be transparent with respect to its quality, data collection, and performance to result in the best possible repair service.

Decisions
Customers and OEMs set demands and regulations on what GKN can and must do. For example, how often components need to be serviced or checked, and may result in repair. Thus, decisions within the commercial function that affect the proposed circularity goals of 2 and 3, and can be seen in Table 6.4.

Table 6.4: Decisions in the commercial function connected to the circularity goals

Name	Decision	Goal
Com1	Decide how and when to engage with customers and OEMs early in the material specification process to align on circularity goals, such as acceptable levels of recycled content.	Goal 2
Com2	Decide how to communicate and demonstrate the value of circular offerings, such as repair services and take-back programs, to ensure customer buy-in and participation.	Goal 3

6.3 Technology Development

Reduce
The development of technologies is what allows new ways of manufacturing, new products, and new innovations in the industry [4, 17]. Since these developments are long and are aimed at changing the future and not the present, the reduction possibilities are large. For example, new manufacturing technologies such as AM

can reduce the amount of material usage that is needed to produce the product.

Repair
With new and emerging technologies, the repair of components can change to reduce the amount of material needed and scrapping. With new repair methods, such as the use of AM, less material can be used. For example, AM can repair broken fan blades by adding material to the damaged area, eliminating the need to scrap the entire blade.

However, before repairs even start, quality needs to be controlled. New technologies may enable better ways of controlling quality in terms of efficiency and accuracy. Therefore, reducing the amount of repairs needed, or creating predicative maintenance to lengthen product life.

Decisions
Decisions on implementing new technologies that reduce material usage, minimize landfill, and support repairability are made within the technology development function. Relevant decisions within technology development can be seen in Table 6.5.

Table 6.5: Decisions in the technology development function connected to the circularity goals

Name	Decision	Goal
TD1	What innovative manufacturing and repair methods are adopted to improve material efficiency and reduce waste, e.g., AM.	Goal 1
TD2	What new quality assurance technologies to develop.	Goal 3

6.4 Design

Reduce
The design function has a significant influence on several areas of the organization, as illustrated as a quality house in the Appendix B. Decisions made during the design phase directly affect the product's lifespan, with an extended lifespan reducing overall material consumption and fewer replacements are needed. In addition, design determines how much material is required to achieve the desired functionality, making it central to improving material efficiency. It also shapes which manufacturing methods can be used, potentially enabling more efficient or combined processes that further reduce material use. Furthermore, since the design relies on a wide range of information to guide decision-making, supportive documentation can help steer the design toward more circular outcomes.

Recycle
The design function at GKN has a large impact regarding recycling since the design phase sets many prerequisites for recycling of the product's life cycle. The choice of material is part of the design phase that sets the foundation for whether the material

is easy, difficult, or even possible to recycle. In addition, supporting documents and product passports can help choose and trace the material to ensure that it is from recycled content. The design phase is also crucial for determining how easy it is to dismantle the product, which results in a better possibility of sorting and recycling. Furthermore, having a product and a product family of as few materials as possible could make recycling more efficient and pure.

Repair
The design directly influences how the component is mounted on the engine, its resistance to damage, and its potential for repairability. In addition, the design determines the choice of materials. Since GKN's components are built for long lifespans, repairs often occur many years after the initial design phase. Therefore, material selection must account for future requirements and conditions. For example, if the material will be available when the component needs to be repaired or if a substitute material could be used.

Decisions
There are multiple decisions relevant to the design function that are crucial for circularity. The decisions made in the design function that are related to the three proposed circularity goals can be seen in Table 6.6.

Table 6.6: Decisions in the design function connected to the circularity goals

Name	Decision	Goal
Des1	Decide on the material and manufacturing approach for a product or product family, including what and how much material is used, the acceptable level of recycled content, and which manufacturing methods that are compatible with the design.	Goal 1 & 2
Des2	Decide on the product's design in terms of intended lifespan, the balance between durability and repairability, and the ease of disassembly or dismantling.	Goal 1, 2, 3
Des3	How supportive documents such as an LCA and ISO standards are used in the design phase.	Goal 1, 2, 3
Des4	How traceability is enabled in the design, for example, through a product passport.	Goal 2

6.5 Procurement

Recycle
The degree of recycled incoming material is directly affected by the selection of suppliers. However, the decision to acquire and use recycled material is complex and depends mainly on two variables. Firstly, it is the supplier that currently decides how much recycled material they are selling and able to supply. Because of this,

GKN is not aware of how much of the incoming material is recycled. Secondly, the allowed amount of recycled material is regulated by GKN's customers and the material specification. The process of changing a material specification is long and expensive and, therefore, is not often prioritized.

Recycling is also important for outgoing materials, where one approach is to manage and recycle waste through collaboration with suppliers. Some of GKN's suppliers have been able to recover waste material after machining has taken place at GKN. Some of the waste material is reprocessed and sent back to GKN, and some are sent to other customers of the supplier.

Decisions
Procurement is very important for circularity as it sets up a large part of the upstream supply chain. The decisions made in this function related to the circularity goals can be seen in Table 6.7.

Table 6.7: Decisions in the procurement function connected to the circularity goals

Name	Decision	Goal
Pro1	Choosing a supplier that has a high degree of recycled material that still meets the correct regulations and standards.	Goal 2
Pro2	Collaborating with suppliers who can take back waste material for reuse and recycling.	Goal 2
Pro3	Decide if supplier audits should be conducted to assess and ensure circularity performance.	Goal 2

6.6 Manufacturing

Reduce & Recycle
Manufacturing is a critical function for both reducing material usage and increasing material recycling at GKN. Many of the current manufacturing methods are subtractive, involving the removal of large amounts of material that generates significant waste. By shifting toward more material-efficient, the need for raw material can be reduced and less waste is produced. Furthermore, the choice of manufacturing method directly affects the recyclability of the waste, as it determines factors such as the degree of mixed waste, which in turn impacts the ease with which the waste can be sorted and recycled.

Decisions
Manufacturing methods influence circularity in terms of both reduction and recycling, as they directly affect material efficiency and the ease with which excess material can be recycled. The important decision made in this function that supports the circularity goals can be seen in Table 6.8.

Table 6.8: Decisions in the manufacturing methods function connected to the circularity goals

Name	Decision	Goal
Man1	Decide on manufacturing methods, in collaboration with the design function, to minimize waste and improve material efficiency, including the potential for combining different methods.	Goal 1 & 2

6.7 Product Quality Assurance

Repair
One function that supports repair operations is product quality assurance which occurs before the component is sent from the customer in question of being repaired or not. Currently, if the user of the engine detects an anomaly of the component, they send the evidence to GKN to understand how to proceed. Two paths are possible, either GKN ensures that the quality is acceptable, without risk, and can continue flying, or the component is sent to GKN for it to be repaired. Quality is of highest importance in the aerospace industry due to the high safety standards, and if there is doubt as to whether the component needs to be fixed or not, it will always be sent for repair. After the component is repaired, a quality control will be performed to approve it to be returned to the customer.

Decisions
With quick, efficient and secure quality assurance, decisions regarding the quality can be made more efficiently. To make product quality assurance as best as possible, the decisions in this area can be seen in Table 6.9.

Table 6.9: Decisions in the product quality assurance function connected to the circularity goal

Name	Decision	Goal
PQA1	How data is collected and analyzed to determine the quality of a component.	Goal 3
PQA2	What quality is accepted on the damaged components.	Goal 3

6.8 Waste Management

Recycle
Recycling is heavily impacted by the waste management at GKN as the company works with advanced and expensive alloys. Therefore, how the waste of these materials are handled is of great importance. The waste material during the manufacturing phase has three different routes in terms of recycling. Firstly, the waste can go back to the previous steps in a closed loop inside of GKN processes, as illustrated in Figure 4.2. Secondly, the waste is sent back to the supplier who will handle and recycle it in an open or closed loop. Lastly, the waste is sent to the external recycling

company who will process and recycle the material.

When GKN is handling its waste, the purity of the waste is crucial to ensure it can be sold for the highest possible price, as cleaner, single-material waste streams are more valuable and easier for recycling companies to process without additional separation or treatment. Therefore, a high degree of purity in the waste is not only interesting from a recycling perspective, but also a profitability perspective.

Decisions
Waste management has decisions impacting one circularity area, recycle. The decisions relating to the circularity goal of recycling can be seen in Table 6.10.

Table 6.10: Decisions in the waste management function connected to the circularity goal

Name	Decision	Goal
WM1	What methods and protocols are used to sort waste from different stages of manufacturing, ensuring proper separation of materials.	Goal 2
WM2	Decide the level of employee training needed and how to ensure that they understand the impact of their waste handling.	Goal 2
WM3	What waste handling partners GKN should collaborate with.	Goal 2

6.9 Engine Maintenance

Repair
How the engine is serviced is crucial for the repair part of GKN. The possibility to repair components will result in a longer lifespan of the products.

Decisions
The decisions that are important for the third circularity goal in the engine maintenance function can be seen in Table 6.11.

Table 6.11: Decisions in the engine maintenance function connected to the circularity goals

Name	Decision	Goal
EM1	Selection of repair technologies and methods that are used to repair components.	Goal 3
EM2	Decide whether improvements and changes should be implemented at the level of individual repairs or across entire workshops.	Goal 3

6.10 EOL Management

Recycle
In order to create a loop of materials, the materials need to work cradle-to-cradle instead of cradle-to-grave. Meaning that the materials should work with a circularity perspective in mind, instead of utilizing the linear economy. This in turn means that all products manufactured by GKN need to be recycled at the end of their lifespan. With better EOL management, products can be recycled and materials can be returned to the production flow.

Today, the EOL of the engine is often due to rotating parts or the need for a more modern engine. However, all parts of the engine are still taken out of operation. This results in the EOL of GKN's components as well, even though it is often a static, still functioning, part. Since the fate of the engine at its EOL stage is determined by the final owner of the engine, possible scenarios for the components include recycling high-value materials, reusing parts as spares, repairing components, or disposing of them if reuse is not possible.

