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Circularity Readiness Assessment of Product Value Chain in the Aerospace Industry

Master's thesis in Production Engineering

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Master's thesis in Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: Schematic image showing symbols representing aviation, recycling, nature, industry, and a circular economy icon. Given name for the tool "ENGREEN-CRA", shorten research tittle is included as a text.

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Abstract

This thesis presents the development of a circularity readiness assessment tool tailored to the value chain of the aerospace industry. The tool, named ENGREEN CRA, helps companies identify gaps, assess improvement areas, and promote collaboration across the value chain. "Circularity readiness of the value chain" is defined as the psychological and structural preparedness of a company's value chain to adopt circular economy principles. A comprehensive review of 30 existing tools led to the identification of eight critical areas that shaped the framework, with a focus on scope, interface, and objectives. Furthermore, two essential dimensions: "Regulatory & Compliance Readiness" and "Performance Measurement" were recognised through an analysis of the context in one of the case companies. The tool underwent validation through expert interviews and was tested in two case companies: GKN Aerospace and SAAB AB. This test included individual and group assessments, revealing insights on the usability and effectiveness of the tool in supporting organisational reflection. The tool enables internal evaluations without requiring sensitive data and can be used to map readiness between value chain partners. The results highlighted "Organisational Readiness" as a key enabler and identified weak areas in "Procurement and Supply Chain". The tool offers a practical platform to support strategic alignment and collaboration in the circularity transition of the aerospace sector.

Keywords: circularity, circular economy, circularity assessment, value chain, aerospace.

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List of Acronyms

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

AI	Artificial Intelligence
CE	Circular Economy
CRA	Circularity Readiness Assessment
E.g.,	Examples
EoL	End-of-Life
i.e.	That is
KPI	Key Performance Indicators
LCA	Life Cycle Assessment
RQ	Research Question

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1
Introduction

Assessing circularity readiness is crucial to overcome value chain barriers, identify missed opportunities, and enable sustainable industrial transformation. In this context, this chapter presents the background, aim, research questions, objectives, scope, and the structure of this thesis report.

1.1 Background

Circularity is an essential element in the aerospace industry today for global connectivity and technological advancement (Vogiantzi & Tserpes, 2023). The circular approach to the value chain of the product encompasses all stages of the product life cycle. The complexity of the value chain, combined with a lack of transparency and communication, is currently creating organisational challenges for companies trying to implement sustainability goals (Esteban-Amaro et al., 2025). The Circular Economy (CE) is becoming increasingly important in the industry to gain economic and environmental benefits by minimising waste and utilising resources efficiently (Dias et al., 2022).

However, the transition to CE in the aerospace sector is far from straightforward. A large aircraft consists of more than half a million components (Dias et al., 2022). All of these components have their own product life cycle, and assemblies are creating more complex life cycles. The components move from the extraction of materials to End-of-Life (EoL) with different value additions from different value chain partners that create an environmental impact, and the product life cycle, which is closer to linear has a greater impact, as shown in Figure1.1. Complex and fragmented product value chains face great challenges with limited transparency and weak communication across organisational boundaries (Gardner et al., 2019). These barriers reduce or eliminate circular opportunities such as reuse, re-manufacturing, or material recovery (Dias et al., 2022). In addition, the Open Strategic Autonomy (OSA) of the European Union emphasises secure and resilient value chains and reduced dependence in critical sectors such as trade, energy, and industry (Jakimów et al., 2024). More regulations are introduced by regulatory bodies and increase the pressure on circularity and sustainability (Dias et al., 2022).

The aerospace industry faces significant challenges when implementing an CE because it needs more ground-level supporting solutions. Data sharing and management are crucial elements in the value chain that enhance collaboration and transparency (Esteban-Amaro et al., 2025).

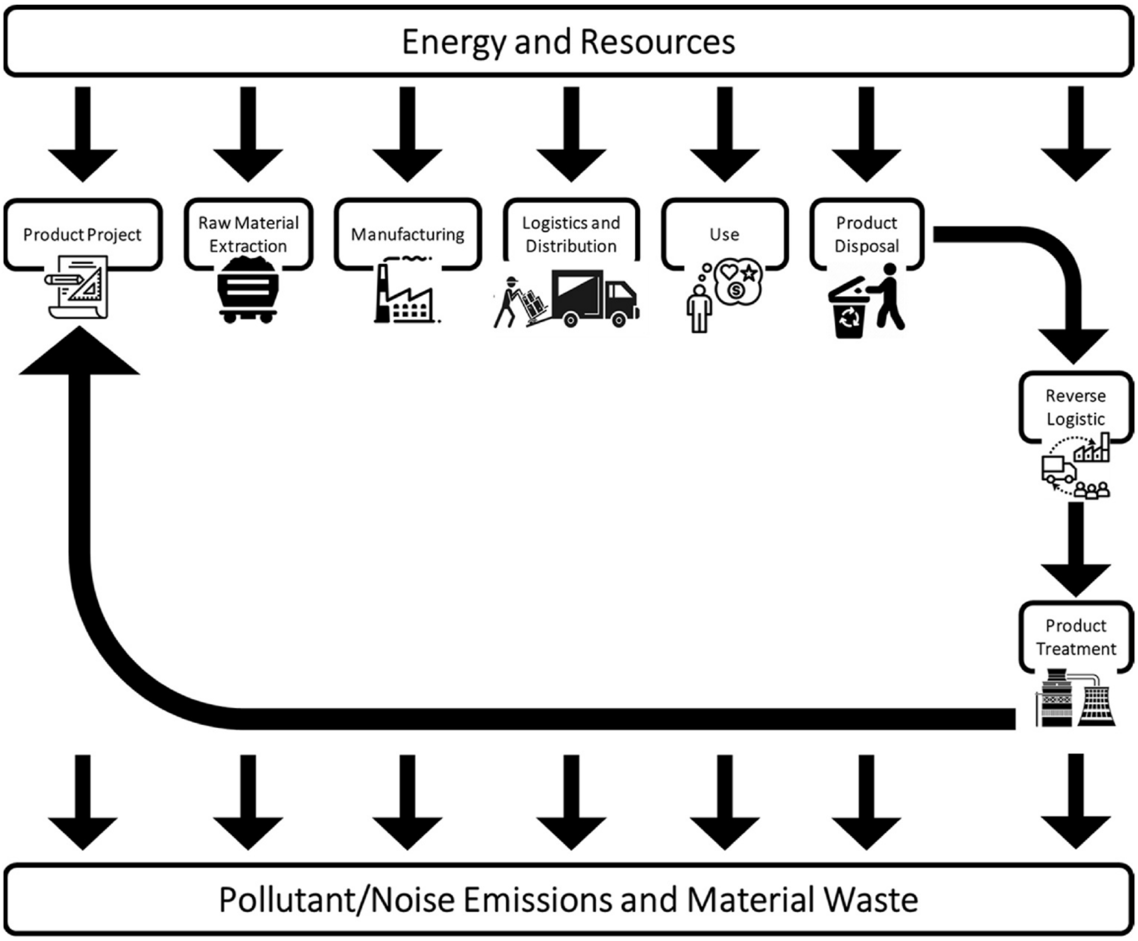

Figure 1.1: Environmental impact of the product life cycle that closer to linear , (Dias et al., 2022)

These practices allow stakeholders to track material flow, monitor product life cycles, and optimise resources effectively. In addition, implementing best practices in circular design, such as designs for disassembly, re-manufacturing strategies, and advanced material recycling techniques, is essential to achieve long-term sustainability goals (Vogiantzi & Tserpes, 2023). Standardising product portfolios and ensuring regulatory alignment with stakeholders also facilitate the industry's efforts to attain circularity objectives. Moreover, Artificial Intelligence (AI) driven predictive methods can enhance circularity by addressing complexity, transparency, and resource optimisation related challenges and preparing the company for a more resilient and sustainable future (Dias et al., 2022).

When using advanced materials such as composites, fibres that have long product life cycles are primarily plastic-based and difficult to recycle (Vogiantzi & Tserpes, 2023). Even metallic alloys are technically recyclable but have a low recycle content to improve quality and safety. The industry has a long product life span, often exceeding 25 years, which means that EoL is not an immediate priority (Dias et al., 2022). Increasing circularity in the aerospace industry is a complex challenge that requires the involvement of multiple levels within the organisation (Chirumalla et al., 2024). Collaboration across the entire value chain is essential, to ensure that all stakeholders, including suppliers, manufacturers, and end users, are aligned. An effective assessment tool is essential to evaluate current practices, measure circularity performance, and develop strategies for a more sustainable and efficient transition (Vogiantzi & Tserpes, 2023). Circularity Readiness Assessment (CRA) is emerging as one of the best solutions that can identify gaps in a structured way, align stakeholders in the value chain, and support the movement toward more circular and sustainable operations (Camacho-Otero & Ordoñez, 2017). Hence, there is a clear need for tools that not only assess the current circularity status of the value chain, but also guide strategic decision making.

1.2 Aim

This master's thesis project aims to develop a practical circularity readiness assessment tool tailored for the aerospace industry. The tool is to support companies in the processes of identifying gaps and improvement areas, exploring collaboration opportunities to improve the circularity performance, enhance their ability to self-assess circularity readiness, strengthen value chain collaboration, and strategically plan for sustainable improvements.

1.3 Research Questions

Building on the aim of the thesis, this study is guided by four research questions. These questions were developed to provide a structured path towards developing the tool and understanding its broader impact.

I. What does circularity readiness mean?
Understanding and clearly defining the concept of circularity readiness is essential to establish the theoretical foundation needed to develop an assessment tool.

II. How is circularity readiness assessed in research?
This question consists of investigating the existing methods and tools in the literature. It helps to understand the best practices, different frameworks, methodologies, and gaps, which inform the structure and focus of the proposed assessment tool.

III. What are the key indicators for circularity readiness assessment, and how can they be identified?
To make the tool operational, it is important to identify relevant indicators in the context of circularity in aerospace value chains. In addition, it is important to focus on the selection and structuring of these indicators.

IV. How can a circularity readiness assessment support companies in collaborating across the value chain and enhance circularity performance?
This focus area of the study emphasises the practical value and the broader impact of CRA in complex industrial contexts such as aerospace.

Together, these questions guide the development process of the tool. In addition, the tool is ensured to be conceptually sound and grounded in practical relevance.

1.4 Objectives

- To explore and conceptualise the systemic barriers and drivers of circularity readiness in complex aerospace value chains.
- To develop a conceptual framework for circularity readiness assessment in the aerospace industry based on a review of existing literature and frameworks.
- To design a self-assessment tool that aligns with the developed conceptual framework, focusing on key circularity indicators relevant to the aerospace value chain.
- To test the relevance and usability of the self-assessment tool through case studies.
- To provide actionable recommendations and develop a strategy for implementing more sustainable practices using that self-assessment tool.

1.5 Scope of the Study

The scope includes the development of a circularity readiness assessment tool for the aerospace industry. The tool was applied and tested through two case studies with GKN Aerospace and SAAB. The self-assessment has been designed to emphasise collaboration and co-creation of value chains, circularity in materials, manufacturing processes, and EoL considerations. The conceptual framework has been grounded on some existing literature and previous research, as explained in Section 2 of this report.

This chapter gives a concise overview of the background, scope, research objectives, and research questions that researchers aim to answer through this research. Section 2 explains the theoretical foundation for CRA, it focusses on the typology of definitions, highlighting existing studies related to the CRA, key indicators for circularity assessments. Next Section 3 provides a comprehensive explanation of the research methods used to develop the tool and tool testing. It is followed by Section 4 that provides the results, including the final version of the tool and the results of the tool testing. The answers for all the research questions are discussed in Section 5, discussion. Finally, Section 6 provides the conclusions of the thesis, including key limitations of the study, and suggestions for future research.

2

Literature Review

When a company transitions from a linear economy to a CE, it must pay attention to the entire value chain collaboration (Bressanelli et al., 2020), focusing on sustainability, resource efficiency, and waste reduction (Vogiantzi & Tserpes, 2023). The evaluation of circularity within the value chain is crucial to identify limitations and discover opportunities for improvement(Esteban-Amaro et al., 2025). This literature review analyses current research on circularity in the product value chain, existing circularity assessment tools, dimensions for circularity readiness assessment and their suitability within the product value chain of the aerospace industry. This review aims to identify gaps, challenges, and opportunities to improve the circularity of the value chain.

2.1 Circular Economy

The linear economy follows a take-make-dispose model, which leads to several limitations and inefficiencies, such as resource depletion, waste generation, environmental impact, economic risk and price fluctuations in the value chain (Ellen Macarthur Foundation, 2013). The CE concepts have evolved over time due to the challenges in achieving sustainability in economic systems (Vogiantzi & Tserpes, 2023). One of the most well-known definitions is presented by Ellen Macarthur Foundation (2013) "A circular economy can be considered an industrial system that is restorative and regenerative by design and intention". Figure 2.1 shows that the concept of EoL is replaced with restoration, which eliminates waste through sustainable practices and promotes a shift to renewable energy within the business model (Ellen Macarthur Foundation, 2013).

Researchers have studied and analysed different definitions of CE with different view points which include interpretations in different industries (Vogiantzi & Tserpes, 2023). Vogiantzi and Tserpes (2023) have studied eight analyses of CE definitions to gather insights and conducted survey questionnaires inside their project "RECREATE" to propose a very comprehensive definition of CE. The CE is an economic model based on closed cycles, aiming to regenerate resources, reduce waste, and support value creation through sustainable practices, renewable energy, and supportive policies (Vogiantzi & Tserpes, 2023).

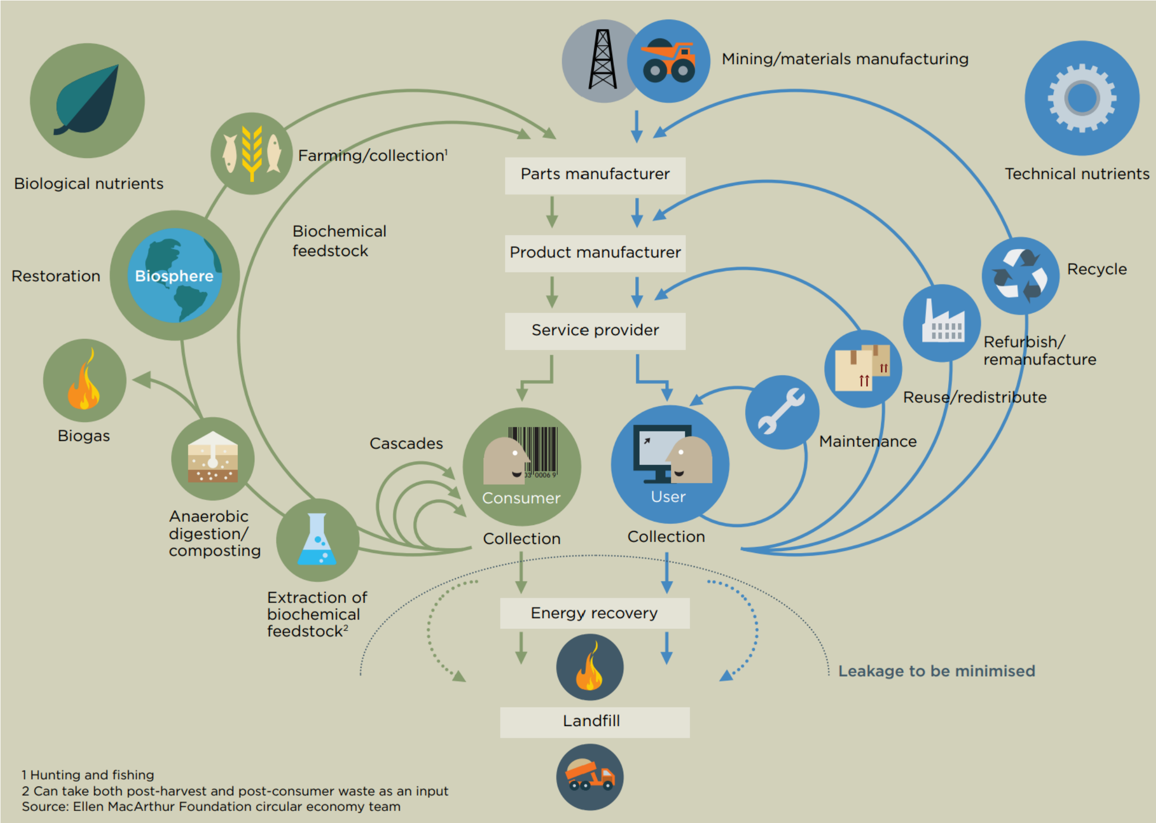

Figure 2.1: Circular economy in industrial systems
, (Ellen Macarthur Foundation, 2013)

2.2 Circularity in Product Value Chains

Pande and Kumar Adil (2019) has cited the concept of Value Chain as a succession of activities that take a product or service from production to final consumers, including inbound logistics, operations, outbound logistics, marketing, sales, after-sales service, and support activities such as design, procurement, human resource management, and infrastructure management.

The value chain includes a network of partners, flows of information, goods, and money flows, and shared value. Partners range from suppliers to customers, users, innovation networks, universities, and other knowledge institutions, regulatory bodies, and civil society organisations (Jørgensen & Remmen, 2018). The value chain of a company in its ecosystem and the stronger interconnections between internal and external stakeholders in a CE were represented graphically by Eisenreich et al. (2022) and shown in Figure 2.2.

The connection between the value chain and circularity has been explained by Esteban-Amaro et al. (2025) such that the value chain includes the flows of information, goods, and money; In circular models, these flows become multidirectional instead of linear; traceability and transparency are important. They help facilitate sharing, repair, and recycling. They also support access to new funding and investments; The value is created at every stage of the value chain and passed on to the next. This shared value helps both businesses and society; value chain covers all phases of the life of a product, from raw material supply to disposal; Business models, investments, and regulations also play a role in creating value; Connecting the value chain to the product life cycle is important and helps to evaluate the circularity of the value chain.

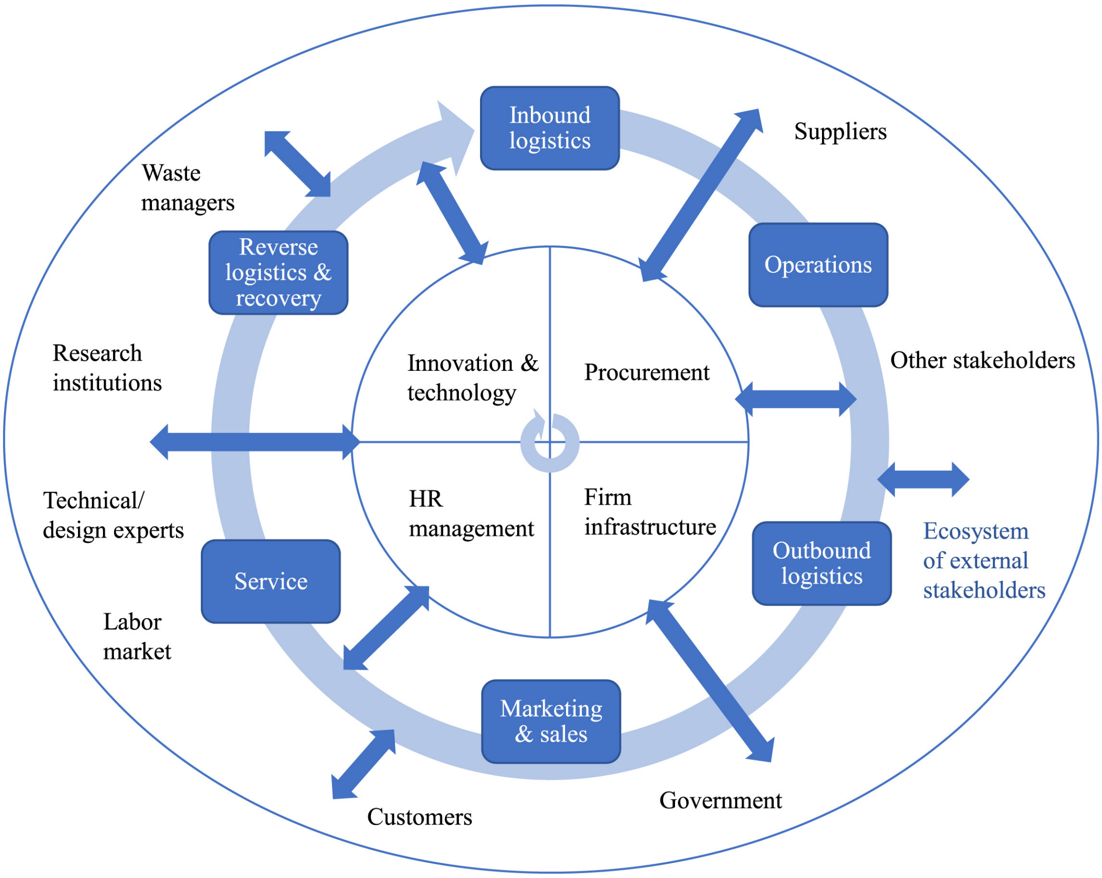

Figure 2.2: Circular Value Chain
, (Eisenreich et al., 2022)

2.3 Circularity Readiness of Value Chain

The transition from linear economy to CE is a change for an organisation. Any organisation has their own value chain. Hence, circularity is not just a change in one organisation, but a whole set of interconnected changes. Adjusting and evolving to changes has become the new normal in today's unstable, less predictable, complex, and ambiguous world (Ford et al., 2021). An organisation should continuously measure their readiness for changes to make adjustments and evolve to changes. The degree to which both individuals and the organisation have their psychological and structural needs met, allowing them to effectively accept and carry out organisational change (Jo & Hong, 2023) can be considered readiness in an organisation. This definition of the readiness of an organisation can be refined and adapted to define the readiness of the value chain. Circular readiness of the value chain is the extent to which a company's value chain is psychologically and structurally prepared to transition to CE principles.

2.4 Circularity Readiness Assessment in the Value Chains

Measurement or assessment of readiness means analysing how well an organisation can handle and go through a change considering opportunities, gaps, and potential challenges (Pirola et al., 2020). In addition, assessment promotes transparency and continuous improvement, which can guide society in using Earth's limited resources in a better and more balanced way (Vogiantzi & Tserpes, 2023).

The readiness assessment can be done using qualitative (i.e. interviews and observation) or quantitative (i.e. surveys and questionnaires) data collection and it is important to make sure the results are accurate and reliable (Holt et al., 2007). Pigosso and McAloone (2021) have reviewed the existing literature and found readiness assessment on numerous levels, including: country level, sectorial level, ecosystem level, regional level, organisation level and individual level (readiness of employees).

Although the "Table 3" in Vogiantzi and Tserpes (2023) provides a detailed summary of CE assessment methods such as life cycle assessment, material flow analysis, design for X methodologies (E.g., design for disassembly, design for EoL) and multi-criteria decision making which are primarily aimed at evaluating the current state of circularity across various dimensions; they also offer critical inputs and conceptual building blocks for circular readiness assessment.

Multilevel readiness assessment frameworks have been developed that assess circular readiness across different layers of organisation. For example Chirumalla et al. (2024) proposed a framework with five readiness levels starting with a basic understanding of concepts at level 1 and advancing through increasing levels of operationalisation, leading to full implementation at level 5 within four key focus areas: ecosystem, customer/business model, internal culture, and design/development. Here, the author has considered general levels of circularity as key focus areas.

An important aspect of readiness involves evaluating how well circularity is integrated into product design to support the circular economy principles. In this context, readiness assessments are considered factors such as End-of-Life management (Boorsma et al., 2022; Cayzer et al., 2017; CCPE, 2025); modular design (Boorsma et al., 2022; Cayzer et al., 2017; Dagilienė et al., 2024), longevity (Boorsma et al., 2022; Brändström & Eriksson, 2022; LeNSlab Polimi team, 2024).

Material based circularity assessment methods, such as Circular Transition Indicators by WBCSD (2023), Material Circularity Indicator by Ellen MacArthur Foundation (2015), and the Circularity Calculator by IDEAL&CO Explore (2022), explore primarily the evaluation of the material flow and recovery of materials considering factors like recycled content, material composition, product lifespan, and EoL reconcilability to generate quantitative circularity scores. Brändström and Eriksson (2022) developed a material efficiency metric based on material flow oriented circularity assessment principles, drawing inspiration from both the Material Circularity Indicator (Ellen MacArthur Foundation, 2015) and the Product Circularity Indicator (Bracquené et al., 2020) but adapted them to assess circular readiness across value chains by linking circular business models and circular design strategies to the mechanisms of narrowing, slowing, and closing material loops, offering a system level view on circular readiness assessment.

The business strategy and implementation focused CRA tools are mainly evaluating the strategic alignment, organisation culture, leadership commitment, and cross functional collaboration. For example (EcoDesign Circle, 2022d) is to provide a simple tool canvas with the objectives of an organisation and the circular maturity.

The growing challenges associated with the CE and sustainable development have led researchers to develop an increasing number of frameworks to measure circular readiness (Esteban-Amaro et al., 2025). According to Esteban-Amaro et al. (2025), circularity assessment frameworks can be grouped into two main categories; The first category includes frameworks that are designed to support the transition to a CE by providing tools for the development and implementation of strategies, decision support frameworks, innovation of business models and digital transformation; The second category focusses on measuring the degree of circularity already achieved using indicators, scores and value-based models, enablers and barriers analysis, and product level tools to analyse product contribution to circularity.

2.4.1 Existing Circularity Readiness Assessment Tools

There are many circularity assessment tools discussed in the literature. Using the methodology described in Section 3.2, authors identified 30 distinct tools, which are listed in Appendix A. The analysis in Appendix A focusses on the characteristics and categories of these tools, building on the work by Keita Sekijima (2024), which was further developed and expanded in this study to provide a more comprehensive overview. This analysis provides key insights that were later used to inform the development of the assessment tool presented in this study.

There are three main assessment methods used in the literature. Self-assessment is the most common form of assessment in which the user evaluates their own systems (Dagilienė et al., 2024; IDEAL&CO Explore, 2022; WBCSD, 2023). Some tools can be used as self-assessment and group assessment that involve collaborative evaluation. Jamie Evans (2023) is provide guidelines to use the "Circular Economy Toolkit" to run the company's own workshop and find opportunities in the company. Boorsma et al. (2022) and CIRCit NORDEN (2020) in their tool methodology highlight the need to appoint two or more employees with expertise in the CE and a deep knowledge of the product to ensure an accurate and effective assessment. DTU researchers (2025) also explained that the readiness assessment can be updated at any time, with options to skip uncertain questions or invite colleagues to fill knowledge gaps. The readiness results can be externally benchmarked by comparing the company or its business units with a defined group of other companies (DTU researchers, 2025; Pigosso & McAloone, 2021); that is a different way of assessing circularity in a broader scope.

The level of circularity reflects the system boundary at which circularity is assessed. Tools can operate at different levels, including product, company, industry, regional, or value chain levels, depending on their intended scope and application. Many tools were developed with product focus level to achieve circularity through circular products (CIRCit NORDEN, 2020; EcoDesign Circle, 2022d; IDEAL&CO Explore, 2022; Keita Sekijima, 2024). Ellen MacArthur Foundation (2022), Pigosso and McAloone (2021), and WBCSD (2023) were developed their tools specially that focussing on company level assessments. DTU researchers (2025) and Ellen MacArthur Foundation (2022) are providing assessments to identify readiness in industry level. Indeed (2024b) is highlighting how a circularity assessment index can be used for a region. Few assessment tools have extended the assessment level from the company to the value chain to get a broader scope for the assessment and create circularity as a collaborative journey. Eco Design Circle (2022c) is providing a canvas which can include all living and non-living elements that reveals hidden impacts and value creation across the product value chain. Corsini et al. (2024) and DTU researchers (2025) have developed "Circular Assessment of Suppliers (CAoS)" and "Making the Transition to a Circular Economy (MATChE)" tools respectively, those support value chain actors in assessing readiness, planning, and enabling collaborative circular transitions.

The review of tools reveals a wide range of stated objectives. To structure the analysis, those were categorised into six main objective categories based on common patterns and recurring objectives. These objective categories include business strategy and CE implementation, maturity assessment, circular product design and development, value chain and resource management, performance measurement, and industry-specific assessments.

The output types of these tools are quantitative, qualitative, or mixed-method formats. Quantitative outputs typically involve mainly numerical indicators or scores for example (Ellen MacArthur Foundation, 2015; IDEAL&CO Explore, 2022; LGI Circular Economy & Université Paris Saclay, 2018). Qualitative outputs based on descriptive insights and provide in (Cambridge UK, 2013; Jamie Evans, 2023). Most of the tools are in the category of combined output in both qualitative and quantitative aim to provide a more comprehensive understanding of circularity (DTU researchers, 2025; Ellen MacArthur Foundation, 2022; Ganbatte, 2025; Keita Sekijima, 2024; Prospektiker et al., 2021).

The interface refers to the format through which users interact with the tool, and these tools were in web-based platforms, Excel-based tools, and canvas-style interfaces, each offering different levels of usability, accessibility, and visual representation.

This analysis highlights the diversity, complexity, and covered areas of existing tools and emphasises the need to select parameters for tools based on specific contexts and assessment objectives and users' perspective. The summary of the analysis of these tools is shown in Table 2.1 and detailed analysis is presented in Appendix A.

Table 2.1: Summary of Analysis of Circularity Assessment Tools

Attributes	**Entities**
Assessment method	Self Assessment, Group Assessment, External benchmarking, External Assessment
Level of circularity	Product, Company, Industry, Region, Value chain
Objective Category	Business Strategy & Circular Economy Implementation, Circular Economy Maturity Assessment, Circular Product Design & Development, Circular Value Chain & Resource Management, Circularity Performance Measurement, Industry-Specific Circularity Assessment
Output	Quantitative, Qualitative, Quantitative& Qualitative
Interface	Web-base, Excel, Canvas

2.4.2 Dimensions and Elements in Circularity Assessment Tools

The analysis of tools in the literature review has included identification of the dimensions and elements of each tool. As shown by Esteban-Amaro et al. (2025), the research has developed an increasing number of frameworks to measure circular readiness; causing the use of more than 142 dimensions, including synonyms. Some dimensions included more than one element and could list more than 180 elements, including synonyms. Authors found that some elements in one tool are dimensions in another tool, and vice versa. Further analysis of these sets was continued using the knowledge and expertise of the authors to remove synonymous, identify the correct parent-child connections between dimensions and elements, and list them under correct placement of elements under correct dimensions.

Huybrechts et al. (2018) explained that implementation of the CE needs both bottom-up approaches (companies' efforts) and top-down approaches (integration of CE principles with legislation and policy).
Information and data are often missing due to poor documentation and limited sharing in value chains; Industry 4.0 and technologies like blockchain and digital twins can help improve data flow and value chain sustainability (Berger et al., 2022).

According to Saari et al. (2021) the digital transition supports better product and material circulation by improving information flow; It also promotes fair data exchange between companies, helping to optimise the full material loop.

The holistic approach to CE requires that all stakeholders can be involved in the shift from individual profit to shared value; in other words, create value by collaboration and shared systems instead of competition to make the value chain more eco-efficient and resilient (Houssard et al., 2022). A study by Kirchherr et al. (2018) has identified cultural barriers such as low consumer interest, limited awareness, and a hesitant company culture as major challenges for businesses and policy makers.