Decision
Although the EOL management function has an important influence on circularity as a whole, GKN cannot currently make any decisions in this function since it has no ownership of the products at the EOL. Therefore, decisions that affect the proposed circularity goals and what happens at the EOL are made in the strategy function.

7

Information for Decision-Making

This chapter explores the decisions outlined in the previous chapter, focusing on the information needed in each function to support and enable them in order to improve the proposed circularity goals at GKN.

Although all the functions presented in Chapter 6 are relevant to supporting circularity at GKN, it was concluded that several of the decisions within these functions are either made by external actors or are significantly influenced by other functions, as can be seen in Appendix B. As a result, the degree of independence in these decisions is limited. For example, decisions related to manufacturing methods are closely dependent on inputs from both the design and technology development functions. As a result, the information discussed throughout this chapter can still serve as a valuable foundation to enable more informed and circular-oriented decision-making in those functions not explored in detail. Therefore, the functions that were considered to be not as influential at GKN are Manufacturing, Product Quality Assurance, Engine Maintenance, and EOL Management, and will not be discussed in detail in this chapter.

All information presented in this chapter is derived from interviews and site visits. Any additional sources are appropriately referenced.

7.1 Strategy

The decisions defined in the strategy function from the previous chapter can be divided into three topics: circularity goals, circular business model, and repair certifications and portfolio, which affects all of the three proposed circularity goals. This section explores the result of the information that is needed in these decisions, as illustrated in Figure 7.1.

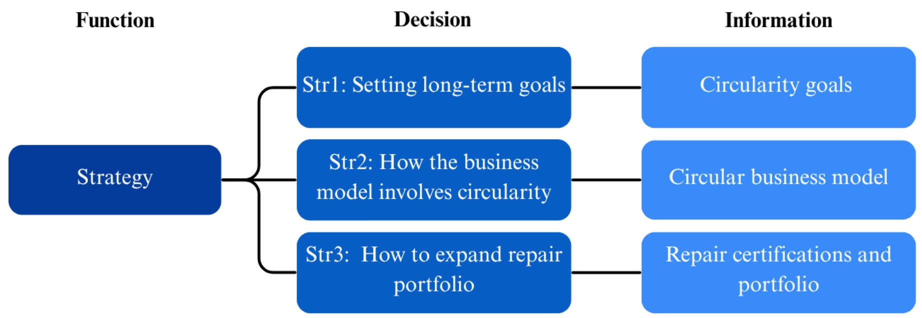

Figure 7.1: The strategy function and its relevant decisions and information

7.1.1 Circularity Goals

Although the decision to set goals, for example the three proposed circularity goals, and strive toward them is crucial, it is equally important to ensure that these goals are relevant to GKN. Therefore, both internal and external information would help form the basis for these goals. One of the most significant factors influencing GKN's goals is the impact of other organizations. For example, organizations such as the EU and its Green Deal and CSRD requirements compel GKN to take action in the same direction. Therefore, it is important to have knowledge and the ability to anticipate future regulations related to sustainability that can impact a circular strategy. It could also benefit GKN to obtain information about industry comparisons and best practices from peers to establish realistic and competitive circularity goals. Either way, it needs to be clear what GKN wants to achieve with the circularity goals.

Helpful information for setting and showing the progress of internal circularity goals includes how circular performance will be measured and applied, such as material recovery rates, internal material efficiency, the percentage of recycled content used, and the number of components reused or repaired.

7.1.2 Circular Business Model

How the company decides to involve circular aspects is critical to the strategy to achieve a higher degree of circularity in the company. As presented previously, GKN already uses several circular strategies in its operations such as recycling excess material, collaborating with suppliers for potential closed loops, and repairing products. Therefore, a lot of information required is related to the cost of activities, savings, and future trends in the industry.

Another aspect to consider is when the engine has reached its end of operation, as GKN's component may not need to be taken out of operation since they are most likely still functional. Although the component may not be owned by GKN at the time of the engine's EOL, the decision of possibly regaining and reusing the component, for a new engine or as a replacement part, could benefit GKN. However, for this to be possible, information about who owns the product at the EOL and who's responsibility it is to take care of the component is needed. Information about the traceability of components is useful in tracking its movement and final owner, which can open up for discussion to possibly transfer ownership back to GKN or the OEM, by buying the components back. In addition, to decide whether the component is even profitable to take back, information is needed on whether current products are built in a way that supports it, such as the cost of the return operation and if it is possible to reuse, remanufacture, or recycle the component. In addition, there are also regulations that must be followed, such as limitations of age and quality restrictions and certifications.

7.1.3 Repair Certifications and Portfolio

To efficiently repair products, several pieces of information are needed to make a well-informed decision on what components GKN is certified to repair. Information about the specifications and requirements for each product that is up for evaluation is needed to ensure that it is something that GKN can manage. For example, information about material specifics, costs, the ownership of the component, etc, is information that is influencing this decision.

Before making a decision on the potential expansion of the repair portfolio, information about the current situation will provide an understanding of the difficulties and problems that might arise at GKN. For example, an overview of how many and what types of components are certified for GKN's repair services, including repair volumes and trends over time. Afterwards, it is important to know and understand the limitations that currently prevent an expansion of the repair portfolio, such as certification requirements, material compatibility, competition, or process constraints, to know where changes are needed. If the decision is to extend GKN's repair portfolio, it would be beneficial to have insight into which repairs are most commonly requested by OEMs or airlines, and where unmet demand exists in order to obtain new certifications to cover additional parts.

7.2 Commercial

Since the commercial function works with communicating with the customer and the OEM, there is not only a lot of information needed in this function but also a lot of information being generated. In this section, the result of the information needed to make decisions regarding the management of the customer and OEM is presented, as illustrated in Figure 7.2. This affects mainly the proposed circularity goals of increasing material recycling and growing the repair business.

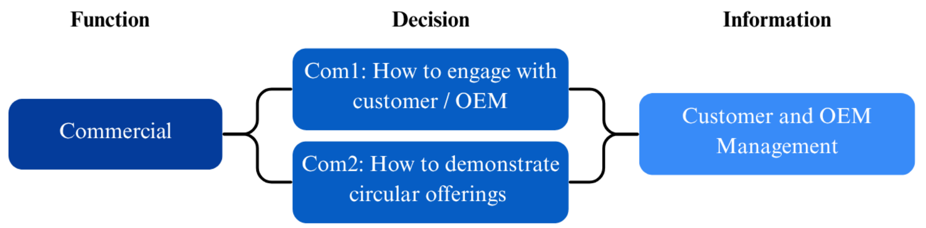

Figure 7.2: The commercial function and its relevant decisions and information

7.2.1 Customer and OEM Management

Since a lot of the requirements and regulations are regulated by the material specification, discussions are needed before these specifications are written with the customers and OEM. An example of such a regulation is the acceptance rate in terms of recycled material in the products. In addition, information and a mapping of when GKN communicates with customers and OEMs throughout the product life cycle could identify where circularity topics, such as repair options, return logistics, or reuse opportunities, can be introduced or reinforced. Furthermore, to predict engine maintenance, information on how usage data, repair history, and component condition are shared between GKN and the customer could be of use.

In addition, since there are many actors involved in a CE, it is important that stakeholders is informed about the possible circular activities in the supply chain. In order for GKN to progress its circular operations, its customers need to be well informed on the services GKN is offering, such as repair services and take-back programs, and whether there is any value in these services.

The commercial function also provides information that other functions will take advantage of in their respective decisions, for example, the allowed amount of recycled material. The commercial function provides customer requirements and demand data that will be useful throughout the organization, for example, customer demands, potential revenue streams, and market trends.

7.3 Technology Development

The decisions defined in the technology development function of the previous chapter could be divided into two topics: manufacturing and repair technologies and quality control technologies which influence the goals of reducing material use and growing the repair business. This section explores the result of the information that is needed in these decisions, as illustrated in Figure 7.3.

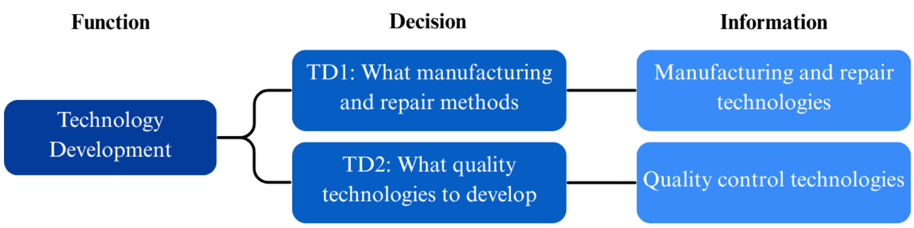

Figure 7.3: The technology development function and its relevant decisions and information

7.3.1 Manufacturing and Repair Technologies

When deciding to develop new manufacturing and repair technologies, information on the current situation on what works, what does not, and the possibilities for improvement is important. For example, data on how different manufacturing and repair methods impact raw material use and waste generation can help GKN understand which methods and processes need development. Similarly, information about processes' ability to collect, reprocess, and reintegrate material waste from production directly into new manufacturing cycles results in understanding possible improvement areas. For example, if we look at operational flights, it is vital to gather data from engines to understand where repair technologies are most frequently needed.

7.3.2 Quality Control Technologies

Furthermore, in the technology development function, it is decided which quality control technologies should be developed. To develop the most useful quality control technologies, information is needed on current repair problems and failure rates.

7.4 Design

The identified decisions were mostly related to long-term circularity and influence all three of the proposed circularity goals. The defined decisions were divided into three topics: material and manufacturing approach, design characteristics, and supporting documentation. This section explores the result of the information that is needed in these decisions, as illustrated in Figure 7.4.