2.4.3 Dimensions as Enablers and Implementers and Uneven Contribution

During our analysis of the dimensions in multi-criteria circularity assessment tools, most dimensions could be categorised into two main purpose-based groups: enablers and implementers. Ellen MacArthur Foundation (2022) and Prospektiker et al. (2021) clearly divided the dimensions into "Enables", which represent the foundational organisational capabilities and can be applied for any company or any value chain partner; and "Outcomes", which reflect the practical execution of circular strategies and applicability of these can be varied depending on the nature of the company or value chain partner. In addition, each subcategory under "Enables" and "Outcomes" is assigned a weight that reflects its practical importance in enabling the shift to a CE (Ellen MacArthur Foundation, 2022). Similar concept has been explained by Corsini et al. (2024) that in their tool "Circular Assessment of Suppliers (CAoS)" has three main categories: (i) critical environmentally related criteria, (ii) circularity of the relationship established with the supplier, and (iii) inner circularity of the supplier and they are differentially weighted based on their significance. However, actions related to circularity are not just "Outcomes", but a collection of circularity implementation actions that are driven by collaboration between value chain partners (Dias et al., 2022). Hence, a better term is "implementers" than "outcomes".

Another aspect of dimensions has been identified through the study that not all dimensions contribute equally to the final circularity readiness score. This has been reflected in Pigosso and McAloone (2021) in their MATChE tool development, where experts identified overlaps and gaps across dimensions during MATChE testing, leading to the tool incorporating a prioritisation step after the assessment for further use of the results. Chirumalla et al. (2024) highlighted that each dimension needs to be prioritised or addressed differently based on the maturity of the dimension. The weights are based on the characteristics of the company and the guided inputs, ensuring that each theme and indicator reflect the core activities of the company and the circularity priorities (Ellen MacArthur Foundation, 2022).

2.5 Circularity and Circularity Assessment in the Aerospace Industry

The aerospace industry faces increasing pressure to align with global climate goals, particularly the commitment to net-zero emissions by 2050 (Melrose Industries PLC, 2023). Chatziparaskeva et al. (2022) highlight the the disposal of EoL aviation composite materials and aircraft structures is one of the major challenges that must be handled effectively. The aerospace sector has a prominent position on the global market and is among the top fuel consumers in the transportation industry (Huang et al., 2016). The transformation of the aviation industry reflects not only regulatory pressure, but also increasing stakeholder expectations and the need for operational resilience in a future with limited resource availability (Melrose Industries PLC, 2023). Hence, adaptation to the CE can enhance the overall performance of the aerospace industry.

2.5.1 Opportunities for Circular Economy in Aerospace

By adopting CE principles like recycling, re-manufacturing, and reuse, companies in aviation industry can gain enhance brand image, expand market share, and increase profitability while minimising environmental degradation (Dias et al., 2022).

Melrose Industries PLC (2023) explaining that improving raw material recycling creates opportunities to reduce energy use, emissions, waste, and costs; investing in research and development for technologies such as additive manufacturing and nesting also supports these reductions. Using raw materials more efficiently means that fewer materials need to be purchased, leading to shorter supply chains and ultimately emissions associated with purchased goods can be significantly reduced (Domone et al., 2021).

2.5.2 Circular Initiatives in Aviation Industry

Reuse and refurbishment of components from decommissioned aircraft is one of the key initiatives for circularity, as explained by (Dias et al., 2022). In addition, Domone et al. (2021) highlighted that 10,000 aircraft are estimated to reach retirement in the next 20 years, and then the reuse and refurbishment of components can be considered as a need. There are many emerging technologies such as additive manufacturing that enable design for longevity and light weighting (Domone et al., 2021); Digital Twins & AI for predictive maintenance and lifecycle optimisation to increase the life time of aircraft (Dias et al., 2022). Bio based & Recycled Materials can be used especially in the interior of the cabin, or composites can reduce significant waste and land fill (Domone et al., 2021).

In Figure 2.3 shows circular practices that can be used in the aerospace industry.

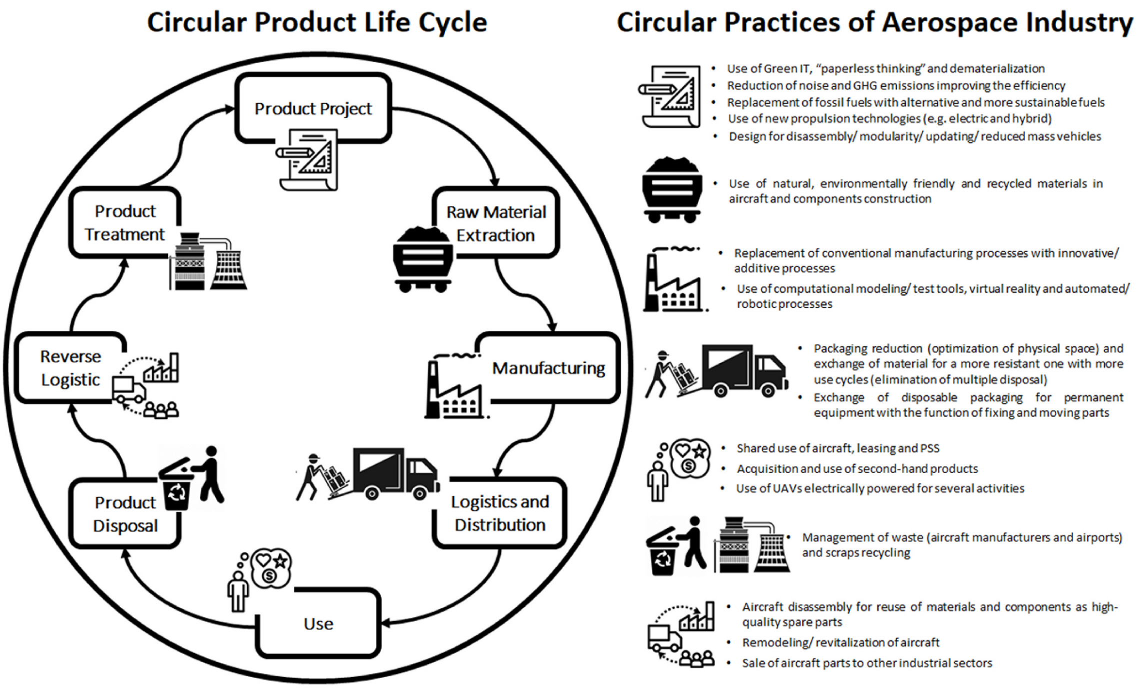

Figure 2.3: Circular Practices in Aerospace Industry
, (Dias et al., 2022)

2.5.3 Existing Circularity Assessment Practices in Aerospace

Vogiantzi and Tserpes (2023) has explained how the Life Cycle Assessment (LCA) tool can be effectively applied to measure and evaluate the benefits or impacts of CE strategies, often supporting the comparison and selection of different circular options in the aviation context. Dias et al. (2022) has explained how the ReSOLVE framework (Regenerate, Share, Optimise, Loop, Virtualise, Exchange) in the aviation setting. The Ellen MacArthur Foundation developed the ReSOLVE framework that provides a structured approach to implementing the principles of the CE by guiding businesses to rethink value creation through resource efficiency, innovation, and systemic transformation throughout operations; ReSOLVE can be used in aviation settings, but needs some adaptations, especially in aviation industry specific factors such as regulatory constrains, safety standards, and complexity of the value chain (Dias et al., 2022). Despite the range of existing readiness approaches listed in this literature review, the tools developed for the assessment of circularity in the aviation industry focus only on the LCA and ReSOLVE frameworks, and none of them used the multi-criteria element base assessment.

The literature review indicates that "circularity" and "circularity readiness assessment" are highly demanding research areas. Based on the literature review conducted in this study, very few studies focused on the intersection of circularity, readiness, and the aviation industry. In addition, the literature has not adequately addressed CRA in the aviation sector, highlighting a gap that this study seeks to address.

2.6 Research Implications on Circularity Readiness Assessment of Product Value Chains in Aerospace Industry

Many CE metrics have been developed across various levels: micro-level (product), meso-level (industrial symbiosis) and macro-level (regional) level circularity; yet there is no consensus on what they should specifically measure or how these different levels are interconnected (Brändström & Eriksson, 2022). Corona et al. (2019) highlighted the limited interconnection between different levels of assessment (e.g., product, company, and value chain levels) is a challenge for the development of such circularity assessment tools. Hence, CRA in the value chain is the ideal option to create the interconnection between levels which assess all the circular paths, material circularities, and co-creation. Huybrechts et al. (2018) also highlighted that the aim of CE can only be achieved by using the entire value chain during the assessment rather than evaluating industrial activities in isolation. (Vogiantzi & Tserpes, 2023) have explained for the progress of circularity in the aviation industry need of complex interplay of dimensions and challenges while offering realistic solutions such as CRA tools to support the transition across the value chain. 3

3
Methods

This chapter outlines the methodology and approach used in this thesis. It begins by describing the process of reviewing the existing literature, followed by the creation of a conceptual framework that identifies key areas related to circularity in the value chain. The chapter explains the design process for the tool, the validation and testing methods employed, and the analysis of the tool's performance. The process of developing the new self-assessment tool is clearly outlined in Figure 3.1.

3.1 Social, Ethical, and Ecological Aspects

The thesis project on the assessment of the readiness for circularity in the aerospace industry requires careful consideration of the social, ethical, and ecological aspects.

Stakeholders in GKN Aerospace and SAAB have been involved inclusively, ensuring impartial participation in data collection and workshops. The self-assessment tool has been designed for accessibility and practical application in different sections while minimising disruptions to industry professionals during research activities.

Ethical considerations include safeguarding data privacy and confidentiality, as sensitive company information has been collected. Transparent methodology was essential to ensure that the assessment tool remains unbiased and does not favour specific sections or technologies. To maintain research integrity, results has been accurately represented without exaggeration or misinterpretation.

From an ecological perspective, minimising waste in research activities by using digital tools and virtual collaboration was crucial. The assessment tool has been adopted a life cycle perspective, considering the entire value chain to ensure its effectiveness in promoting circularity. In these aspects, research is ensured that sustainable, ethical, and socially responsible.

3.2 Methodology of Literature Review

The literature review is a basic and initial approach of the tool development methodology to identify keywords and key terms related to the readiness of circularity, including its definition, theoretical background, and existing assessment framework methodologies. The detailed literature review is described in Section 2.

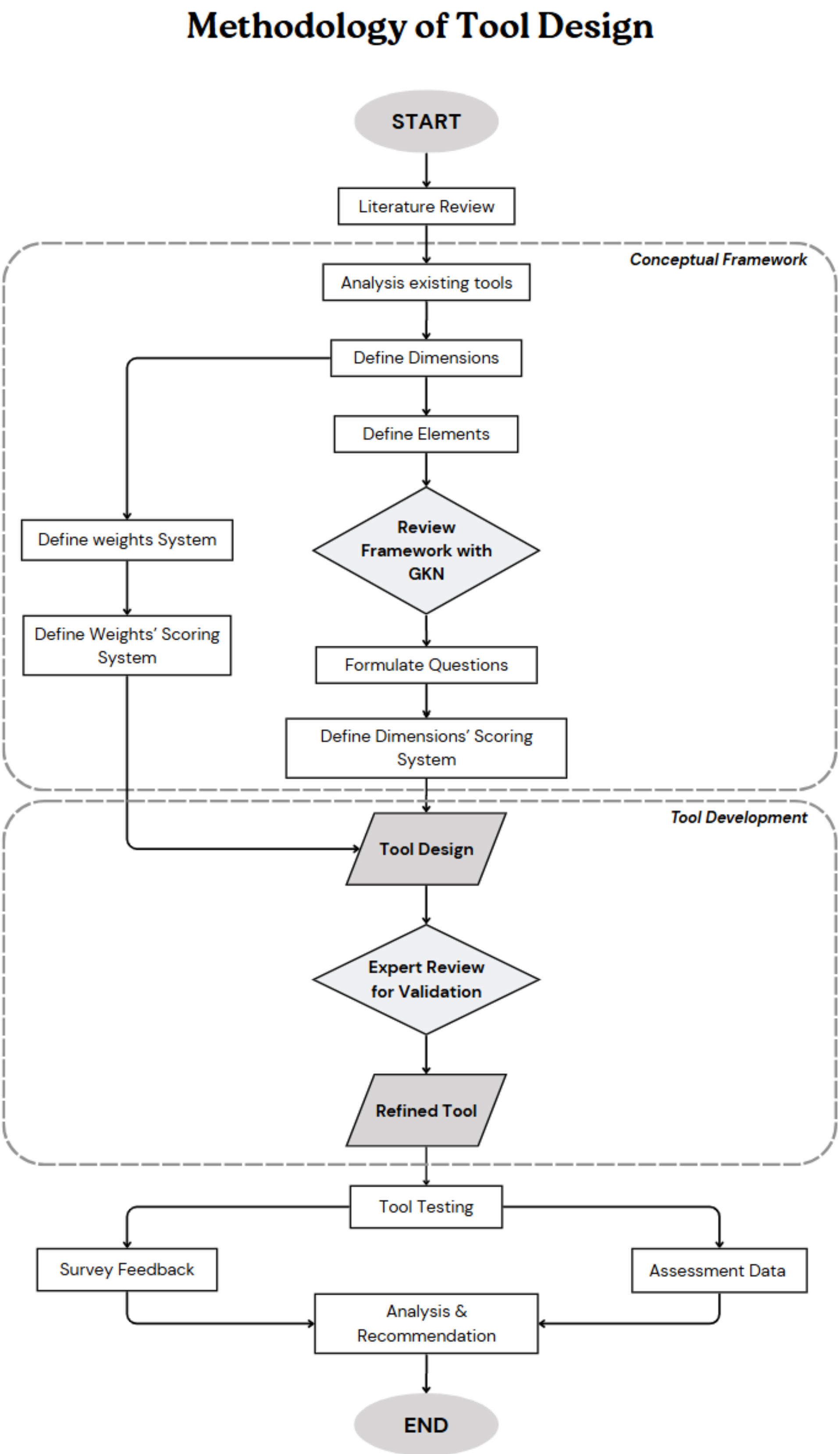

Figure 3.1: Tool Development Methodology

The search strategy involved the use of academic databases such as Scopus and Google Scholar. The primary keywords used were "circular economy," "circularity assessment", "product value chain," "circularity assessment tools," and "circularity in aerospace". Boolean operators (AND, OR) were employed to refine the search results. This approach enabled a critical evaluation of the existing literature, highlighting trends, gaps, and emerging directions of future research (Ellen Macarthur Foundation, 2013; Vogiantzi & Tserpes, 2023).

The literature review was conducted using a systematic approach to cover all relevant research areas. Ellen Macarthur Foundation (2013) highlighted essentiality to define key terms of the CE and product value chain in the initial stage. Understanding the importance of the product value chain, along with the challenges and barriers, is crucial to grasping the concepts of CE and circularity within the product value chain.

The objective was to collect a wide range of information on the strategies and tools that various industries are employing to evaluate their readiness for CE practices. Specifically, existing circular readiness assessment tools tailored to different sectors were examined to assess their effectiveness and applicability. This process involved examining various frameworks and models, highlighting the importance of sustainable practices within the value chain by combining findings from established and new sources.

The academic literature on tools for assessing circularity readiness is limited. In particular, Pigosso and McAloone (2021) highlighted Circulytics, introduced by the Ellen MacArthur Foundation in 2019, which has not yet been reported in academic publications. This prompted an exploration of the grey literature as well. A list of circularity assessment tools was found in Keita Sekijima (2024) and helped to easily expand the list of tools. A total of 30 tools were selected from both the academic literature and the grey literature, underscoring the need for further analysis. These tools primarily concentrate on assessing circularity and readiness for circularity at both product and company levels, with very few addressing the value chain. A systematic analysis was conducted to identify the varying levels of circularity assessments, different outputs, scopes of assessment, interface types, and primary objective categories of tools. A summary of this analysis is presented in the Section 4.1.

Out of 30 tools evaluated, six tools, Circulytics (Ellen MacArthur Foundation, 2020), Circularity Assessment Tool (Ganbatte, 2025), Ready2Loop (DTU researchers, 2025), Compass Circular Economy (Circular Economy Forum Austria et al., 2023), CircularStart (Prospektiker et al., 2021), and Circular Assessment of Suppliers (CAoS) (Corsini et al., 2024) were selected as they were aligned closely with the scope of the CRA of the value chain. A detailed analysis was performed to identify the dimensions and elements that can inform the scope of the tool to be developed. In this context, the dimensions represent the primary areas that the tool will evaluate, while the elements serve as subcategories within those main areas. It is worth noting that tool developers may use a variety of terminologies. The key dimensions and elements have been identified and are detailed in the Appendix B.

The authors started by analysing the key principles of CE and aligning them with the specific characteristics and challenges of the aerospace value chain. Subsequently, information was collected from the literature and current tools to identify the components of the circular readiness assessment. The entire product life cycle was examined from material sourcing, product design & manufacturing, operation, and end of life to determine areas where CE principles can be applied to enhance.

The structure assesses operational and strategic aspects in which circularity initiatives should be implemented throughout the organisational value chain. Especially integration of the principles of 9R included in the dimensions.

3.3 Define Tool Conceptual Framework

In the initial stage of developing the conceptual framework, the authors categorised the tools identified for assessing the readiness for circularity according to the specific aspects of circularity they addressed. The dimensions and elements of the six selected tools were filtered to concentrate primarily on their relevance to the value chain perspective. This selection process was further refined by evaluating the specific applicability of these dimensions and elements within the aerospace industry, which included several brainstorming sessions.

An initial interview was conducted with the expertise within the GKN sustainability team, which represents a strategic approach to identifying the most critical dimensions that influence the aerospace industry's value chain. Before the interview, a structured set of questions was developed, focused on six key thematic areas. Circularity Goals & Strategy, Measuring & Tracking Circularity, Materials & Waste Management, Product Design & Circularity Strategies, Stakeholder Engagement & Collaboration, and Tools & Systems for Monitoring Circularity. Refer to the interview questions and key takeaways outlined in the Appendix C. These questions aimed to explore the current practices, challenges, and strategic priorities of GKN in the CE, including their goals, tracking methods, material flows, product lifecycle strategies, stakeholder participation, and digital systems used to monitor circularity. The insights gathered from this interview were used to refine and filter the initial selected dimensions and elements of the tool, ensuring that the framework aligned with the challenges of circularity and the operational realities specific to the aerospace industry.

Following the identification of key dimensions and elements relevant to circularity, the next step focused on integrating these into a usable self-assessment tool. Drawing from the concept of "Enablers" and "Implementers" introduced in Section 2.4.3, dimensions were linked to organisational roles to support strategic prioritisation.

Initially, users were prompted to assign priority levels to each dimension using a 5-

point Likert scale. This helped capture the perceived importance of each dimension within their specific organisational context. To improve clarity and usability, the authors later included scenario-based questions. These questions provided context-specific examples, making it easier for users to assess the relevance of each element and assign meaningful priorities.

Assessment questions were formulated in the present tense to evaluate the current state of practices. Each question represented one of the identified elements and was structured for quantitative input using a standardised Likert scale. This approach followed guidance from existing research Demko-Rihter et al. (2023) and Pigosso and McAloone (2021), which demonstrated the value of Likert-based evaluation in measuring circular readiness.

During the development process, approximately 50 elements and their associated questions were initially drafted. However, through pilot testing by the authors, this number was reduced to 40 to minimise respondent fatigue and maintain focus during evaluations. The final set of questions allowed for systematic scoring and prioritisation, forming the basis of the tool readiness assessment framework.

3.4 Self Assessment Tool Development

The structure of the tool was finalised following several brainstorming sessions. Initially, the decision was made to develop the tool using a Microsoft Excel spreadsheet, chosen for its ease of creation and the fact that users are generally more familiar with it. The structure of the tool went through multiple iterations to improve usability, simplicity, and overall appearance. Subsequently, macro-functions were incorporated to provide users with easier access to different sections and to facilitate various commands, such as checking that all questions were answered, saving data and generating reports. The tool has been named **"ENGREEN CRA"** with **"CRA"** standing for "Circularity Readiness Assessment" and **"ENGREEN"** reflecting the concept of "Green Engines" in alignment with the main case company GKN.

To validate the new tool, interviews were conducted with a diverse group of circularity experts from academia and industry. These included a sustainability specialist from industry, a postdoctoral researcher in sustainable product development, a professor with expertise in integrating strategic sustainability into product innovation, and an associate professor focusing on sustainable digitalised production. Their collective feedback was instrumental in refining the assessment tool and strengthening its practical relevance and credibility. The interviews were conducted in an unstructured format, without a prepared questionnaire. The tool was shared with experts prior to interviews, allowing experts to review it beforehand. During the discussion, clarifications were provided on any ambiguous areas. Some feasible feedback was incorporated into the tool, while other suggestions were considered impractical given the constraints of the thesis timeline. These latter points have been documented as recommendations in Section 5. All discussions with experts and output have been compiled in the Appendix D.

3.5 Tool Testing

The **ENGREEN CRA tool** was tested through a series of interviews and workshops conducted with two case companies: GKN Aerospace and SAAB AB. These companies were selected because of their significant roles in the aerospace industry and their ongoing efforts toward sustainability and CE practices. Both represent complex global manufacturing organisations with extended value chains, making them highly relevant to evaluate the applicability and robustness of the tool. Although GKN and SAAB share a commitment to advancing circularity, they differ in organisational structure and operational focus, offering a broader perspective for testing. The testing process included three workshops involving testers from various departments across both case companies, ensuring diverse insights from functions spanning the entire value chain.

To evaluate the effectiveness of the tool, the authors conducted tests in individual and group settings. This dual approach allowed for a comparative analysis of user interaction, feedback quality, and overall usability in different contexts. Participants in each setting were asked to perform the same tasks using the tool, and their experiences were documented through structured feedback forms and observations. The results of these tests, along with user feedback, were analysed to determine which testing method, individual or group, provides more comprehensive and reliable insights.

In the first phase, a selected group of participants from one of the case companies was invited to participate in individual self-assessments. Each participant completed the assessment independently, allowing them to provide personal insights and perspectives.

The second phase shifted to a collaborative approach, where the same participants who had completed individual self-assessments were invited to perform the assessment again as a group. This group setting fosters discussion among participants and allows them to share ideas and insights while evaluating the perspectives of others.

The third phase resembled the previous group assessment format, but included participants from the next case company. This session proved to be a valuable opportunity for comparative analysis, as it allowed participants from another leading aerospace organisation to interact with the **ENGREEN CRA tool** in a similar collaborative manner. Feedback was collected in the same way, encompassing the overall validation process with diverse perspectives from participants at both GKN Aerospace and SAAB AB.

Those workshops to test the **ENGREEN CRA tool** were organised according to a structured agenda. Individual and group tests were conducted through separate online meetings. In addition, the second and third workshops for the group tests took place in two distinct sessions after the individual tests. Before starting the assessment in the workshop, the authors provided an overview of the tool and outlined the testing procedures. Participants were encouraged to ask questions and seek clarification throughout the testing process, while the authors kept track of the time, discussions, and observed behaviour patterns. After the test, the assessment data was collected.

In order to gather valuable feedback from participants of the workshop, the authors prepared two survey forms: one tailored for individual tests and the other for group assessments. These surveys were designed using the user-friendly Google survey format, which facilitated easy navigation and response collection. Refer to the individual survey form in the Appendix E and the group survey form in the Appendix G. Once the tests were completed, the authors shared the survey links with the participants, encouraging them to respond thoughtfully to the questions provided. In particular, even in the group test setting, each participant was required to complete the survey on an individual basis, ensuring that all feedback was personal and reflective of their unique experiences during the workshop. After both tool testing and a survey, participants were given an open forum to provide their feedback on the experience, suggestions, and ask questions to the authors. Individual test feedback is detailed in the Appendix F, and group test feedback is included in the Appendix H.

4

Results

This chapter presents the key results of the study, including the results of the literature review, the tool development process, feedback gathered from expert interviews, and the findings from tool testing. Together, these results demonstrate how the tool was shaped, validated, and applied, highlighting its relevance and potential impact on evaluating circularity readiness in the aerospace value chain.

4.1 Literature Findings for Tool Scope

A review of the relevant literature, using keywords such as "circular economy," "circularity assessment," "product value chain," and "circularity in aerospace," has revealed several significant insights regarding the concept of circular economy, the readiness of the value chain for circularity, and the importance of conducting readiness assessments including the definitions. Those were consumed during conceptual framework development of the new tool, to identify the dimensions and elements from the existing tools, to formulate the questions, and to develop the user interfaces. A systematic analysis of existing tools has highlighted variations in their scope of assessment, types of output, interface designs, and primary objectives. In addition, a comprehensive evaluation of six selected tools has identified key dimensions and elements that could inform the development and scope of new circularity assessment tools.

The general distribution of the attributes of the tools is shown in Figure 4.1. The following Table 4.1 highlights the set of scope options available to develop circularity assessment tools. With the context and application area of the new tool, the key entities considered in the development of the new tool are in bold.

In summary, the new tool with the objective of assessing circularity readiness (CE maturity assessment) for the level of value chain with both self & group assessment capability using the Excel interface to give both quantitative & qualitative output.

Tool Name and Reference	Assessment method				Level of circularity					Objective Category						Output			Interface		
	Self Assessment	Group Assessment	External benchmarking	External Assessment	Product	Company	Industry	Region	Value chain	Business Strategy & Circular Economy Implementation	Circular Economy Maturity Assessment	Circular Product Design & Development	Circular Value Chain & Resource Management	Circularity Performance Measurement,	Industry-Specific Circularity Assessment	Quantitative	Qualitative	Quantitative& Qualitative	Web-base	Excel	Canvas
CD-Tool (Dagilien˙e et al., 2024)	X				X						X						X		X		
CE indicator prototype (CEIP) (Cayzer et al., 2017)	X				X						X							X		X	
Checklist for Life Cycle Design Strategies Pursuit Evaluation (ICSxToolkit) (LeNSlab Polimi team, 2024)	X				X						X							X		X	
Circular Design Rules (CDR) (Institute of Design Research Vienna, 2023)	X				X						X					X			X		
Circular Economy Toolkit (CET) (Cambridge UK, 2013)	X	X			X						X						X		X		
Circular Pathfinder (IDEAL&CO Explore & ResCoM project, 2017)	X				X						X						X		X		
Circular Product Readiness (Boorsma et al., 2022)	X	X			X						X					X				X	
Circular Transition Indicators (CTI) (WBCSD, 2023, 2024)	X					X								X		X			X		
Circularity Assessment Tool V.4 (CIRCit NORDEN, 2020)	X	X			X						X					X				X	
Circularity Calculator (IDEAL&CO Explore, 2022)	X				X						X					X			X		
Circularity Index (Indeed, 2024a)	X		X			X		X							X		X				X
Circularity Indicators Advisor (CIA) (Université Paris - Saclay, 2019)	X				X	X								X				X		X	
Circularity Potential Indicator (CPI) (LGI Circular Economy & Université Paris Saclay, 2018)	X				X									X		X			X		
Circularity Toolset for Benchmarking (Sekijima, Flipsen, Ritzen, Kamran, & Bakker, 2024)	X		X		X									X				X			X
Circulytics 2.0 (Ellen MacArthur Foundation, 2020)	X					X	X							X				X	X		
Cradle to Cradle Certified - Version 4.1 (Cradle to Cradle Products Innovation Institute, 2024)	X				X					X							X		X		
Current State Overview (EcoDesign Circle, 2022)	X					X								X			X				X
Ecodesign Assessment Product (Eco Design Circle, 2022a)	X		X		X					X						X					X
Ecodesign Audit (Eco Design Circle, 2022b)				X	X							X				X					X
Ganbatte - Circularity Assessment Tool (Ganbatte, 2025)	X				X	X								X				X	X		
GREen TArgets (GRETA) (SUPSI & CircThread project, 2024)	X				X	X									X	X			X		
ISO59020 - Measuring and assessing circularity performance (Hans Kröder, 2024)				X	X	X								X				X	X		
Making the Transition to a Circular Economy (MATChE) (Pigosso & McAloone, 2021)	X	X	X			X					X							X	X		
Material Circularity Indicator (MCI) (Ellen MacArthur Foundation, 2015)	X				X	X								X		X				X	
Product & Actant Journey (Eco Design Circle, 2022c)	X	X				X			X				X				X				X
Self-Check Circular Readiness Level (CCPE, 2025)	X				X							X						X	X		
ready2LOOP (DTU researchers, 2025)	X	X	X			X			X				X					X	X		
CircularStart (Prospektiker et al., 2021)	X				X	X				X								X		X	
Compass Circular Economy (Circular Economy Forum Austria et al., 2023)	X				X	X					X							X	X		
circular assessment of suppliers (CAoS) (Corsini et al., 2024)	X					X			X				X					X		X	

Figure 4.1: Tools Attributes - Matrix

Table 4.1: Key Factors Considered from Circularity Assessment Tools

Attributes	Entities
Assessment method	**Self Assessment, Group Assessment**, External benchmarking, External Assessment
Level of circularity	Product, Company, Industry, Region, **Value chain**
Objective Category	Business Strategy & Circular Economy Implementation, **Circular Economy Maturity Assessment**, Circular Product Design & Development, Circular Value Chain & Resource Management, Circularity Performance Measurement, Industry-Specific Circularity Assessment
Output	Quantitative, Qualitative, **Quantitative & Qualitative**
Interface	Web-base, **Excel**, Canvas

4.2 Conceptual Framework

The final framework was generated from the development and application of the **ENGREE CRA tool**. It was structured around key components: categorisation of dimensions and elements, refined through stakeholder engagement, supported by a scoring system, and alignment of dimensions' priority levels with a weight system. This approach ensures a comprehensive assessment and facilitates informed decision-making in the relevant context.

4.2.1 Dimensions

The dimensions identified from the literature review in Section 2, the analysis of the existing tools in Appendix B and the initial interviews with the GKN experts in Appendix C were integrated into the assessment tool. This tool embodies the fundamental principles drawn from the existing literature and incorporates new insights that capture the dynamic aspects of the CE in aerospace. The objective was to develop a comprehensive framework that is both practical and relevant, empowering stakeholders in the aerospace industry to effectively measure and enhance their circularity initiatives.

The following list shows the dimensions identified in the new tool.

1. **Organisation** – Examines company culture, leadership commitment, governance structures, skills, resources, and internal collaboration necessary to drive circular practices.
2. **Business Model & Strategies** – Assesses how well the company's business model and strategic initiatives integrate circular principles, such as circular value propositions and partnerships.