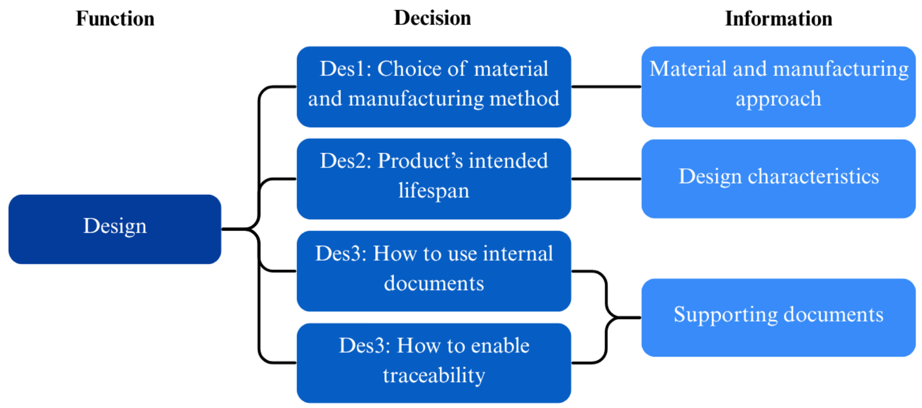

Figure 7.4: The design function and its relevant decisions and information

7.4.1 Material and Manufacturing Approach

To recycle the material, information about the current recycling infrastructure is needed to know if recycling is a feasible option. This could include information such as collection systems, available technologies, and processing capabilities. To support this, information on material recovery rates would be useful. Furthermore, information on the historical or expected efficiency of recovering the material can provide valuable insight into how efficiently the material can be reclaimed and reintegrated into new production cycles.

Deciding to use more than one material in the product affects the ease of sorting and recycling. If several materials are used, information on material compatibility could be useful in determining the risk of contamination during recycling, particularly if the materials are mixed or bonded in ways that hinder separation. In addition, information about what material other products are made of could be beneficial as this could create a standardization across product families that results in the use of the same material, which facilitates more efficient recycling processes and increases opportunities for reuse or recycling at the EOL.

When designing a product, it is good to consider how much raw material input is actually used in the final product versus what goes to waste, that is, material efficiency (or in aerospace terms, buy-to-fly ratio). The output material is also important to have information about, such as which manufacturing method results in less waste, the design could be planned on using the method that creates the least amount of waste. With this information, a decision regarding how the product have to be manufactured could be made, for example AM or forging instead of casting, which could result in a reduction in scrap and raw material demand.

7.4.2 Design Characteristics

Even though the design stage is at the beginning of a product's life cycle, it is crucial to consider its EOL from the start. Understanding whether the product is more likely to be scrapped, upgraded, or repurposed helps determine whether a longer lifespan or modularity is more beneficial to circularity. Therefore, information on the trade-off between durability and repairability is needed. This type of information could be how much material is needed and how many times the product is expected to be repaired versus actually repaired. With higher repairability, it would be beneficial to have a product that is designed to be easy to dismantle for repairs. In order to ease these repairs, common points of failure for similar products would be crucial. Lastly, information is needed on how different manufacturing methods affect durability. Newer types of manufacturing methods, such as AM, is not tested as much as traditional manufacturing methods.

7.4.3 Supporting Documentation

There is documentation that can support several of the decisions that GKN has to make. These documents can be grouped into two different categories, internal documentation and external documentation. LCAs are internal documentations that can help GKN trace the material, see how much is needed, and locate potential circular flows. External documentation can be aerospace standards, customer demands, ISO standards, and government organizations standards. These types of documentation might not only help GKN measure and enhance its circularity but also define difficult terms and set a foundation for how a company in this sector needs to operate. Although these documentations help track the material throughout its lifespan, strict industry regulations and standards require extensive internal documentation once it leaves the factory to ensure traceability and accountability. However, this traceability can be further enhanced with new types of product passports that can help GKN understand ways to improve their circular material flows [51]. These product passports are designed to provide everyone with a better understanding of the origin of a product, provide clear compliance documentation, and provide guidance on product disposal.

7.5 Procurement

Several decisions were found in previous chapters regarding the effect that procurement and suppliers have on the potential to increase material recycling. The decisions defined in the procurement function were divided into three topics: supplier choice, supplier collaboration, and circularity-based supplier audits. This section explores the result of the information that is needed in these decisions, as illustrated in Figure 7.5.

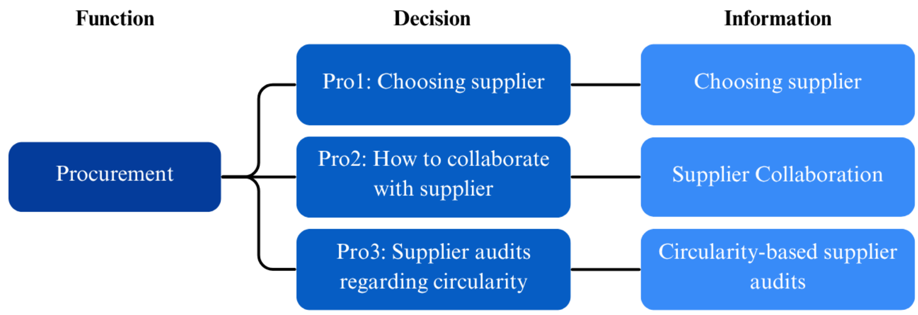

Figure 7.5: The procurement function and its relevant decisions and information

7.5.1 Choosing Supplier

In order to support the decision to choose a supplier that has a high degree of recycled material, several types of information are important to discuss. To keep track and possibly increase the degree of recycled material used, information is needed on what percentage of the incoming material is recycled. Although this number is assumed to be around 40 - 60% today, there are no definite data. Suppliers may also have a different definition of recycled material. Therefore, information regarding the suppliers' definition of recycled material is also needed to ensure that it supports the same as GKN's. In addition, information on the specification of the material is needed to ensure that each material is living up to the strict demands and regulations. A transparent supply chain is crucial for tracking material flows, understanding the level of circularity in GKN's operations, and identifying opportunities for potential improvements and where they can be implemented.

7.5.2 Supplier Collaboration

The decision on who and how to collaborate with suppliers to recycle excess materials requires several pieces of information. Although some excess material is currently returned to the suppliers after machining at GKN, it is not clear where the waste goes once it leaves GKN's premises. An ideal CE would operate through a closed loop, which for GKN means ensuring that manufacturing waste reprocessed by suppliers is returned to GKN for reuse. Information about which suppliers are able to achieve a closed loop and what happens to excess material is important for the total degree of recycling. Furthermore, distance from the supplier is also something that should be taken into account. This could give a better idea of how long the material would have to travel back and forth to the supplier to create a closed loop of materials. This would help to determine whether collaboration with the supplier is possible and beneficial in terms of cost, savings, time, and environmental impacts.

7.5.3 Circularity-based Supplier Audits

The final decision in the procurement function is whether or not GKN should perform supplier audits that focus on circularity. These audits allow GKN to confirm wether or not the supplier is performing as promised regarding their circular practices. In addition, it also increases the producer's responsibility and control over

GKN's supply chain. In the end, circularity-based supplier audits result in information being gathered to understand how circularity can be improved in the upstream supply chain.

7.6 Waste Management

The identified decisions support the proposed goal of increasing material recycling. These decisions were divided into two topics: waste contamination and the final location of the waste. This section explores the result of the information that is needed in these decisions, as illustrated in Figure 7.6.

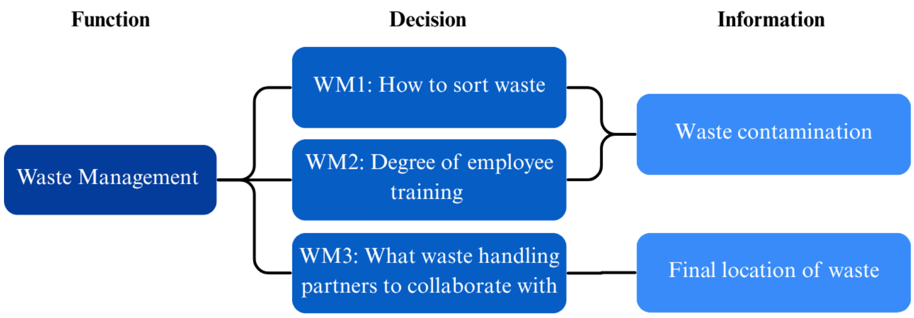

Figure 7.6: The waste management function and its relevant decisions and information

7.6.1 Waste Contamination

The way waste is sorted and separated is an important decisions in waste management to ensure a high recycling rate and low contamination. To achieve and improve these processes, certain information is needed. For example, information about the current contamination rate of waste is useful in identifying where the biggest challenges lie. In addition, better control on how, where, and when waste is generated, in what form, and how it moves through the facility could be useful to GKN when it decides how to optimize collection and separation protocols.

To improve waste management processes, it is important to know how and why contamination can occur in waste management. From the site visits, it was identified that some of the waste was being placed in incorrect waste bins. An example of this is the placement of scrapped parts and non-metal waste being placed in titanium waste bins. With correct traceability and knowledge of why waste occurs, decisions can be made about how employees can be educated and how separation protocols can be improved. A large part of the contamination is due to human behavior and their lack of knowledge about how their action impacts waste management when they do not follow protocols. Information about current knowledge gaps between employees if they understand and follow the protocols results in knowing where resources are needed to improve and minimize these gaps.

7.6.2 Final Location of Waste

The last step of waste management is where waste should go after GKN's processes. To ensure that waste does not end up in landfill, which is the worst-case scenario, information is needed on whether the material can be recycled given its current form, contamination level, or composite structure. Furthermore, to create the best possible circulation of material waste, it would be useful to have information on the external recycling facilities available. For example, information such as whether they have the technology and expertise to recover high-value aerospace materials and whether they comply with relevant regulations and quality standards. This could result in the external recycling partner being able to return processed materials to GKN's own supply chain, supporting closed-loop material systems. For example, the collaboration and contract GKN has with their external recycling partner IMET allows for this process.