3. **Product & Service Innovation** – Measures the company's ability to design and innovate products/services that are modular, durable, reusable, repairable or recyclable.
4. **Production** – Evaluates how circularity is embedded in production processes, including resource efficiency, waste minimisation, and sustainable manufacturing practices.
5. **Supply Chain & Procurement** – Assesses supply chain management and procurement strategies for circularity, focussing on supplier collaboration and circular material flows.
6. **Customers, Support & Maintenance** – Reviews company approaches to customer engagement, including maintenance, repair, overhaul, education and circular service provision.
7. **Reverse Logistics & End-of-Life Strategies** – Evaluates processes and infrastructure for product return, reverse logistics, refurbishment, recycling, re-manufacturing and disposal.
8. **Technology & Data** – Assesses implementation and maturity of enabling technologies (e.g., IoT, AI, blockchain) and data management supporting circular economy strategies.
9. **Regulatory & Compliance Readiness** – Measures preparedness and responsiveness to regulatory changes, compliance standards, sustainability, and circular economy certifications.
10. **Performance Measurement** – Examines the establishment of metrics, indicators, and reporting frameworks to track and improve circularity performance.

The first three dimensions, 1 to 3, are covered in most circular assessment tools and have been recognised as **Enablers** for any organisation looking to implement circular practices (DTU researchers, 2025; Mendoza & Pigosso, 2023; Pigosso & McAloone, 2021). Enablers represent fundamental areas that every organisation should consider when transitioning to a CE. These enablers are commonly recognised in existing self-readiness assessment tools in the Appendix A. The other 7 have been identified as **Implementers** as explained in Section 2.4.3 of the literature review.

Although technology is often seen as an enabler in general circular assessments, in this context, it specifically refers to the actual implementation and deployment of digital systems that facilitate the execution of circular activities. Modgil et al. (2020) described technologies not only as support systems, but also as active drivers of circular initiatives. similarly, Saidani et al. (2019) emphasise that digital tools should not be treated only as strategic inputs but rather as practical mechanisms for monitoring, optimising and closing loops.

While product & service innovation is often seen as an implementer in various circular assessment frameworks, this tool regards it as an enabler. This perspective emphasises design intent, innovation mindset, and capability building rather than focussing solely on the outcome of circularity. Chirumalla et al. (2024) has underscored the importance of design and development as a critical strategic lever for readiness, rather than mere implementation. In addition, Camacho-Otero and Ordoñez (2017) argue that design and innovation strategies are among the most essential enablers of the CE, as they play a crucial role in determining long-term value creation.

Meanwhile, dimensions 4 to 8 pertain primarily to the entire value chain. To keep the possibility of self-assessment and reduce the collaboration & time requirement to complete the assessment, users need to complete both the upstream (suppliers' side) and the downstream (customers' side). The questions have been developed to reduce user stress while accurately capturing the true status of both sides. However, the tool can be shared among value chain partners as it supports all entities within the value chain, allowing manufacturers to gather input from their partners for a more comprehensive assessment of the value chain.

Dimensions 9 and 10, based on insights from the GKN sustainable team and literature such as (Esteban-Amaro et al., 2025), emphasise the necessity of evaluating factors specific to the aerospace sector. Regulatory compliance is particularly critical in this industry due to stringent safety controls. The purpose of the tool is to assess how well regulations and compliance standards align with the principles of circularity. Furthermore, performance measurement is essential; it is vital to consider how effectively circularity principles are integrated when calculating performance and Key Performance Indicators (KPIs) within an organisation. Antwi-Afari et al. (2021) has underscored the need for a performance assessment in the tool to optimise the principles of CE within organisations.

4.2.2 Elements

The elements serve as key performance measurements within the circular readiness assessment. Following an extensive review of the literature in Section 2 and an evaluation of existing assessment methodologies and elements (see Appendices A and B), a total of 40 elements were identified that can represent the value chain.

These elements were categorised into key dimensions, detailed in Table 4.2. The dimensions can be assessed through elements using a scoring system that considers the organisation's specific maturity level and readiness to transition towards a CE. These elements have been transformed into questions that enable users to effectively assess their current state, pinpoint areas for improvement, and strategies their journey toward greater circularity within their operations and value chains.

The integration of the principles of **9R - Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Re-manufacturing, Repurpose, and Recycle** (Potting et al., 2017), is particularly significant within the dimensions of **Product & Service Innovation** and **Reverse Logistics & End-of-Life Strategies**. These elements enhance the development of a closed material loop and extend the life of the product. Furthermore, the incorporation of the 9R strategies within these domains will not

Table 4.2: Categorization of Elements under Circularity Dimensions

Dimensions	**Elements**
Organisation	Resources, Risks & Investment, Knowledge & Skills, Cross-functional Collaboration
Business Model & Strategies	Circular Business Model, Organisational Strategies, Business Value & Opportunities, New Revenue Generations, Circular Innovation and Collaboration
Product & Service Innovation	Product & Service-Systems, Design for Life Extension, Design for End-of-Life, Design for Resource Conservation, Efficient Manufacturing Design
Production	Resource/Energy Efficiency, Waste Management, Hazards Material Management
Supply Chain & Procurement	Supplier Circularity Engagement, Mutually Beneficial Relationship, Circular Procurement
Customers, Support & Maintenance	Customer Awareness, After Service, Repair, Circularity-driven Services
Reverse Logistics & End-of-Life Strategies	Reverse Logistics, Disassembling & Re-manufacturing, Materials Recycling, End-of-Life Waste Management
Technology & Data	Circular Design Technology, Smart Manufacturing, In-service Assessment, Product Longevity Solutions
Regulatory & Compliance Readiness	Regulatory Compliance, Influence on Legislation, Responsibility Delegation, Stakeholders' Circularity Compliance
Performance Measurement	KPI for Circularity, Life Cycle Assessment, Employee-Led Circular Initiatives, Material Circularity

only facilitate an evaluation of existing practices, but will also promote the adoption of circular design principles, improve resource efficiency, and promote value recovery throughout the comprehensive value chain of the organisation.

4.2.3 Stakeholder Engagement to Review Framework

The insights gained from the initial interview with the GKN sustainability team provided valuable guidance in pinpointing the most critical aspects of the aerospace industry's value chain. The interview took place during the final stages of developing the conceptual framework as the method described in Section 3.3. Following this discussion, the framework was meticulously refined and solidified to ensure its relevance and completeness in the evaluation of the value chain in the aviation industry. Two critical areas for evaluation were identified in the aerospace industry during the interview: Regulatory & Compliance Readiness and Performance Measurement. Subsequently, these areas were included in the list in Section 4.2.1. Several key assessment areas have been identified in Section 4.2.2 from the literature, and existing tools were confirmed as essential elements to evaluate the assessment tool, given that GKN has recognised the gaps and weaknesses within their organisation.

A significant identified issue was the lack of structured tracking for circularity within the organisation. The tool has included specific elements, such as Circular Design Technology, In-Service Assessment, and Product Longevity Solutions, within the Technology & Data dimension. These elements help to evaluate how new technologies can be utilised to track material traceability in the context of product circularity, allowing qualitative measurements rather than relying solely on separate quantitative analyses.

A notable identified gap is the absence of an assessment method for the end of life of the product. This gap is addressed in the dimension of Reverse Logistics & End-of-Life Strategies within the tool. It focusses on elements: Disassembly and Re-manufacturing, Materials Recycling, and End-of-Life Waste Management, aiming to promote greater transparency in dismantling and recycling processes.

The interview revealed a weakness in the way suppliers engage in circularity efforts. This underscores the necessity of incorporating a readiness scoring feature within the Supply Chain & Procurement dimension. In particular, focussing on Supplier Circularity Engagement, Mutually Beneficial Relationships, and Circular Procurement elements.

Ultimately, the focus on circularity in design was not adequately prioritised throughout the design and innovation process. Consequently, greater attention was directed in the tool towards the Product & Service Innovation dimension, specifically on Design for End-of-Life, Design for Life Extension, and Design for Resource Conservation. These strategies are intended to enable companies to proactively improve circularity through innovative design solutions.

4.2.4 Scoring System

The development of a common scoring system for 40 questions was a challenge. The Likert scale, a versatile tool frequently utilised in surveys, effectively captures attitudes and opinions. Respondents are able to indicate their level of readiness or current status on a defined Likert scale. This structured methodology yields valuable quantitative data that facilitates the analysis and comparison of responses across various elements (Demko-Rihter et al., 2023; Pigosso & McAloone, 2021). Table 4.3 presents the defined Likert scale used in this tool.

The scale 0 represents "not applicable" or "don't know", allowing users to skip the questions if they feel the question is irrelevant to their organisation or if they don't know the accurate answer. If the user chooses option 0 then that response is ex-

Table 4.3: Likert Scale to Measure Readiness Assessment Status Levels

Status Level	Score	Description
Not Applicable / Don't Know	0	Not relevant to the Organisation, or the user does not know the answer.
No Action Taken / Exploring Possibilities	1	No discussions or activities have been initiated in this area; gathering insights, understanding potential benefits, and evaluating feasibility.
Laying the Groundwork	2	Developing initial plans, setting goals, and preparing for small-scale trials.
Testing in Practice	3	Running pilot projects and experimenting with initiatives on a limited scale.
Preparing for Expansion	4	Using pilot results to define strategies for broader organisational adoption.
Scaling Up / Fully Integrated	5	Expanding initiatives organisation-wide and ensuring full integration into operations.

cluded from the calculation and will not affect the overall results. The scale ranges from 1 to 5, where 1 represents a lower level of readiness and 5 represents a higher level of readiness. The scores on the Likert scale are then averaged across the questions within each dimension to determine the level of readiness or current status in each specific area.

The Likert scale ranged from 0 to 5, with each level represented by a unique colour code to improve visual clarity for users. The colour coding was as follows: 0 is black, 1 is red, 2 is orange, 3 is yellow, 4 is green, and 5 is blue. It is essential to maintain visual consistency throughout the tool, as this helps users quickly interpret status levels and navigate the assessment process effectively.

4.2.5 Weights

The authors have carefully selected the dimensions to minimise the overlap as explained above. Weight assignment has been established as the initial step in the tool explained in this report, allowing users to adjust the weight to the dimensions based on the maturity level before the assessment. This approach helps mitigate the risk of misrepresenting the true readiness for circularity. The priority level can range from 1 to 5, as shown in Table 4.4, depending on the importance of that area for their organisation. The same colour code described in Section 4.2.4 was used to represent the priority level, which aligned with the general theme throughout the tool. This structured weighting approach ensures a balanced and context-sensitive assessment that significantly enhances the validity of the tool and its practical applicability in the CE of the aerospace industry.

Table 4.4: Weighing System

Priority Level	Weight	Description
Critical	5	Needs immediate action, blocking work, major failure, or urgent requirement.
High	4	Important but not an emergency, has a significant impact, requires attention soon.
Medium	3	Should be done but not urgent, moderate impact, planned execution.
Low	2	Nice-to-have, minor impact, can be postponed if necessary.
Optional	1	Least priority, non-essential, for future consideration only.

4.3 Tool Development

The following subsections detail the structural arrangement of the **ENGREEN CRA tool** and outline the information provided at each stage of the assessment process.

Currently, most self-assessment tools for circular readiness assessment are developed as web-based platforms. These tools feature an interactive interface, automated scoring, and dynamic dashboards. For more information on the current readiness assessment tools that were analysed, listed in Appendix A. Other options for creating assessment tools include Google Forms, Microsoft Excel, and Google Sheets. The development of a new self-assessment tool was decided using Microsoft Excel due to its simplicity, flexibility, familiarity, data security, and ease of customisation.

The authors opted to incorporate a methodology section in the tool, providing a step-by-step guide for conducting the circular readiness assessment. The first step requires the user to read and understand the procedures and the sequence of steps to follow. Refer to Figure I.1 in the Appendix I.

Another section was added to include all key terms and definitions identified using the literature review on the CE and the assessment of circular readiness. It also provides a detailed description of the dimensions that are considered when assessing the circularity readiness of value chain. See Figure I.2 in the Appendix I.

The next step was added to provide specific user information, including company name, department, and date, along with an optional entry for the user name. This information will be documented in a distinct section alongside the assessment data, allowing the organisation to reference it later for comparison purposes. The user information is depicted in Figure I.3 found in the Appendix I.

The assignment of weights to the **ENGREEN CRA tool** underwent several enhancements. Initially, a predefined table, as presented in Table 4.4 in Section 4.2.5, was available to assist users in selecting a priority level for each dimension based on their experience. However, it proved difficult to evaluate priorities by focussing only on the dimension titles. To improve this process, the authors revised it to incorporate scenario-based questions, which enhance clarity and comprehension. These questions provide examples that enable users to better grasp the significance of each dimension for their organisation.

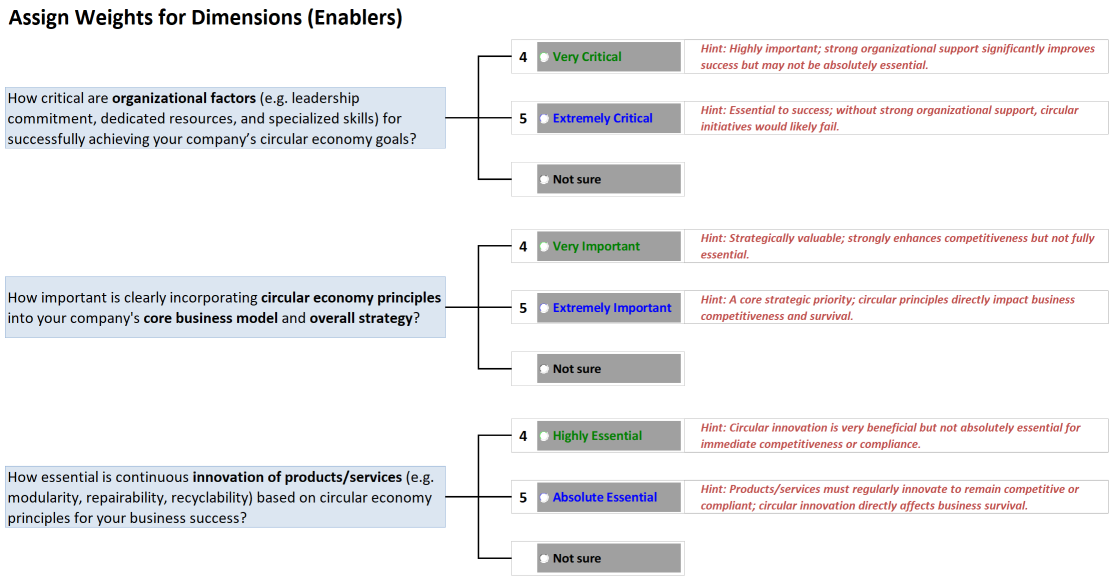

Figure 4.2: Assign weights for Enablers

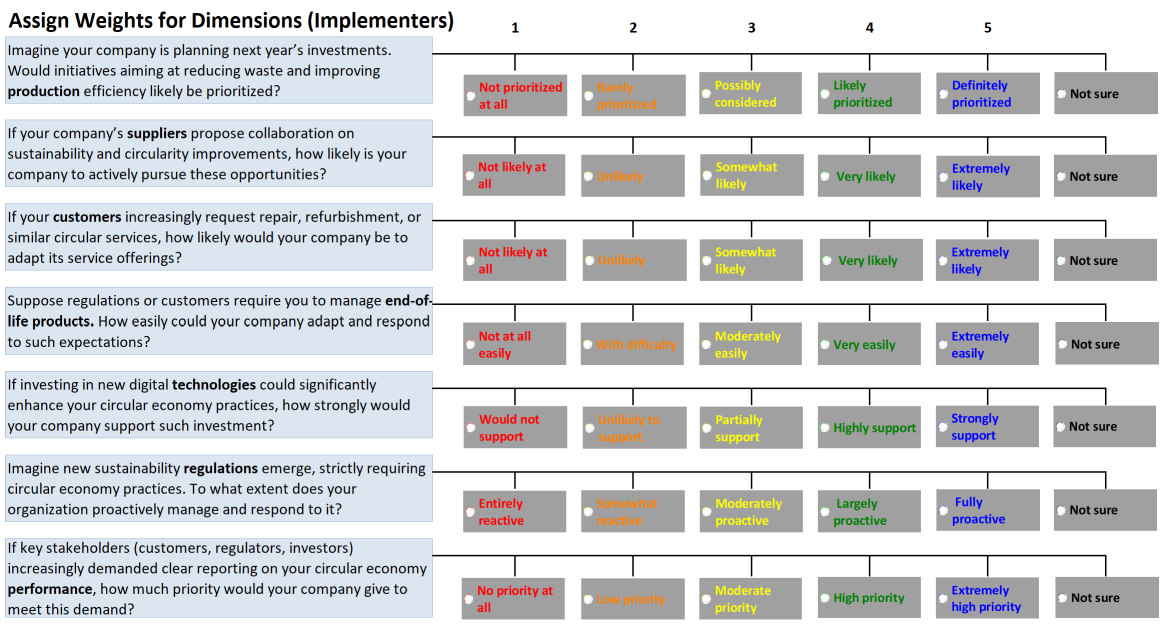

Figure 4.3: Assign weights for Implementers

Two separate tabs were added to the tool to separate Enablers and Implementers. Figure 4.2 illustrates the weight assignment method for enablers, while Figure 4.3 illustrates the weight assignment method for implementers. Initially, the tool lacked a consistent description of the Likert scale in the weight section. However, after receiving feedback from expert interviews, it was refined to ensure uniform descriptions of the Likert scale for all questions.