8

Suggestions for Circular Indicators

Based on the defined functions, their associated decisions, and the information required to support these decisions, a set of circular indicators could be developed with the help of interviews and literature, such as the ISO standard 59020:2024 [3]. Through interviews, data and information that felt missing and could be represented as an indicator were identified. These indicators could then be used to support decisions and report progress of the three proposed circularity goals. Therefore, the following chapter presents indicators that will help GKN measure their circularity in the various functions to report, improve, or control it.

In Figure 5.1 the connections between the circular indicators, the decisions in the different functions, and the circularity goals can be seen. To reach the proposed circularity goals, decisions must be made as discussed in Chapter 6. Almström et al. [36] mention that circular indicators are vital to provide information and explain the progress of the stated goals and to communicate it to the decision makers.

Table 8.1 presents the results of all identified circular indicators together with relevant decisions that these indicators would support. A more detailed description of each indicator, including its definition, formula, and other relevant elements, can be found in Appendix C, following the structure proposed by Almström et al.[36]. The number of indicators should also be limited, as there should not be too many to maintain a sense of priorities. Indicators should have a clear definition to make them actionable and avoid misuse and should be placed at levels within the company where change is possible. The right data and tools must be available to analyze the data.

Table 8.1: Circular indicators, their objective, supported decisions, and location in appendix

Circular Indicator	Objective	Decisions	Appendix C
Circular product initiatives	Improve and report amount of circular products	Str2; Com1; Com2; Des1; Des2; Des3	C.1
Average lifetime of product	Improve total material usage by reducing it	Str1; Str2; Com2; TD1; Des2	C.2
Material efficiency	Improve material efficiency by reducing the weight of incoming material	Str1; Str2; TD1; Des1; Des3; Man1	C.3
Recyclability of material	Improve and report recyclability	Str1; Com1; Man1	C.4

Circular Indicator	Objective	Decisions	Appendix C
Percentage of recycled material in product	Improve circularity by increasing recycled material in products	Str1; Com1; Des1; Des3; Des4; Pro1; Pro3	C.5
Excess material sent back to supplier	Improve recycling of waste	Str1; Pro2	C.6
Excess material returned to GKN for closed loop	Improve the recycling of waste material through a closed-loop process	Pro2	C.7
Accepted products after repairs	Improve repair quality	Str1; Str2; Str3; Com2; TD2; Des2; PQA1; PQA2; EM1; EM2	C.8
Scrap ratio	Improve production by reducing products that are scrapped	TD1; TD2; PQA1	C.9
Purity of waste	Improve and report quality of waste	TD1; Des2; Man1; WM1; WM2	C.10
Waste diverted from landfill	Report and reduce the total amount of waste going to landfill, both from EOL and from waste in manufacturing.	Str1; Str2; TD1; Des2; Des3; Des4; Man1; WM3	C.11

These indicators will be able to help GKN measure circularity in the organization to report values, improve circularity, and control values that align with the proposed goals in Chapter 1. In Appendix C, the indicators are explained in more detail, along with their corresponding target values. These target values can be interpreted in two ways. The first approach is to set highly ambitious and visionary targets that may not be realistically achievable with current technologies. For example, the material efficiency target is set at 100%, a value that is unlikely to be fully reached, but serves to push GKN toward maximizing performance. The second approach involves setting more realistic targets that make it easier to convince stakeholders that they can be achieved. However, it may risk lowering ambitions or making goals too easily achievable, thereby limiting potential improvements. Therefore, it is crucial that these indicators are applied thoughtfully, with carefully chosen target values that balance ambition and feasibility applicable to its current practices.

8.1 Summary of Circularity Result

Chapters 6, 7, and 8 identified and analyzed the key functions that influence the proposed circularity goals for GKN's, with a focus on the three R's: Reduce, Repair, and Recycle. The functions of Strategy, Commercial, Technology Development, Design, Procurement, and Waste Management were found to be the most influential and were examined in detail. For each function, decisions to be made and the relevant information to achieve the proposed circularity goals were discussed. Functions deemed less central were excluded due to their strong dependence on other functions, as explained in Chapter 7. Based on the findings, a set of circularity indicators was developed, as seen in Table 8.1, to support GKN in reporting, controlling, and improving its circularity throughout the organization.

9

Circularity's Effect on Business

Although circularity is crucial for achieving sustainable practices, its implementation must also align with economic interests to obtain full organizational support. From interviews with external researchers, they agreed that circularity and sustainability-related changes should not negatively impact other areas of the business long-term, as this could reduce the organization's willingness to implement them. Therefore, many of the changes needed to improve circularity also need to contribute to financial performance, as shareholders often prioritize short-term profitability over long-term earnings. Every decision involves trade-offs, and while some changes may lead to improvements in one area, they can also have unintended consequences on other parts of the business.

In addition to the suggested circularity goals presented in Chapter 1, it is suggested that another goal is put in place as well: maintain and increase profitability. This goal would therefore track the long term profitability of the company, and could be calculated with the help of models such as the DuPont model [28].

The following chapter presents the business implications of circularity based on the interview findings, complementing the functions discussed in Chapter 7. Any additional sources are appropriately referenced. In the end, additional indicators are introduced with a focus on business performance.

9.1 Strategy

From one of the interviews with an employee at GKN, it was mentioned that companies that prioritize sustainability within their business models are often rated higher on the stock market, as this signals a commitment to sustainable practices and a long-term strategic perspective. Therefore, with GKN's mission to become *'the most Trusted and Sustainable Partner in the Sky'* [45], prioritizing topics such as sustainability and circularity could positively influence its market value.

It was previously presented that the strategy function is involved in various decisions, for example, business model and ownership throughout the product's life cycle. During the interviews, the concept of maintaining ownership of the product throughout its entire life cycle was highlighted as a potential enabler of circularity. This approach could create opportunities to retrieve components at the engine's EOL, allowing for actions such as reuse, repair, or recycle of the components. Since GKN's components are developed to last a very long time, they could potentially be reused in new engines or retained as spare parts for repairs. This would reduce the need to manufacture new components from scratch and reduce material consumption and, therefore, costs and new asset acquisition. In addition, it would also result in a reduced dependence on suppliers as the demand for new material would decrease. Retaining or maintaining ownership would give GKN greater control over where its products ultimately end up, thereby increasing visibility into circular material flows. However, this introduces possible additional costs and uncertainties. For example, logistics costs could increase when trying to track and retrieve components, and an increase in administrative resources would be needed to manage these processes. In order to balance profitability, the gains of changing the ownership would therefore have to outweigh the extra costs that might be incurred.

Expanding the repair portfolio was a decision mentioned in Chapter 6. From a business perspective, broadening the range of components that GKN is able to repair could contribute to increased overall revenue. Furthermore, an increase in repair offerings may also strengthen GKN's position and influence in future RRSPs. However, this strategy also carries additional costs and challenges. Securing customer certifications to enable the repair of new components can be time consuming and expensive. Furthermore, GKN's current repair facilities may need to be expanded or upgraded to accommodate the increased portfolio. Therefore, a careful evaluation of the portfolio expansion is needed by comparing the required costs with the potential revenue gains to determine its financial viability.

9.2 Commercial

Since the commercial function works with the sale of products and services, it is responsible for communicating possible circular benefits and understanding customer requirements. Some customers, especially European ones, are more interested in sustainability and circularity and could be interested in paying extra for a circular product to support their own circular and sustainability goals. Therefore, a higher development cost of the product might be compensated for by the customer paying a higher price if it aligns with the customers interests. Products might also require product passports to easily communicate the origin and proof of circularity of a product, which could further increase the development cost.

If circularity is a higher priority, customers and OEMs might be interested in collaborating to tackle the difficult sustainability challenges that exist in the industry. When there is an MRO contract in place, an extension in time of the contract would not only increase the revenue of GKN, but would also improve the circularity by increasing the amount of repairs. However, it should be argued that a longer MRO agreement can lead to the customer waiting longer to buy a new engine, which would be a source of lost revenue for GKN. The balance of income from a new engine and current engine would therefore have to be examined.

9.3 Technology development

The technology development lays the foundation for many other functions and activities that GKN perform. Since technology development is deeply rooted in R&D, this function does not generate revenue, but gives other functions the ability to. Developing new technologies that focus on circularity would have to have the cost perspective in focus to make sure that they are profitable in the long run. Therefore, when developing new technologies for the company, it is important to take all company goals into consideration. This includes their sustainability goals, the proposed circularity goals, and the goal of maintaining and increasing profitability.

Many aspects of circularity work with the reduction of the amount of material needed, which is one of the core activities of technology development. This aligns with cost reduction, as using less material results in lower purchasing needs and, consequently, cost savings. Therefore, new manufacturing methods such as AM could be ideal not only for reducing material costs but also for improving circularity. However, energy, investment, and operating costs should also be taken into account, as they might make these investments invaluable. Given the rapid pace of technological advancement, making large investments too quickly can be risky, as emerging technologies may soon surpass and render earlier ones obsolete.

9.4 Design

The design function is important in deciding how much products will cost to develop, including material and manufacturing costs. When designing for circularity, products could be designed to be reusable, repairable, and recyclable. The materials currently used are difficult to recycle while maintaining the necessary properties and quality required for continued use in aerospace applications. To enhance circularity throughout the product's life cycle, recovery at the end of the use of the product must be considered during the design phase. This introduces an additional step that extends the cycle and therefore requires analysis together with the strategy function to assess how the choice of more easily recyclable and recoverable materials may influence costs and potential new revenue streams.

Another important aspect to consider is how extending a product's lifespan affects profitability. Designing for durability often requires additional or higher quality materials, which can increase production costs. However, it may also reduce the total number of units needed over time, thereby lowering overall material consumption. Although this might decrease sales revenue, it might increase RRSP revenue by providing a more expensive, durable product that can be serviced for longer. In addition, more durable products will be in service longer, which is a good selling point for customers. Therefore, the trade-off between durability and repairability is particularly relevant for GKN, whose products are typically expected to last for the entire lifespan of the engine.

9.5 Procurement

The procurement function at GKN is responsible for managing upstream supply chain activities. Due to the high quality requirements in the aerospace industry, there are for some materials, relatively few possible suppliers that GKN can chose from, which poses risks related to supply risk and pricing power. An approach to improve sustainability and efficiency within this function is through circularity, which aims to increase the volume of materials kept in circulation, as this can contribute to cost reductions and decrease supplier dependence. This could increase competition between suppliers and has the potential not only to reduce procurement costs but also to stimulate innovation, particularly in the development and differentiation of materials. Such innovations may include higher proportions of recycled content or other attributes that contribute to improvements in environmental and circular performance. Furthermore, an increase in circularity can also come from deeper collaborations with suppliers when returning excess material and focusing on maintaining a closed loop. Since this secures a higher degree of supply, the supply chain becomes more robust and predictable.

Circularity and the industry of aerospace components are something that requires a lot of documentation to make sure where the material originates, what it might have been in contact with and used for, and how it will stand up to new demands when being reused or recycled. This documentation could potentially be expensive, since products might need product and material passports. However, while expensive, this would provide benefits to the organization in terms of supply chain transparency. Creating reports could potentially require less work since the information is more accessible and the origin of material and products would be more visible. More visibility would make it easier to identify errors in material requirements and prevent potential issues in procurement. Since materials are scarce and could come from geopolitically sensitive regions, such as Russia and the Democratic Republic of Congo, increased visibility could help avoid poor working conditions in the supply chain. GKN counteracts this risk by imposing clear requirements on their suppliers through their Supplier Code of Conduct, aimed at preventing human rights violations [12]. In addition, monitoring through supplier audits of higher-tier suppliers could also increase visibility, although the cost of such audits could be significant.

9.6 Waste Management

The management of waste generates a range of costs that are not always immediately obvious. An example of such costs are warehousing costs, which involve different costs influenced by various factors such as storage duration and space requirements. In addition to warehousing costs, other relevant cost aspects include potential contamination, administrative efforts, and waste handling operations, both by GKN and external partners. Each of these must be carefully managed to ensure that the overall process remains economically viable. Estimating the value of waste, particularly production waste, is also challenging, as its market value is often only determined at the point of sale to external recycling firms. Contamination of the waste can substantially reduce this value, making it crucial to maintain quality and purity throughout the process. As a result, there are strong economic incentives to establish and maintain an efficient and effective recycling system to increase profitability.

It is important to recognize that, particularly when dealing with high-value materials, waste management is important, but the primary focus should be on minimizing waste generation from the start. Although waste handling is inherently a reactive process, proactive strategies that aim to prevent waste offer significantly greater potential for cost savings. In some cases, investments in waste reduction can be more economically beneficial than investments in waste management [52]. Moreover, GKN is currently involved in the development of AM technologies, which can be more material efficient and are expected to result in lower waste volumes. Therefore, it is critical for GKN to anticipate when AM will be scaled up to represent a more substantial share of manufacturing activities, as this will influence the relevance and long-term value of further investments in traditional waste handling improvements.

9.7 Additional Indicators

Given the importance of the business perspective in improving circularity at GKN, additional business-related indicators have been developed with the help of literature and interviews at GKN to support and complement circular initiatives. The business indicators can be seen in Table 9.1, and more detailed information about them can be found in Appendix D.

Table 9.1: List of business indicators and their location in appendix

Business Indicator	Objective	Circularity Goals	Appendix
Repair revenue	Report amount of revenue from repairs	Goal 3	D.1
Recycled material cost ratio	Report the difference in cost between recycled and virgin material	Goal 2	D.2
Revenue from recycled material waste	Report and improve revenue from recycling	Goal 2	D.3
Delivery time recycled material ratio	Report, improve and control the delivery time of recycled material	Goal 2	D.4
Material productivity	Improve revenue while decreasing linear resource consumption	Goal 1	D.5
Value per mass	Improve circularity	Goal 1, 2	D.6

In the interviews, it was also stated that having indicators of monetary value makes it easier for several stakeholders to understand and relate to them. This makes it easier to discuss the effects that circularity has and promote circular activities.

9.8 Summary of Business Result

This chapter highlights that circularity should align with economic interests to gain full organizational support. This means that the goal of maintaining and increasing profitability should be implemented along with the proposed circularity goals. Strategic initiatives like maintaining component ownership and expanding repair offerings can improve circularity, but must be weighed against added costs. To understand and break down the impact of new costs on profitability, a model such as the DuPont model can be useful. Technology development, design, procurement, and waste management all present opportunities to improve circularity while supporting financial performance. For example, new technologies such as AM and greater transparency in the supply chain could be important drivers for the transition to a CE. Finally, business-focused indicators have been introduced to better support and communicate the monetary value of circular efforts.

10 Discussion

In the following chapter, a discussion of the differences and similarities between the result of the thesis and the literature is presented. The discussion focuses mainly on how to handle circular indicators and how the business of GKN complies with theoretical frameworks. This is followed by a discussion of societal, ethical and ecological aspects, pros and cons with the methodology of the thesis together with gaps in literature, and finally ending with suggestions for future research.

10.1 Circular Indicators and Their Implementation

As presented in the theoretical framework, there have been multiple attempts to create circular indicators at various manufacturing companies and industries. Saidini et al. [31] and Moraga et al. [30] present a compilation of multiple indicators, which in total account for about 70 circular indicators. This in turn means that deciding upon what circular indicator to use at a company might become difficult since they would all need to be researched to find which ones are appropriate. A lot of these indicators try to create a single value for a whole product as well on a micro-level. An example of this is the Material Circularity Indicator (MCI) created by the Ellen MacArthur Foundation [35]. The MCI consists of several variables, such as material type, source, regenerative rate, lifetime, collection rate, and EOL destination. This could be considered appropriate when trying to report how circular a product is but might not give a good control or measurement unit since the MCI uses multiple inputs to calculate its value. Also, since the input variables are somewhat fixed and not a lot of customization is available, the result might not be as accurate as it can be. This also goes against one of the principles presented by Almström et al. [36], which is to keep the indicators simple. Merging multiple indicators into one can quickly become complex, making it difficult to understand the target audience, the intended purpose, the proper use, ways to improve it, or the root cause of any changes in the result. This is also something that the ISO foundation [3] agrees with when they present examples of circular indicators. They also present micro-level indicators since they are focused on company or product level. The interviewees agreed with the idea that important indicators are placed within resource inflows and resource outflows. This was because these resource flows were easy to get information on while also having a large control of them. For example, people from the procurement function mentioned what data they have access to, and how they would act upon this data with good indicators.

The indicators identified for GKN are on the micro- and meso-level [30, 31, 32, 33]. The micro-level indicators focus on the organization as a whole or on specific products and processes, which align with their intended purpose and correspond to the indicators outlined in ISO 59020:2024 [3]. The indicators presented that could be said to be of meso-level are the ones that are measuring something in relation to the suppliers because they are working together with another company and producer. Therefore, these indicators are focused not only on improving the circularity at GKN but also on its suppliers. The indicators brought forward were not identified to be of macro-level, since they are not focused on large geographical areas or on international organizations. An organization that could establish indicators for CE goals might be the IAEG. However, their work group related to CE is only recently started and any measurable goals are not yet public.

After ISO 59020:2024 was published, guidelines on how to create circular indicators were presented [3]. These guidelines also align with what Almström et al. [36] mention in terms of utilizing a pull approach. This approach ensures that the created indicators have a useful purpose, that the right parties are consulted and informed, and that the indicators are simple and easy to use. This aligns with the approach that was taken when designing the indicators that were presented in Chapters 8 and 9.

Multiple circular indicators were suggested for GKN and some could be argued to be more important than others. From the results, the ones that were deemed the most important were:

- Material Efficiency
- Incoming recycling material
- Purity of waste

The reasoning for this is that the indicators together have a very high influence on several functions, circularity in general, and together will make GKN reach a higher degree of circularity. The material efficiency will control how much material waste is generated. A higher material efficiency will reduce the amount of waste created, and therefore reduce the amount of focus needed in the functions managing waste. This directly influences other proposed indicators: excess material sent back to the supplier and purity of waste. If the material efficiency reached 100%, no material waste would be created at GKN. This in turn would result in these two indicators being less relevant. Even if the target would not reach 100%, it would greatly affect these two indicators since less waste would be generated. The second indicator of the incoming recycled material sets the foundation for creating a recycling loop together with the supplier. Lastly, even though the purity of waste is influenced by the material efficiency, it is still very important since it could improve circularity from a short- and long-term perspective. This would not only help GKN increase the potential of having closed loops but would also be of economic interest since it will increase the sales revenue of the waste.

As Almström et al. [36] mentions, an improvement in a specific indicator within one segment of the value chain may have consequential effects on other segments of the chain, so called sub-optimization. For example, an increase of incoming recycled material may lead to higher material costs, which could negatively affect certain parts of the business. It could also impact the material properties, which might not completely align with the customers' needs or could require additional testing to ensure that it lives up to the correct requirements. An optimization does not necessarily have to make one part of the value chain worse, it could also improve other parts. An improvement in material efficiency will affect other circular indicators as mentioned above. Therefore, not all indicators are equally important. Some could be argued to have a higher level than others, and even remove other indicators if it were to reach its target score.

Something worth mentioning is the reason for measuring circularity. In one of the interviews, it was mentioned that it was clear that circularity should not be done for the sake of circularity, since it may have negative consequences on other aspects of the organization, such as an increase in emissions by having more transports. Circularity should not be something that reduces the performance and quality of other functions but something that sets the foundation for becoming environmentally friendly. However, to know that an increase in circularity leads to better environmental performance, indicators are needed within circularity, and indicators that measure other areas that might be impacted need to be analyzed as well.