A comprehensive set of questions was developed to assess the level of circular readiness and was designed to evaluate each element within the framework. The tool comprises 40 questions. For every element, a corresponding question is formulated. A total of 40 questions capture the level of readiness of the organisation in a clear and measurable way. The questions were formulated to elaborate on what each element represents, often incorporating examples for a clear understanding. This allows the user to respond accurately without hesitation, even when overly technical and lengthy statements are used.

The 40 questions are distributed differently across the 10 dimensions, depending on the number of elements considered for each dimension. Each dimension contains 3 to 5 questions. The tool's interface is organised into 10 tabs, each corresponding to a specific dimension, which enhances usability and improves navigation. The layout of the questions in the dimension "Organisation" is illustrated in Figure 4.4, demonstrating their organised arrangement within the tool. For a complete view of all tabs, refer to Figures I.6 through Figure I.15 in Appendix I. This structure provides users with a clear understanding of the differences between the dimensions and contributes to a more user-friendly assessment experience.

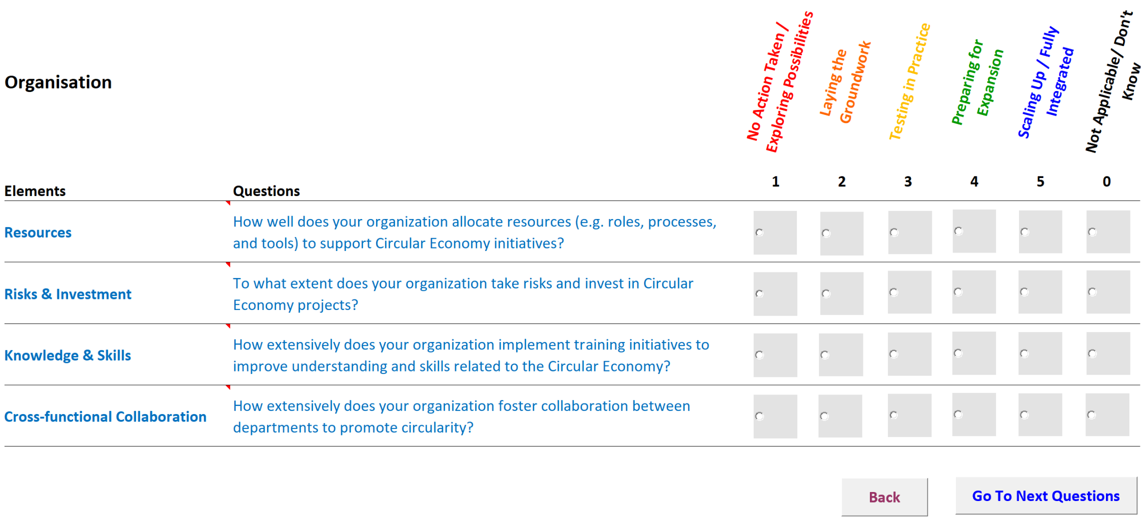

Figure 4.4: Questions - Organisation

The tool includes a dedicated tab to calculate the readiness score or the average current status. The **Status Score** is determined by calculating the average of all valid responses (on a Likert scale from 1 to 5) for the questions within that dimension. Responses marked as 0 are excluded from the calculation to ensure precision. To calculate the total score, the status score of each dimension is multiplied by its assigned weight, which ranges from 1 to 5. The following figure 4.5 illustrates the calculation of the status score.

- Q = total number of questions in a given dimension (typically 3–5),
- Si = status level selected by the user for question i, where i = 1, 2, ..., Q,
- n = number of valid responses where Si ≠ 0 (i.e., non-zero scores).

Then, the Status score R for a dimension is calculated as:

$$R = \frac{\sum_{i=1}^{Q} S_i \text{ (where } S_i \neq 0)}{n}$$

Figure 4.5: Status score

The total readiness score is then determined by summing the status scores of all dimensions and dividing that sum by the total of weights assigned to all dimensions. The final **Total Readiness Score** is expressed as a percentage, providing a comprehensive assessment of overall circular readiness considering both performance and the relative importance of each dimension. See Figure 4.6.

- D = total number of dimensions
- R_j = Status score for dimension j
- W_j = weight assigned to dimension j

Then, the total score for dimension j is:

$$T_j = R_j \times W_j$$

The Total Readiness Score (TRS) is calculated as:

$$TRS = \left(\frac{\sum_{j=1}^{D} T_j}{\sum_{j=1}^{D} W_j} \right) \times 100$$

Figure 4.6: Total readiness score

The dashboard was designed to provide a consolidated view of all assessment results for the user. It includes a pie chart that shows readiness and priority levels in different dimensions, offering a clear picture of the performance distribution. The total readiness score is prominently displayed at the top of the dashboard for quick reference.

The dashboard space was designed to fit the size of the computer window, allowing users to view it without scrolling. However, this made it challenging to display the status details and recommendations for all dimensions simultaneously. To address this, a drop-down menu was included, allowing users to select a specific dimension. The corresponding readiness status and recommendations are then displayed on the right side for the selected dimension. The interface maintains a clear and user-friendly layout. Refer to Figure 4.7 for a sample test result displayed on the dashboard.

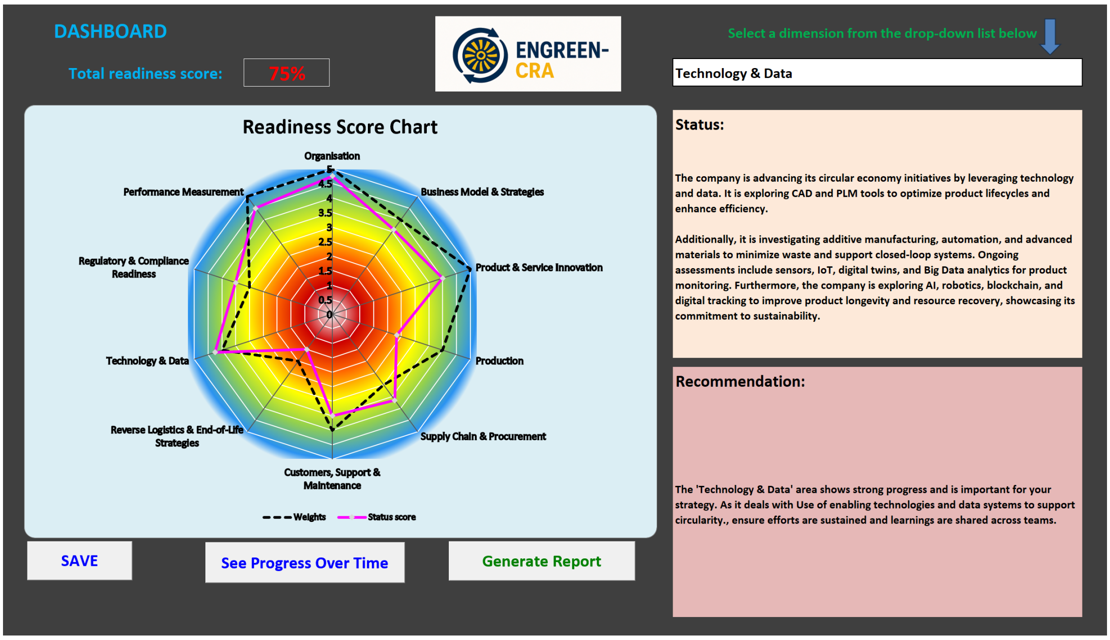

Figure 4.7: Sample test results in Dash board

Users can save the assessment data by clicking the "SAVE" button, "See Progress Over Time," those links to the next tab that "Progress Over Time". In addition, the tool includes a report generation feature that consolidates all results, including the questions and the corresponding user responses, current status, and recommendations for all dimensions. This generates a comprehensive and exportable report for further analysis or documentation purposes.

The tool includes a separate tab called "Progress Over Time" designed to save assessment data. Users can access historical data and comparisons through this tab. See Figure I.17 in Appendix I for the progress over time tab in the tool. The feature enables organisations to review past assessment results for internal analysis and strategic planning. In addition, this tab provides graphical representations for each dimension, allowing organisations to track performance over time, identify trends, and spot areas of improvement and emerging gaps.

4.4 Expert Interviews for Validation

The authors conducted four interviews with industry and academic experts to validate the **ENGREEN CRA Tool** with the theoretical framework of the tool and ensure complete coverage of the principles of CE. The interview process was conducted as described in Section 3.4. This process provided valuable information for improving the tool's structure, content, and practical features. In addition, the feedback from the experts contributed to a clear formulation of the questions, better navigation guidance, and the inclusion of supporting elements, such as definitions and examples. This process improved the usability of the tool, ensuring that it can also be used effectively by other organisations. See more details of the expert interview in the Appendix D. The Table 4.5 below shows key highlights from interviews.

Table 4.5: Key Highlights from Expert Interviews

Expert	Key Highlights
Expert 1 - PHD, Sustainable specialist	• Add hint text to clarify weight allocation • Included examples and pop-up notes for a question under the "Organisation" dimension • Rephrase “Regulatory & Compliance” question in weight allocation to assess proactivity • Introduce a guide for the dashboard drop-down list
Expert 2 - Postdoctoral researcher, Sustainable product development	• Apply a unified Likert scale across all dimensions, align questions according to the Likert scale • Add a feedback question in the survey to test the enablers' weighting flexibility
Expert 3 - Professor, Sustainable product development	• Clarify the tool use for both internal and external stakeholders' evaluation • Emphasise inclusion of all 9R strategies • Add examples when multiple factors were considered within a single weight • Received positive feedback on colour scheme and usability
Expert 4 - Associate professor, Sustainable digitalised production	• Add simple pop-up definitions for all 40 elements • Positive feedback on clarity, and consistency • Confirmed the tool is as effective and user-friendly

Drawing on insights from expert interviews, the tool underwent significant enhancements aimed at improving clarity, usability, and consistency. Key improvements included the incorporation of hint texts and examples to better explain weight allocation and address specific questions, particularly within "Organisation" and "Regulatory & Compliance" dimensions. A guide was added to highlight the availability of a drop-down list within the dashboard. To ensure uniformity, a standardised Likert scale was implemented across all dimensions, accompanied by a feedback question to evaluate the flexibility of enabler weighting. The scope of the tool was broadened to accommodate both internal and external stakeholder assessments. The tool effectively addresses all 9R principles across various dimensions and elements. In addition, pop-up notes containing simple definitions were introduced for all 40 elements to improve user understanding. These enhancements, combined with positive feedback regarding the tool interface and structure, have collectively reinforced its reliability and improved the user experience.

4.5 Tool Testing

The applicability and effectiveness of the **ENGREEN CRA tool** were evaluated through a multistage testing process in collaboration with two leading aerospace companies, GKN Aerospace and SAAB. These companies were chosen as case studies because of their strong commitment to circularity and their significance in the aerospace manufacturing sector, enabling them to offer valuable information on the readiness for circularity. The tool was tested in three distinct stages: first, through individual assessments with participants from one of the case companies; followed by two group assessments, one involving the same participants collaborating as a group, and the other involving a separate group from a second case company. These stages were designed to collect both assessment data and qualitative feedback, allowing an evaluation of the tool's clarity, relevance, and capacity to accurately reflect real-world circularity practices across various departments and organisational contexts. For the first case company, individual tests were conducted with three participants from the sustainability team. The group testing included the same three members of the sustainability team, along with a LCA specialist and a procurement representative. For the second case company, the group testing involved three participants: one from the Global Environmental Team, another with a similar role focussing on sustainability challenges, and a third from the same team specialising in eco-design.

4.5.1 Individual Tool Testing

The individual tool testing phase was conducted with the first case company to explore how the **ENGREEN CRA tool** performs when used independently by participants within a case company setting. This phase aimed to evaluate how well the tool supports users in assessing circular readiness without group discussion or facilitation. It served as an initial evaluation of the clarity, usability, and ability of the tool to guide users through a self-assessment of the circular practices of their organisation.

4.5.1.1 Data Assessment

The **ENGREEN CRA tool** was independently evaluated by three participants (Individual T1, T2, and T3) from the first case company. Each participant assigned weights and status scores across the tool's ten dimensions, reflecting their assessment of the importance and current state of circularity within their specific areas of expertise. The individual spent 18, 22 and 29 minutes completing the assessment. This process provided valuable insight into internal alignment and variations in perceptions throughout the organisation. For individual results, refer to Figures 4.8, 4.9, and 4.10 below.

Based on the results, the dimensions, Organisation, Business Model & Strategies, and Product & Service Innovation received the higher weights, since the tool does not allow scores below 4. Production emerged with a consistently higher score (greater than 4) in all testers, indicating well-established practices in operational efficiency.

In addition, Customers, Support & Maintenance also received higher scores, reflecting strong service capabilities and customer engagement. Conversely, Reverse Logistics & End-of-Life Strategies received the lowest scores from all testers, highlighting it as a significant blind spot within the organisation. Supply Chain & Procurement also emerged as a concern, with all three testers reporting low maturity despite recognising its relevance. However, Product & Service Innovation saw the greatest divergence in status scores (2.0 to 4.5), possibly reflecting the varying levels of involvement of the testers in design and development roles.