10.2 Business and Financial Effects

From the result in Chapter 9, it was shown that circularity has a clear impact on the business of GKN, both strategic and economical. As mentioned in the result, circularity can have an impact on innovation, efficiency, and sustainable growth, which according to the literature influences financial outcomes at both micro- and macroeconomic levels [9, 25]. Furthermore, the literature also states that companies that focus on sustainable practices could gain a higher market share as a result [27]. This aligns with insights from one of the interviews, where it was mentioned that companies demonstrating higher levels of circularity tend to be valued more positively in terms of market value. This is because investors associate circular practices with long-term resilience, better risk management, and greater potential for sustainable revenue. To see the progress of potential revenue, indicators in monetary value can be of use. At the end of the result in Chapter 9, several business indicators were presented, some from the ISO standard 59020:2024 which builds upon the ISO standard 14008 about 'Monetary valuation of environmental impacts and related environmental aspects' [3]. Such indicators were also discussed during the interviews, in which it was indicated that the use of indicators expressed in monetary terms is often advantageous, as their impact is easier to interpret and communicate from a business perspective across various stakeholder groups.

In the literature, it is stated that there is a positive correlation between circular strategies and financial performance, which therefore affects the business model of GKN [26]. Some of these benefits in financial performance can be explained by the DuPont model [28]. A circular strategy can help reduce the current assets that a company relies on, which, in turn, improves return on total assets and lowers procurement costs by requiring less material. For GKN, this aligns with its potential strategies that can increase recycling and improve material efficiency. In addition, since the DuPont model also considers revenue, selling production waste can directly increase the company's income. As noted in Chapter 4, pure waste can be sold at a significantly higher price, up to 132% more, compared to contaminated waste [1]. It is mentioned in GKN's annual report from 2024 [15], that with new AM technologies it is possible to reduce material usage by up to 70% . If the assumption can be made that this in turn will reduce their material costs with 70%, a clear increase in the return on assets will be seen. Using less material reduces both total assets and costs, two key areas of the DuPont model, highlighting the importance of material efficiency. GKN's sustainability report supports this, noting that combining different manufacturing methods has led to a 60% reduction in material use for a specific product which corresponds to 90 tonnes of titanium waste annually [17].

The literature on CBMs states that the company's strategy focuses on how to minimize resource use, waste, and emissions [39]. Five types of CBMs were stated: circular supply, product life extension, sharing, resource recovery, and PSS [38]. From GKN's perspective, they fall in line with circular supply, product life extension, resource recovery, and PSS. Circular supply aligns with the business of GKN, as it uses recycled material, but is uncertain of the exact amount. The CBM of product life extension fits GKN as they are designing their product to last and be recyclable and focusing on material circulation. However, this CBM could hinder the possibility of innovation and upgrading. Given that GKN's products are highly durable, with an estimated life cycle of approximately 50 years, which raises the question of whether it is better to implement more innovative technologies or upgrades over the course of that time. A possibility would be to replace or refurbish the component instead of long lifespan. Another aspect would also be to discuss this with the RRSP by reducing the lifespan of the engines or upgrading them more often. However, this seems unlikely since the materials are of high value and would create a great logistic and resource cost because of the many partners involved in developing each engine. The third CBM of resource recovery matches GKN's business, since they have a high interest and practices in reusing and recycling their material in collaboration with suppliers, mostly because of the high material value. Therefore, the last resort is to send the material to waste. Finally, PSS is the fourth CBM that aligns with the business of GKN in the form of product-oriented services, where GKN sells their product but still offers additional services such as repair services to extend components lifespan. It could be discussed that GKN is also touching the PSS of a result-oriented services by its power-by-the-hour contract within the RRSPs and its MRO practices since these are aimed at keeping the customer operational. However, GKN's main business is selling and repairing components, which is more aligned with product-oriented services. The last PSS, user-oriented, does not align with GKN at the moment. User-oriented is a possibility for the future and was also discussed in the result, where GKN keeps ownership of the product and is therefore responsible for its maintenance and disposal. Since their products have a really long lifespan, it could open doors to reusing their products or keeping them as repair parts instead of manufacturing new ones. The last CBM is sharing,

[1] Internal Document, 2024

which GKN is not doing at the moment, as it is not applicable to their business. Its components remain in the engine for its entire lifespan and therefore are not shareable. For the sharing model to be applicable, GKN would have to have complete ownership of the engine, which they do not. As they are a few steps away from the end user, a sharing business model is not possible.

A challenge that was discussed for GKN is the discussion of supply risk and resilience. In the result, it was shown that GKN could reduce their supplier dependency by keeping the material in circulation for as long as possible. This also aligns with the literature that states that by focusing on material reuse, remanufacturing, and recycling, the risks associated with raw material shortages and geopolitical uncertainties could be reduced [9].

Something that was not discussed in the result is the effects this has on the employees at GKN, such as job creation versus loss. Although, according to the literature, circularity itself is estimated to create a lot of jobs in all of EU [9], which could be assumed to be applied to GKN as well. However, with new manufacturing methods such as AM, less waste management would be needed and could potentially cause job losses in that area, but new job opportunities and specifications should also arise regarding the new practice of AM. Thus, the effects of circularity could possibly create more jobs in repair practices and eliminate jobs in manufacturing. However, if circularity leads to growth, both areas could increase.

As mentioned in the result, several business indicators were developed to support circular initiatives to ensure they are strategically and economically feasible. This is also aligned with ISO 59020:2024 [3] where it states that the economic-related circularity indicators are of high importance in this regard. The ISO standard continues to explain that with these indicators, economic viability can be assessed by examining how economic value is created, captured, and influenced. As highlighted in Chapter 9, using indicators expressed in monetary terms can enhance clarity, making these assessments quicker and easier for various stakeholders to understand.

10.3 Societal, Ethical, and Ecological Aspects

In addition to technical and economic considerations, it is also important to discuss the societal, ethical, and ecological aspects of the research and its potential implementation. These aspects are related to the goals of sustainable development and should be considered when evaluating both the chosen methods and the implications of the results.

10.3.1 Societal Aspects

This thesis focuses on material flows within GKN, with the aim of providing a foundation for the design and implementation of CE indicators. Although social dimensions such as labor conditions, job displacement, or community impact were not directly addressed in the result, which could be an important opportunity for future research as discussed at the end of this chapter. An approach to circularity should eventually incorporate these societal elements to ensure that circular transitions are inclusive and equitable.

In promoting circularity at the societal level, it is also essential to consider possible negative effects. In a linear model, many industries rely on the extraction of raw material, often in low-income regions. Significantly reducing the demand for virgin materials, as suggested in the result, could threaten employment in such sectors. However, this transition could also lead to the creation of new, potentially safer and more regulated jobs in areas such as recycling and sustainable logistics. These jobs would most likely be located in more developed countries, which potentially moves work opportunities from developing countries to developed ones. Therefore, the societal shift presents both risks and opportunities.

It is also worth noting that a circular approach in high-precision industries such as aerospace must maintain rigorous quality standards. Compromising on these standards could pose safety risks and undermine societal trust in circular products. Ensuring that circularity supports rather than detracts from public safety is therefore a critical consideration.

10.3.2 Ethical Aspects

This thesis was conducted in close collaboration with GKN, which required attention to transparency, integrity, and ethical responsibility throughout the thesis. To accurately present the company's practices while maintaining objectivity, multiple steps were taken during data collection and reporting.

All data collected were thoroughly analyzed and information that was deemed relevant to the scope of the thesis, focusing on circularity and material flows, was included in the report. Data collected that fall outside the scope were not included, but are discussed for future research at the end of this chapter. Furthermore, following academic standards, all sources have been referenced to avoid plagiarism and to support the validity of the findings. In addition, the literature review included a broad selection of sources from various authors, allowing for a diverse theoretical basis.

All interviews were referred anonymously to protect the identities of the participants. To ensure that the findings were not biased by individual perspectives, stakeholders who occupy similar roles at GKN and external actors from the industry were interviewed. This approach allowed for a more holistic understanding of CE practices within and beyond the company. Furthermore, to ensure accurate representation of the company and alignment with its interests, the thesis supervisors at GKN were continuously updated on the thesis' progress and were able to give feedback during that time.

However, ethical challenges may arise, especially within industries like aerospace, where confidentiality is critical. Although circularity demands openness in terms of data and material tracking, some of this information may be sensitive and difficult to disclose publicly, potentially limiting full transparency.

10.3.3 Ecological Aspects

Circular indicators are helpful tools for capturing and measuring environmental impact, but not all impacts are discussed. Since the thesis is limited to the material flow, other environmental aspects are missing, such as emissions and energy usage. Furthermore, unintended ecological trade-offs are not discussed. For example, promoting material circularity could come at the expense of energy efficiency. However, the suggested circular and business indicators create incentives for GKN to make more ecologically sound decisions, such as increasing recycling and reducing the extraction of virgin materials.

The implications of the result are also correlated with some of the SDGs and its targets [53] presented by the UN, can be seen in the following list.

- **SDG 9: Industry, Innovation and Infrastructure**
  The suggested indicators, together with the discussion of circular design, encourage investment in R&D and the adoption of practices such as MRO and technologies such as AM, which support sustainable industrialization. This aligns well with target 9.4, as shown below.
  - 9.4: By 2030 upgrade infrastructure and retrofit industries to make them sustainable, with increased resource use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes [53].
- **SDG 12: Responsible Consumption and Production**
  The result promotes sustainable resource use and minimization of waste. These actions reduce the dependency on virgin materials and extend product life cycles, the core principles of CE and SDG 12. Circularity measurement in production will help GKN control their production and consumption of materials. More specifically, the suggested indicators align with targets 12.2 and 12.5 as listed below.
  - 12.2: By 2030 achieve sustainable management and efficient use of natural resources [53].
  - 12.5: By 2030, substantially reduce waste generation through prevention, reduction, recycling, and reuse [53].
- **SDG 13: Climate Action**
  To take action on climate change, measurements are needed to report and see improvement (or deterioration).