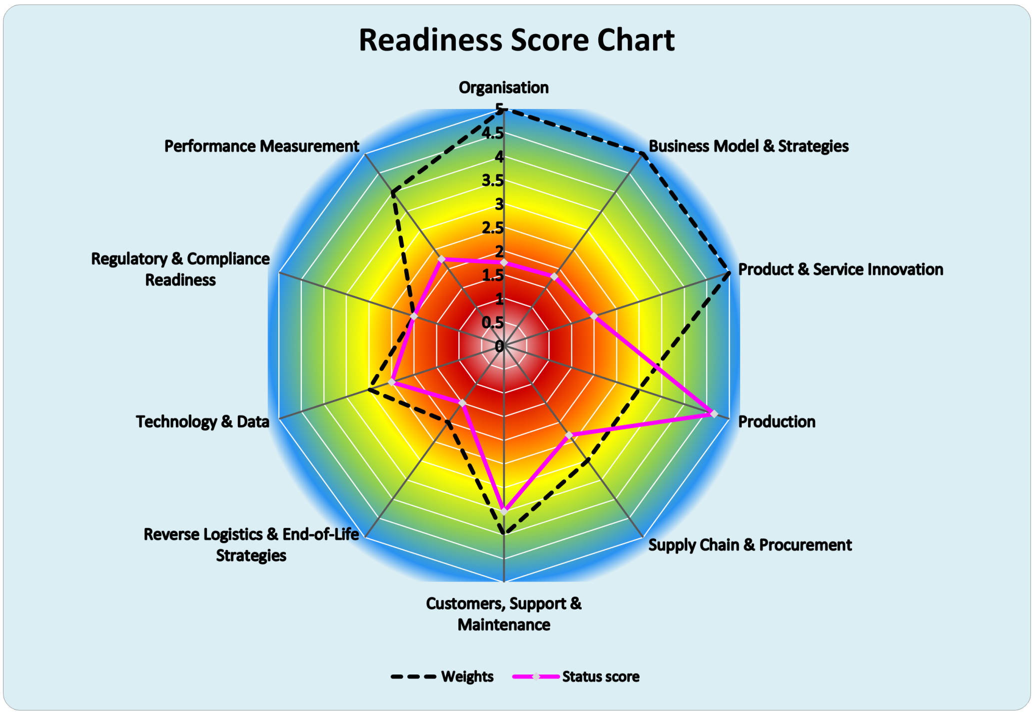

Figure 4.8: Readiness score chart - Ind-T1

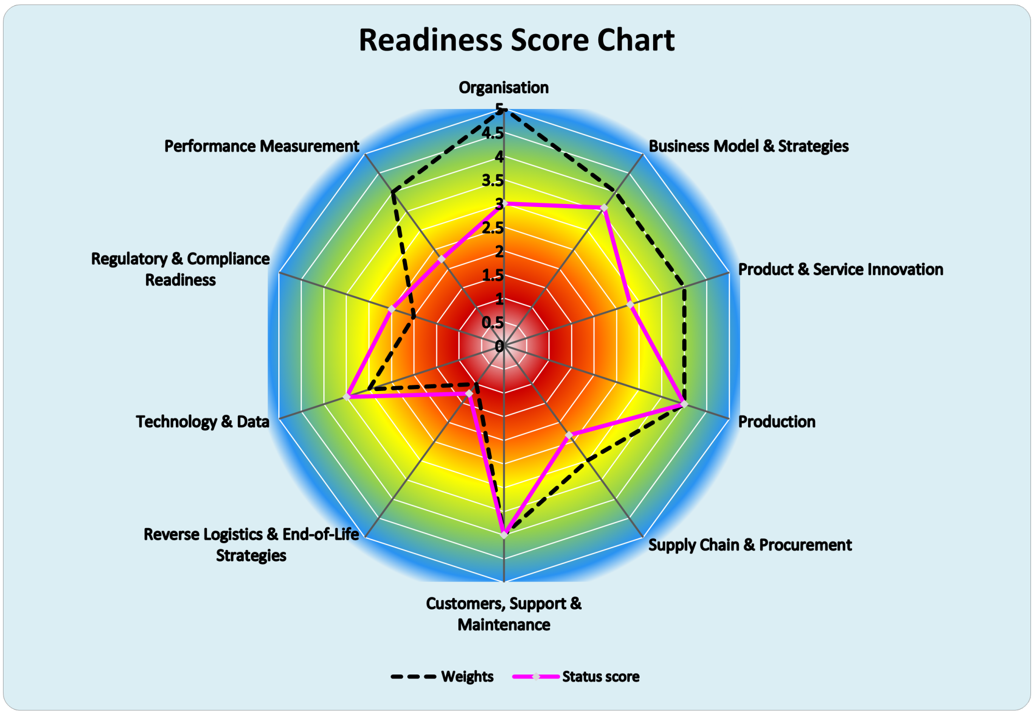

Figure 4.9: Readiness score chart - Ind-T2

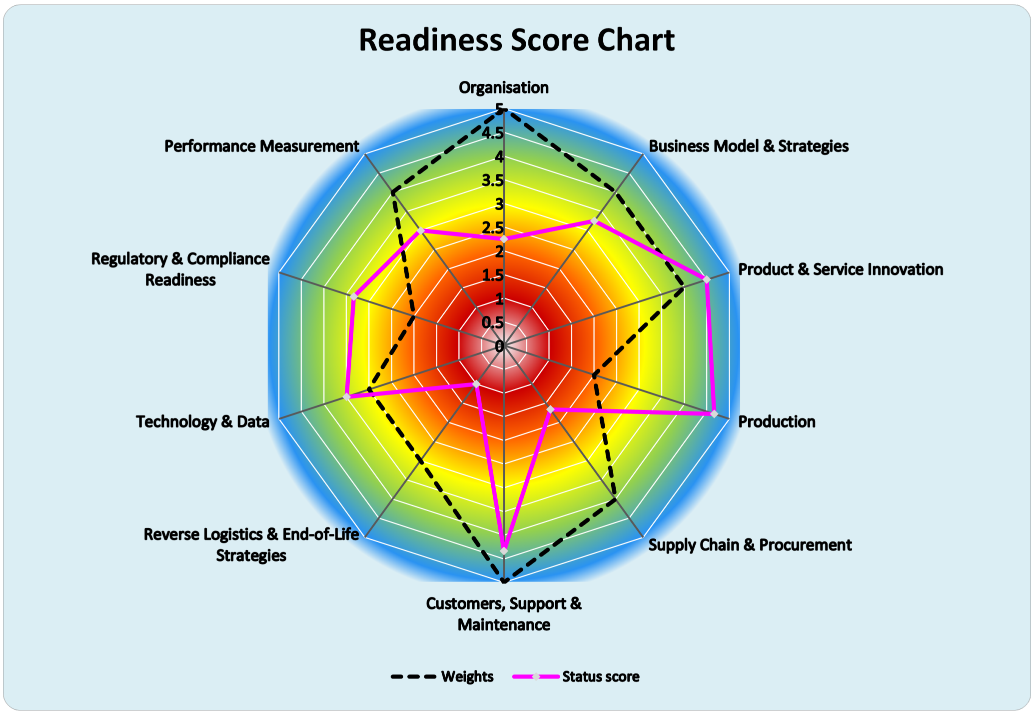

Figure 4.10: Readiness score chart - Ind-T3

4.5.1.2 Individual Post Assessment Feedback

The individual post-assessment feedback offered qualitative insights to evaluate the applicability, usability, and alignment of the developed **ENGREEN CRA Tool**.

This feedback was instrumental in exploring how such an assessment can foster collaboration and enhance circularity performance throughout the aerospace value chain.

Usability and Practicality: All three testers completed the tool in 18 to 29 minutes, demonstrating its practical feasibility. Feedback highlighted that the tool's structure and flow were intuitive and well-arranged, confirming its relevance for real-world applications.

The weighted scoring system (Weights1 and Weights2) helped users prioritise topics according to business relevance. However, the testers recommended enhancing the user's flexibility in setting weights and including justification prompts to reduce ambiguity and support internal traceability.

Relevance and Contextual Alignment: The tool was regarded highly relevant to circularity issues within the aerospace sector, particularly due to its comprehensive but focused set of questions. The testers valued its coverage of technical, organisational, and supply chain aspects of circularity. However, feedback indicated the need for context sensitivity, such as distinguishing between product domains (e.g., commercial vs. defence) and addressing potential biases in responses, especially in areas concerning regulatory compliance, where a score of "5" may reflect more on perception than on actual performance.

Identifying Gaps and Shared Priorities: The tool helps testers identify overlooked or underdeveloped areas, fostering dialogue between different functions. By scoring and prioritising various aspects of circularity, the tool highlights common pain points and areas for improvement that can benefit from collaborative action.

Enabling Strategic Alignment: A key recommendation is to track previous assessments and provide profile-based feedback. This would help organisations benchmark progress and align internal teams around consistent sustainability goals and metrics.

Providing a Structured Framework for Action: The tool provides a structured framework for integrating circularity principles into business practices. Despite some feedback on the depth of the recommendations, it helps organisations formalise their circularity efforts, which often lack operational frameworks. This clear pathway helps companies adopt circular practices systematically and advance environmental responsibility.

4.5.2 Group Tool Testing

The group tool testing consisted of two distinct sessions with representatives from both case companies. During each session, participants engaged in discussions to collectively agree on responses to the assessment, fostering a shared understanding of the organisation's readiness for circular practices. This collaborative setting facilitated cross-functional dialogue and encouraged cooperative thinking, often leading to more balanced and consensus-driven evaluations. The group testing yielded insights not only into the tool's effectiveness in promoting organisational reflection but also into how group dynamics can shape assessment outcomes. The findings of these sessions will be compared and analysed in the subsequent sections to identify consistent patterns, divergences, and perceived levels readiness of circularity in organisations value chain.

4.5.2.1 Data Assessment

The group test was conducted in a collaborative session with 3 to 5 participants from different departments of the case companies. One participant operated the **ENGREEN CRA tool**, entering responses while actively gathering input and opinions from the rest of the groups. Whenever differing opinions emerged, participants engaged in discussions to align their perspectives and reach a shared understanding before finalising each response. This deliberative process encouraged reflective thinking and cross-functional dialogue, which contributed to a more balanced and representative assessment. As a result of this interactive approach, each group assessment took approximately 50 to 60 minutes to complete.

The readiness score for Group-T1 is illustrated in Figure 4.11.

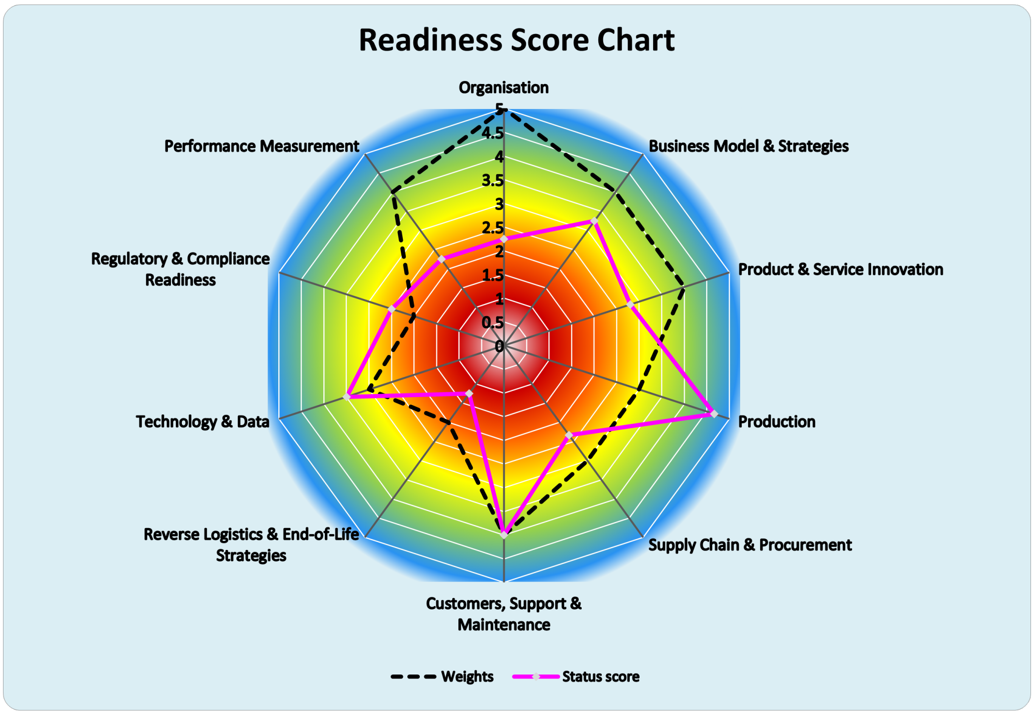

Figure 4.11: Readiness score chart - Grp-T1

To better understand the organisation's readiness in context, the individual assessment data from the first case company is compared with the corresponding group assessment results. Figures 4.12 illustrate a comparison of priority levels between the results of individual and group tests of first case company.

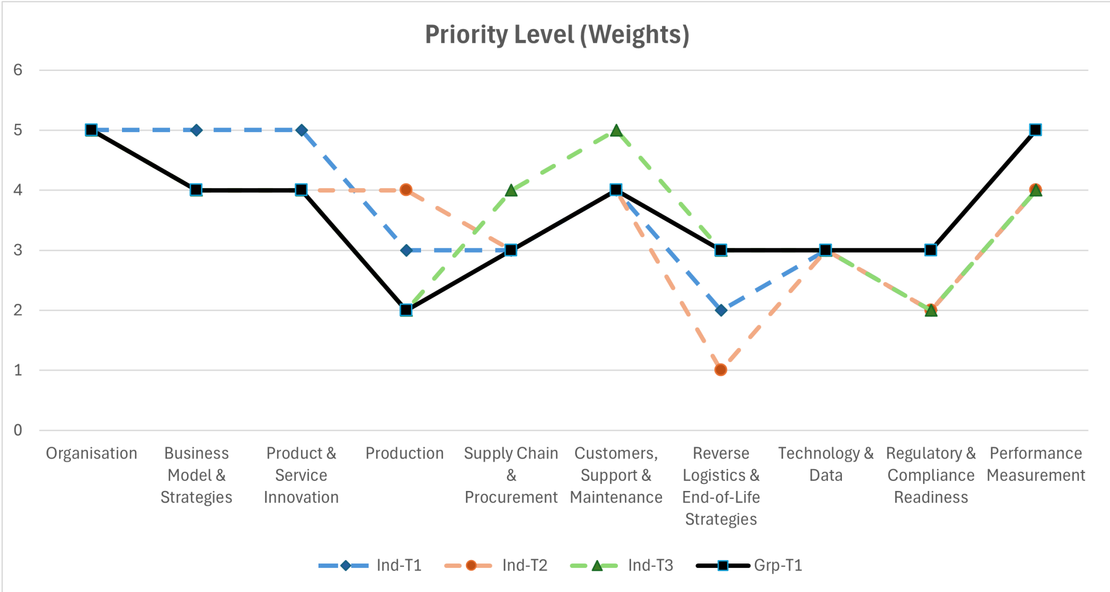

Figure 4.12: Priority level (Weights) values comparison - Individual vs Group-T1 test

Figure 4.13 illustrates a comparison of the current status score for the individuals vs. the group of the first case company.

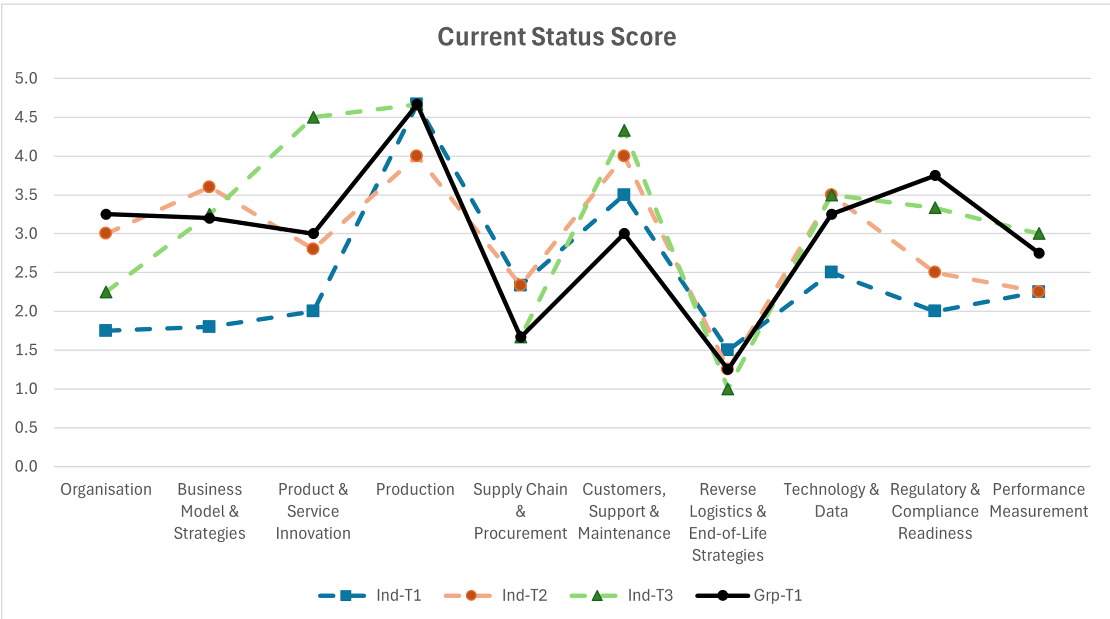

Figure 4.13: Current status values comparison - Individual vs Group-T1 test

In particular, apart from enablers, Reverse Logistics & End-of-Life Strategies and Production exhibit a significant divergence in priority levels when comparing individual responses to group outcome. This indicates possible variations in participants or knowledge gaps. In contrast, Technology & Data and Regulatory & Compliance Readiness demonstrate moderate alignment, suggesting that during group discussions, participants have reconciled their views or reached a common understanding.