10.4 Pros and Cons of the Methodology

The methodology was structured to first establish a foundation of the subject, industry, and actors in the industry by reviewing the literature to later dive deeper into more specific topics, such as circularity indicators. This resulted in a good understanding of the different topics, and it was easy to build the knowledge over time. As can be seen in Figure 3.1, data collection was performed prior to analysis and the draft of the result. However, during data collection, it was realized that when feedback was given by supervisors and representatives at GKN, some corrections and additional data had to be collected and added to the analysis. This worked well since a loop of feedback from several stakeholders could be taken into account during the project and added to the thesis.

By researching several areas of literature, a large foundation could be built on which interviews could be based. However, one challenge here is the gap that exists in the literature as of writing. There is not a lot of literature written on circularity and circular indicators in the aerospace industry. Therefore, to gain an understanding of circularity and indicators, articles written within other industries were reviewed and used to write questions to researchers within circularity and circular indicators.

From interviews with GKN employees, it was understood what functions for circularity were important and how to improve and measure circularity. It was concluded that GKN works cross functionally, which means that multiple functions work together. Since multiple actors across the organization were interviewed to get multiple perspectives, it ensured that as little information as possible was missed and as many uncertainties as possible could be worked out. However, an improvement to the methodology could, therefore, be having more group interviews or workshops to reduce the amount of contradictory information, uncertainty, and gain a greater understanding of circularity throughout the organization. This would also save time, as many of the interviewees said the same thing. To avoid bias from the interviews, external actors were also interviewed. This consisted mostly of researchers from Chalmers, but also a person from the IAEG. With these interviews, the circularity challenges could be investigated further and trade-offs that might arise when addressing circularity could be understood.

10.4.1 Gap in Literature

As mentioned above, there is a literature gap when it comes to measuring circularity in the aerospace industry. Although there is some literature and research related to AM and energy usage in production, the literature related to material efficiency, closed-loop production, recycling waste in manufacturing, and material management at EOL seems to be lacking. Therefore, further research is needed in these areas in which circularity can be improved in the development of aerospace engines.

10.5 Further Research

Reasonable targets for the indicators is a research area that could complement this thesis since it was a discussion that was brought up. For example, finding relevant target for GKN regarding material efficiency would be a good follow up on this thesis. It is also worth noting that the three proposed circularity goals in this thesis are presented without specific numerical targets. As such, future research could focus on establishing realistic and context-specific targets for these circularity goals. In addition, exploring suitable time horizons for each indicator represents another important area for further research.

This thesis presents ways to measure circularity, but not how to find and collect the data needed to measure it. A research topic that could be useful is how accessible the data is for each indicator. Well-designed indicators need to have accessible data and ways to find it. Therefore, a suggestion of a data analysis study would be appropriate to add to this research topic. Furthermore, if there is a lack of reliable data, Almström et al. [36] advise performing risk or sensitivity assessments, as this will tell how different parameters affect other, e.g. costs, which could be another research to complement this thesis.

Circularity is directly related to the company's supply chain, which is crucial regarding control and visibility of the supply chain since it can help get a better understanding of the current CE, where and how to improve it. In this context, control refers to the company's ability to influence and manage various aspects of its supply chain, from the sourcing of raw materials and selection of suppliers to production processes, product distribution, and EOL management. Therefore, the second suggestion for further studies is to examine how the company can gain more control and how to effect their supply chain.

Another area of study that is suggested is the impact of circularity on other sustainability aspects. This research could then look at how emissions, energy usage, and other types of waste are related to circularity, since this thesis only considers material flow and its roll in a CE. Furthermore, sustainable practice includes all of the triple bottom line, which include the pillars of economic, social, and environmental. Therefore, since this thesis only considers environmental and economic aspects, further research could be done on social aspects and how this pillar is affected by circularity. For example, moving from a linear economy to a circular one may reduce the number of jobs in mines, but increase them in recycling facilities.

11 Conclusion

The following chapter summarizes the findings and concludes the answer to the research questions introduced in Chapter 1.

1. What functions at GKN make decisions about its circularity?
The functions at GKN were identified in relevance to circularity in the form of the three Rs: Reduce, Repair, and Recycle. It was found that multiple functions are highly important for GKN's circularity, and each one of them has decisions that needs to be made to reach the proposed circularity goals. Some functions, such as strategy, commercial, design, technology development, procurement, and waste management, are highly influential in achieving a high degree of circularity. Other functions such as manufacturing, product quality assurance, engine maintenance, and EOL management are too dependent on other functions and do not have a high degree of freedom in their decisions. This in turn results in them not having as high an impact on circularity as the other functions. The identified decisions within the prioritized functions showed that an early interest in circularity, such as product development, is required to address the difficult problems that arise within the subject. It was also identified that no single function or actor can single-handedly achieve a high degree of circularity at GKN, as multiple functions need to collaborate and even external actors, such as suppliers, need to be involved.

2. What information do these functions need to improve GKN's circularity?
The necessary information relating to circularity was only discussed within the functions that were deemed most relevant. The information provided was related to setting relevant circularity goals, expanding repair capabilities, choosing recycled materials, or tracking waste streams. A lot of the information identified were realized to be useful across several functions and their decisions. This could be information related to material and product traceability, internal and external collaboration, and supporting documents such as LCAs or ISO standards.

3. In the identified functions where circularity can be improved, what are the appropriate ways to measure, report, and improve the results?
To measure, report, and improve the results related to circularity at GKN, several circular indicators were proposed. The three most important ones were related to measuring material efficiency, incoming recycled material, and purity of waste. The reason for this is that an improvement in these areas has a strong influence on other functions and circularity at GKN in general. The circular indicators proposed are based on established guidelines, such as ISO 59020:2024 [3] and principles from Almström et al. [36]. These guidelines and principles highlight simplicity, feasibility, and stakeholder relevance. When using these indicators, the problem of sub-optimization needs to be taken into consideration. This means that a gain in circularity or a specific indicator might impact other areas or indicators. Therefore,

it is recommended for GKN to focus on the three prioritized circular indicators, as it will improve circular performance throughout the organization and set a solid foundation for them to start with.

4. How can an improvement in circularity at GKN affect its business?
An improvement in circularity at GKN can positively impact the business in several strategic and financial ways. GKN could reduce its raw material costs, reduce its dependence on suppliers, and increase waste management revenue by increasing material efficiency, expanding the use of recycled materials, and increasing waste purity. The actions will not only increase operational efficiency, but will also lead to cost savings and increased revenue.

By improving circularity, new possibilities for revenue streams are promoted. For example, by expanding GKN's repair services, they would not only have a higher degree of revenue that originates from circular practices, but GKN's strategic position on the market could be enhanced. By having a stronger circular and sustainable profile, companies are generally favored by investors, which can lead to a higher market value. Lastly, circular practices require a lot of collaboration both upstream and downstream. By collaborating with these actors, deeper relationships and partnerships can be created.

Before implementing circular initiatives, several aspects must be taken into account. There are trade-offs, one of which is long-term sustainability and short-term financial performance. Circularity is usually a long-term investment and a solution that must be supported by new innovations and a resilient supply chain. Looking at the short-term perspective, investments and circular practices should meet stakeholder expectations.

Both the literature and the interviews emphasized that the circular indicators must be clear and easily understandable to all stakeholders. Since some indicators are more relevant to certain groups than others, it was suggested that expressing some indicators in monetary terms can improve their influence by clearly communicating their impact, costs, and benefits.

In summary, circularity at GKN is not just an environmental ambition but a business enabler that supports sustainable growth, financial performance, and competitive advantage.

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A

Interview Guide

This appendix gives an overview of the questions asked in the interviews to the interviewees. In addition to questions, a quick presentation of the master thesis was given, and why the person would be relevant to interview. This would also open up for a quick discussion regarding circularity.

Questions to everyone:

- Do you give consent to the interview being recorded?
- Who are you and what do you work with?
- What function at GKN would have the largest impact on circularity?

Questions to employees at GKN:

- What are your responsibilities within the company?
- Could you describe what a circular economy means in your role within the company?
- Why are you interested in working more with circularity?
- Do you have any goals or measurements regarding circularity right now?
- How do you work cross functionally within GKN?
- Who within GKN do you think would benefit from indicators that measure circularity?
- If you would want to increase circularity at GKN, where would you start looking?
- How would circularity affect you from a profitability or business model perspective?
- Can you describe any current processes or methods you use to support circular product design?
- How do you utilize life cycle thinking within your decision making?
- Do you have any internal or external guidelines to influence how circularity is implemented?
- Can you describe what happens with your products once they reach their end of life?

Questions to external experts:

- What is needed for future improvements to achieve a circular economy?
- How can we distinguish when measuring circularity in today's operation and products versus future operations and products?
- Is it possible to achieve a circular economy with open loops?
- How would you go about measuring circularity at GKN?
- Can you give us an example of a company or industry that has successfully implemented circular initiatives?
- What is important to think about when creating circular indicators?

B

Functions influence

The influencing functions are listed on the left and show which functions they influence with an 'X'. For example, the function of Strategy influences the functions of Commercial, Technology Development, Design, Procurement, and EOL Management. In addition, decisions made within one function can have both direct and indirect affects on other functions. For example, material selection is a design decision made in the design phase, but it directly impacts waste management.

Table B.1: How the different functions affect each other

Influenced

Influencer

Functions	**Strategy**	**Commercial**	**Technology Development**	**Design**	**Procurement**	**Manufacturing**	**Product Quality Assurance**	**Waste Management**	**Engine Maintenance**	**EOL Management**
Strategy		X	X	X	X					X
Commercial			X	X			X		X	X
Technology Development				X	X	X			X	
Design					X	X		X	X	
Procurement								X		X
Manufacturing					X			X		
Product Quality Assurance									X	
Waste Management										
Engine Maintenance								X		X
EOL Management										

C

Defined Circular Indicators

This appendix will present the circular indicators presented in chapter 8. The circular indicators follow the structure presented by Almström et al. [36]. The indicators therefore have a clear objective, description, calculation, target value and which actors are impacted.

Table C.1: Circular product initiatives

Name	Circular product initiatives
Objective	Improve and report amount of circular products
Description	The circular product initiatives aims to measure the amount of products in the product portfolio that has some circular initiative related to it. For example, it could be made of 100% recycled material or be modular to allow upgrades.
Formula	Circular products ratio = Circular products / Total products.
Unit	%
Target value	(Range 0-100%) 100%
Frequency	Each time a product is designed
Source	Design
Who reports	Design personnel
Who acts	Management

Table C.2: Average lifetime of product

Name	Average lifetime of product relative to industry average
Objective	Improve total material usage by reducing it
Description	This indicator shows how the product holds up in value over time compared to the industry average. A higher value indicates that fewer products will have to be produced in total. This could be rebranded as a kind of durability of the product compared to other alternatives. This is also an indicator suggested by the ISO standard 59020:2024.
Formula	Lifetime ratio = Lifetime of product / Industry lifetime average of the product
Unit	Dimensionless
Target value	>1
Frequency	For every product that is designed
Source	Customer
Who reports	Customer and repair personnel
Who acts	Design

Table C.3: Material efficiency

Name	Material efficiency of a product
Objective	Improve material efficiency by reducing the weight of incoming material.
Description	In order to reduce the total amount of material needed, the material efficiency of each product is crucial. It is the ratio between material in the product and the ingoing material in the manufacturing.
Formula	Material efficiency = Weight of material in end product / Weight of ingoing material in manufacturing
Unit	%
Target value	(Range 0-100%) 100%
Frequency	Each time a product is designed or manufacturing method changes for a product.
Source	Manufacturing and design
Who reports	Manufacturing and design personnel
Who acts	Design

Table C.4: Indicator of the recyclability of material

Name	Recyclability of material
Objective	Improve and report recyclability
Description	This circular indicator shows how much of a material of a product that can be recycled and still meet GKN's quality standards. It is calculated by comparing the amount of material that can be reused by GKN after a product reaches its EOL, to the total amount of material from the product at EOL.
Formula	Recyclability = Weight of material still usable at GKN after recycling / Weight of total material at EOL from GKNs product
Unit	%
Target value	(Range 0-100%) 100%
Frequency	Every time a new material is developed or supporting recycling activities
Source	Supplier and procurement
Who reports	Procurement and/or Design personnel
Who acts	Procurement

Table C.5: Percentage of recycled material in product

Name	Percentage of recycled material in product
Objective	Improve circularity by increasing recycled material in products
Description	Measures the degree of recycled material in the incoming material. Expressed as the ratio between total material and recycled material.
Formula	Incoming Recycled Material = Weight of recycled material / Weight of total Material
Unit	%
Target value	(Range 0-100%) 100%.
Frequency	Every order
Source	Supplier and procurement
Who reports	Procurement personnel
Who acts	Procurement

Table C.6: Excess material sent back to supplier

Name	Excess material back to supplier
Objective	Improve recycling of waste
Description	In order to create a loop of material, waste material can be sent back to the supplier. It is expressed by the ratio between the material sent back to the supplier versus the total amount of excess material.
Formula	Excess back to supplier = material sent back to supplier in weight unit / Amount generated in total in weight unit
Unit	%
Target value	(Range 0-100%) 100%
Frequency	Every year
Source	Supplier and procurement
Who reports	Procurement personnel
Who acts	Management

Table C.7: Indicator of achieving a closed loop of excess material

Name	Closed-loop of excess material
Objective	Improve the recycling of waste material through a closed-loop process
Description	This indicator measures how much of the excess material GKN sends to suppliers is processed, for example remelted, and then returned to GKN for reuse, a closed-loop. The indicator is calculated by comparing the amount of excess material returned to GKN with the total amount sent to the supplier.
Formula	Closed-Loop of Excess Material = Weight of excess material returned to GKN by the supplier / Total weight of excess material sent to the supplier by GKN
Unit	%
Target value	(Range 0-100%) 100%
Frequency	Every year
Source	Supplier and procurement
Who reports	Supplier and procurement personnel
Who acts	Supplier and procurement

Table C.8: Accepted products after repairs

Name	Passed products after quality control
Objective	Improve repair quality
Description	Passed products after quality controls aims to see the amount of products that are passed for each quality control made. A higher degree of passed products results in more successful repairs and a higher degree of circularity. It is calculated as the ratio between accepted products and total inspections.
Formula	Passed products after quality control = Accepted products / Total inspections
Unit	%
Target value	(Range 0-100%) 100%
Frequency	Every repair
Source	Engine maintenance
Who reports	Maintenance personnel
Who acts	Design and Management

Table C.9: Indicator of scrap ratio

Name	Scrap ratio
Objective	Improve production by reducing products that are scrapped
Description	Shows the share of the produced products that are scraped.
Formula	Scrap ratio = Scrap quantity / Produced quantity
Unit	%
Target value	(Range 0-100%) 0%
Frequency	Every year
Source	Manufacturing
Who reports	Manufacturing personnel
Who acts	Design

Table C.10: Purity of waste

Name	Waste contamination
Objective	Improve and report quality of waste
Description	The indicator is used to improve and report the quality of the waste. This is done by measuring the various scrap created in terms of different materials in them. It is calculated by taking the ratio of pure waste to the total waste.
Formula	Purity of waste = weight of pure waste from manufacturing / weight of total waste from manufacturing
Unit	%
Target value	(Range 0-100%) 100%
Frequency	At every emptying of waste bins.
Source	Waste management
Who reports	Waste management personnel or Stena Recycling
Who acts	Manufacturing and Management

Table C.11: Waste diverted from landfill

Name	Landfill diversion
Objective	Report and reduce the total amount of waste going to landfill, both from EOL and from waste in manufacturing
Description	The landfill diversion is made to track the amount of waste going to landfill. This will help decision makers see and track their goal. It is proposed that this indicator should measure two types of waste diverted from landfill, the waste in manufacturing at GKN and the waste at EOL. It is calculated as the ratio between the products and waste that is not diverted to landfill to the products and waste that is produced.
Formula	Landfill diversion rate = Waste diverted from landfill / Total waste produced
Unit	%
Target value	(Range: 0-100%) 100%
Frequency	Every year
Source	Waste management and customers
Who reports	Waste management personnel and customers
Who acts	Management

D

Defined Business Indicators

Table D.1: Repair revenue indicator

Name	Repair revenue
Objective	Report amount of revenue from repairs
Description	The repair revenue share is designed to report the total revenue of the business from the repairs. It is expressed as the ratio between repair revenue and total revenue.
Formula	Repair revenue share = Revenue from repairs / Total revenue
Unit	%
Target value	(Range 0-100%) Unknown
Frequency	Every year in reports
Source	Commercial
Who reports	Commercial personnel
Who acts	Management

Table D.2: Cost of Recycled material

Name	Recycled material cost ratio
Objective	Report the difference in cost between recycled and virgin material.
Description	The recycled material cost ratio is meant to report the ratio between the cost of recycled and virgin material. This is important to get an understanding of the price difference between the two materials. The ratio is more appropriate than the value in absolute terms, since the material will always be needed. It is calculated as the price of the recycled material divided by the price of the virgin material.
Formula	Recycled cost ratio = Price of recycled material / Price of virgin material
Unit	Dimensionless
Target value	<1
Frequency	Every order
Source	Procurement
Who reports	Procurement personnel
Who acts	Procurement

Table D.3: Revenue per mass of recycled material waste

Name	Revenue per mass of recycled material waste
Objective	Report and improve revenue from recycling
Description	The revenue per mass from the recycled material is the revenue that comes from selling waste to an external recycling company. However, the revenue has several costs incurred as well and the price of the material is directly related to the purity of it. Costs incurred are handling costs and administration costs. It is calculated as the income from selling the waste minus the various costs.
Formula	Recycled waste income per mass = (Recycled waste revenue - handling costs - administration costs) / Mass of recycled waste
Unit	SEK
Target value	The same price as virgin material
Frequency	Each sold shipment
Source	Waste management
Who reports	Environmental personnel
Who acts	Management

Table D.4: Delivery time recycled material ratio

Name	Delivery time difference of recycled and virgin material
Objective	Report, improve and control the delivery time of recycled material
Description	The delivery time difference of recycled and virgin material aims to indicate the difference in lead time between the two materials. This can be applied for each material that is in use by GKN. This gives the user an overlook of the difference in lead time between the two materials. It can be calculated by dividing the lead time of recycled material by the lead time of virgin material.
Formula	Lead time ratio = Lead time of recycled material / Lead time of virgin material
Unit	Dimensionless
Target value	<1
Frequency	Every order
Source	Procurement
Who reports	Procurement personnel
Who acts	Management

Table D.5: Indicator of material productivity [3]

Name	Material productivity (MP)
Objective	Improve revenue while decreasing linear resource consumption.
Description	The MP indicator (sometimes described as "circular material productivity", CMP) is the ratio of an organization's (or a product's) revenue to total linear (non-circular). An increase in this indicator demonstrates financial growth while reducing (linear) resource dependence.
Formula	MP ratio = total revenue generated in monetary units / total mass of all linear material inflows, in kg or other mass unit.
Unit	Monetary unit per mass unit, e.g. SEK/kg
Target value	As high as possible
Frequency	Every year
Source	Commercial and procurement
Who reports	Commercial and procurement personnel
Who acts	Management

Table D.6: Indicator value per mass [3]

Name	Value per mass
Objective	Improve circularity.
Description	Value per unit mass of material provides estimation of the efficiency of material use. While increasing value per mass shows increasing circularity (whether due to recycling, reuse, remanufacturing, etc. or increased material efficiency), comparisons are only valid within a specified system or closely related systems. The information to be measured is sales, stock and mass of material(s) input. The goal is therefore to increase the product revenue value, while minimizing the total mass of material needed.
Formula	The value per unit mass (VPUM) of material(s) input = the product revenue value, in monetary units / the total mass of material used
Unit	Monetary unit per mass unit, e.g. SEK/kg
Target value	As high as possible
Frequency	Every year
Source	Commercial and procurement
Who reports	Commercial and procurement personnel
Who acts	Management

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