The Production dimension received consistently high scores from both individuals and the group, indicating strong circularity implementation in the specific area and a strong understanding and awareness of this area. The group and individual scores were lower in Supply Chain & Procurement and Reverse Logistics & End-of-Life Strategies, indicating weaknesses in these areas within the organisation. In addition, Product & Service Innovation and Reverse Logistics & End-of-Life Strategies in the group provide a balanced perspective, resulting from collective discussions that mitigated extreme views. The varied scores from groups and individuals on Customer Support & Maintenance and Regulatory & Compliance Readiness indicate the necessity of a cross-functional team that covers the entire value chain for this assessment. These results suggest that testing the tool in a group setting is more effective, leading the authors to recommend group-based evaluations for future assessments.

The second case company also followed a similar process, but due to practical limitation, only a group test was conducted with the second case company. Figure 4.14 displays the readiness score for Group-T2.

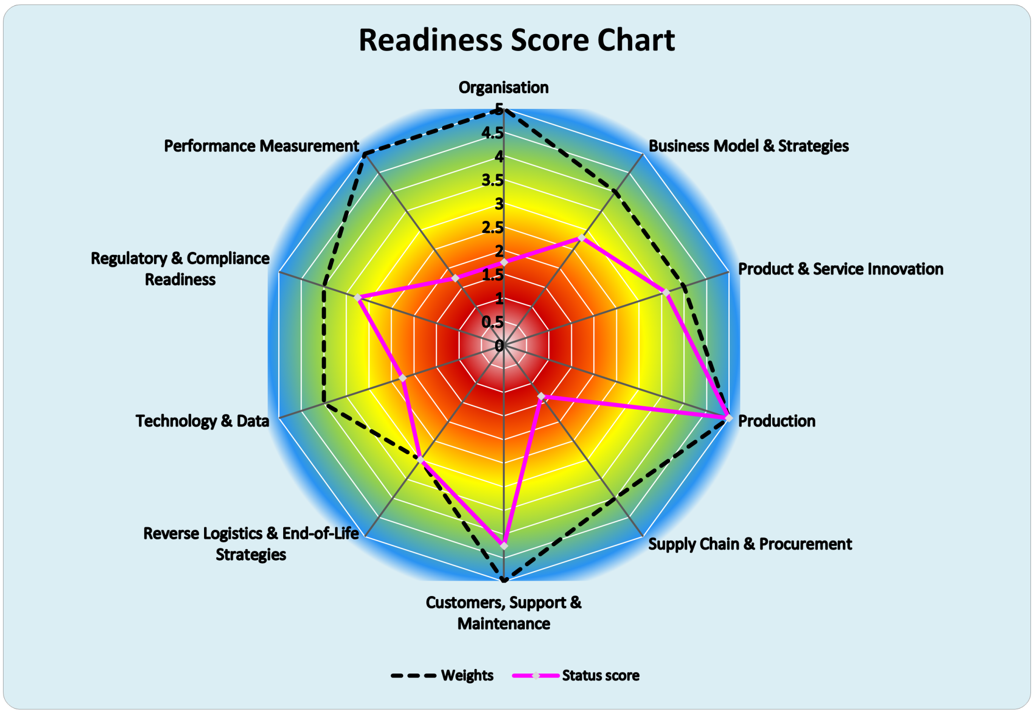

Figure 4.14: Readiness score chart - Grp-T2

Figure 4.15 illustrates the comparison of the results between Group-T1 and Group-T2. Here Group-T1 corresponds to the company in the first case, and Group-T2 corresponds to the company in the second case.

In Group-T1, the Organisation dimension received a significantly higher rating, with a status score of 3.3, compared to Group-T2, which rated it at 1.8. A similar trend is observed in the Performance Measurement category, where Group-T1 scored 2.8, while Group-T2 scored only 1.8. This discrepancy is likely attributed to structural differences between the two companies; the first case company appears to have a clearer delegation of circular responsibilities and more advanced internal tracking mechanisms for circular KPIs. In contrast, the second case company may still be in the early stages of incorporating circular principles into its management and performance evaluation systems.

Group-T2 demonstrated a significantly higher status score in Reverse Logistics & End-of-Life Strategies (3.0) compared to Group-T1 (1.3), indicating that the second case company has made more substantial progress in end-of-life planning, recovery processes, or recycling initiatives. This disparity may reflect variations in product lifecycles specific to the companies or a greater emphasis on extended producer responsibility. In contrast, both compounds in the case showed an average position in Regulatory & Compliance Readiness, with scores of 3.8 versus 3.3. This could be attributed to a more centralised or standardised approach to managing regulatory obligations across multiple regions. These differences highlight how specific legal exposures and priorities related to product recovery can influence company readiness levels.

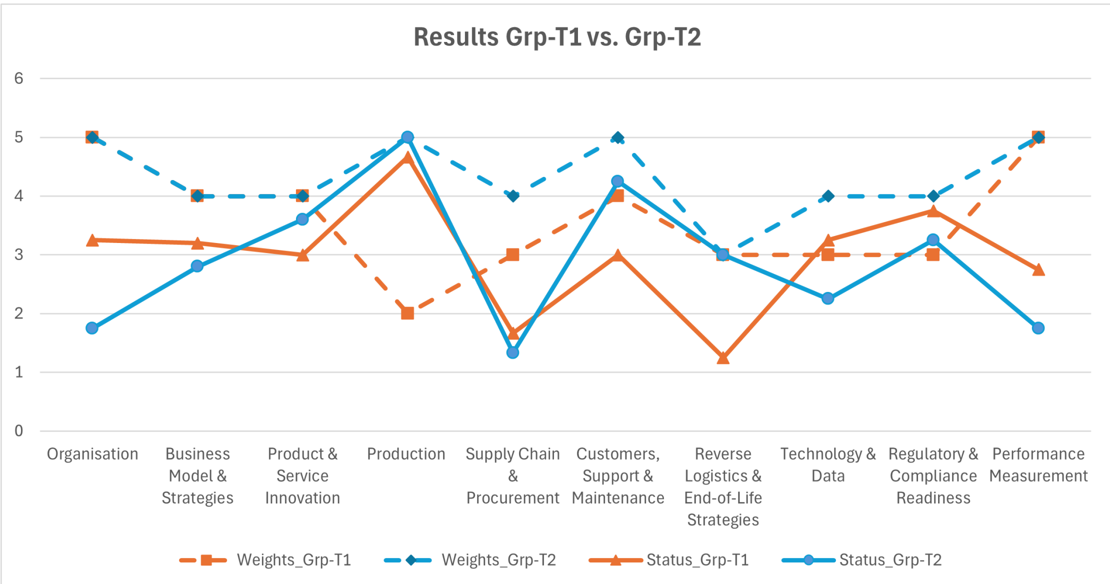

Figure 4.15: Results Grp-T1 vs. Grp-T2

Both companies demonstrated strong performance in the Production dimension, with high status scores of 4.7 and 5.0, indicating a well-established integration of circular practices in their manufacturing processes. This suggests that production efficiency and resource optimisation are common strengths across the aerospace sector. Conversely, Supply Chain & Procurement emerged as a shared weakness, receiving the lowest scores (1.7 and 1.3) in both cases. This indicates that involving suppliers in circularity and ensuring traceability remains a challenge. In the Customer Support & Maintenance dimension, a notable disparity was observed: the first case Company scored 3.0, while the second case Company rated it significantly higher at 4.3. This difference may reflect the second-case company's stronger focus on after-sales services, repair, or long-term customer engagement. In Technology & Data, the first case company slightly outperformed the second case company (3.3 vs. 2.3), possibly due to more advanced digital tools or better systems for circular data tracking and analysis. These variations underscore how different organisational strategies and technological investments shape circular maturity in all functions of the value chain.

4.5.2.2 Group Post Assessment Feedback

The group-based tool testing yielded valuable qualitative insights regarding the applicability, usability, and alignment of the developed **ENGREEN CRA Tool**. These insights were crucial for evaluating how effectively the tool fosters cross-functional collaboration and improves circularity performance throughout the aerospace value chain.

Usability & Format: Group-T1 enthusiasts perceived the tool as intuitive, with particular praise for the dashboard, which effectively visualised gaps and encouraged meaningful discussions. It enhanced cross-functional dialogue and illuminated previously hidden practices. However, the ambiguity surrounding terms such as "exploring" vs. "developing" points to a necessity for more precise definitions.

Group-T2 appreciated the simple structure of the tool and found the weight-performance approach effective for prioritising actions. They liked the visual dashboard to identify strengths and weaknesses. However, some confusion arose due to unfamiliar terminology related to the CE, indicating a need for clearer language and possibly providing definitions before the session.

Value Chain Engagement & Collaboration: Group-T1 observed limited visibility across internal functions and the value chain. Although some reuse and repair activities existed, collaboration with suppliers and downstream stakeholders was minimal, with end-of-life responsibilities primarily placed on customers.

Group-T2 identified similar issues, with fragmented responsibilities and insufficient collaboration that hinders the application of circular practices. Reverse logistics and recovery initiatives were often lacking, and collaboration remained often isolated due to unclear ownership.

Scoring & Assessment Approach: Group-T1 found that the scoring scale was generally intuitive, although several participants interpreted the questions differently based on their roles, indicating the need for calibration to ensure consistent understanding. Some participants struggled to differentiate between response levels such as "developing" and "exploring".

Group-T2 agreed that the scale was mostly straightforward, but suggested further refinement. They recommended clearer definitions for each level and noted that different functional backgrounds caused interpretation discrepancies, affecting scoring consistency.

Strategic Fit & Framing of Circularity: Group-T1 noted that circular activities were occurring but often went unrecognised. The organisation lacked a clear and unified direction for circularity, with most initiatives viewed through cost-saving or efficiency measures instead of focussing on circular value.

Group-T2 highlighted the absence of a comprehensive CE strategy, where maintenance and reuse were mainly driven by economic factors. Circularity was not framed as a core business objective, and many participants recognised their limited awareness of circular principles within the company.

Digital, Data & Technology Use: Group-T1 acknowledged the use of digital tools but found them poorly aligned with the objectives of the CE, with limited data sharing due to a lack of operational integration.

Similarly, Group-T2 valued digital technologies only when they added clear benefits, noting poor data integration and a lack of infrastructure for tracking circular metrics, particularly for reverse flows.

Suitability for Future Use: Group-T1 emphasised the tool's value for internal reflection, training, and team alignment, noting a preference for a digital version to simplify updates and long-term tracking, especially at the value stream or business unit level.

Group-T2 agreed on its potential to facilitate low-barrier discussions, suitable for both internal and external use, and to stimulate broader strategic thinking. The participants highlighted the need for strong leadership and ongoing involvement to integrate circularity across the business.

5
Discussion

The transition to a circular economy presents significant challenges for industrial sectors with complex value chains, such as aerospace. Identification of the current stage of a value chain partner in the circularity journey is essential to plan the next steps. This thesis responded to these challenges by developing a circularity readiness assessment tool tailored to the aviation context. Instead of focussing only on material flows or environmental impacts, this study approached circularity as a broader concept that reflects the overall readiness of an organisation, including both its strategic direction and operational capabilities. The tool was developed based on insights from the literature and practice. It supports companies in assessing their current state, setting improvement priorities, and enhancing collaboration with value chain partners. Tool testing and expert feedback offered valuable input on the relevance of the tool. These insights also highlight practical actions for organisations that aim to improve circularity in their value chain.

In this chapter, the authors have analysed all the results with explanations and interpretations of the results in the context of the thesis questions, tool testing insights, and practical recommendations for aerospace industry companies.

5.1 Analysis of Results

5.1.1 RQ1: What does circularity readiness mean?

Understanding and clearly defining the concept of circularity readiness was a fundamental step in this study. The literature review was conducted through a structured search using the keywords “circular economy”, “circularity assessment”, "circular readiness" and “value chain” combined with Boolean operators (AND/OR), with the primary objective of identifying and defining key concepts such as circular economy, circularity readiness, value chain, and circularity readiness assessment.

The following main definitions, derived from existing literature, were provided to users of **ENGREEN CRA** to support their understanding of the assessment context.

Circular Economy - An economic system that focuses on closed cycles aimed at eliminating waste and promoting resource efficiency through the integration of supportive policies, renewable energy and sustainable practices (E.g.: reuse, re-

manufacturing, and recycling, etc) - (Vogiantzi & Tserpes, 2023)

Circularity Readiness in Value Chain - The extent to which a company's value chain is psychologically and structurally prepared to transition to circular economy principles - Adapted from (Jo & Hong, 2023).

This basis was clearly consumed in the theoretical foundation, specially to understand the dimensions, elements, and formulation of the question that is clearly explained in Section 4.2.

All participants in both the individual and group tool tests were able to follow the tool without expressing any uncertainty about the scope of the tool. Most of them needed to read the "Key Term" section before starting assessment, which helped them to set the boundaries of the tool scope. The users referred to the "Key Terms" tab when needed to better understand definitions and context while answering the current state analysis questions. Survey feedback also highlighting that the introduction tabs (methodology and keywords) were helped to understand the CE context.

5.1.2 RQ2: How is circularity readiness assessed in research?

To support the development of a relevant and structured assessment tool, the study reviewed existing methods and tools used in the literature to assess circularity readiness. This part of the discussion evaluates the insights gained from that review and how the insights from the literature guided the methodological approach adopted in this study.

The academic literature alone was not enough to cover and prepare the list of existing tools in the Appendix A. There are a considerable number of tools that were not published in the academic literature, and some of them were developed by organisations because of the commercial value of such a tool.

The analysis of existing tools in the Appendix A provides an idea about how scattered they are. Out of the 30 tools in the list, 10 tools are in the circular product design & development objective category, another 10 are in the circularity performance measurement object category, and other 10 tools are in 4 different object categories. But each and every tool has a different main objective. In addition, the literature offered essential insights into existing frameworks, methodological approaches, tool interfaces, and established best practices relevant to circularity assessments.

In addition to insights into the technical and functional aspects of the tool, the analysis of existing tools in the literature also provided valuable reflections on the user experience, particularly their cognitive responses, perceived usability, and overall impressions when engaging with the tools. The authors have experienced different levels of fatigue while using and analysing the tools listed in the Appendix A. The scope of the circularity readiness dimensions extends across most strategic and operational areas of the value chain, which can lead to user fatigue during the assessment process. User friendliness is a critical aspect of tool development. Among the evaluated tools, features such as structural clarity, number of questions, colour themes, and overall methodology were identified as key contributors to a positive user experience. These aspects were considered when developing the ENGREEN CRA and the tool users during tool testing accepted the user friendliness and quality of the tool features are described in Section 4.5 and the Appendices F and H.

5.1.3 RQ3: What are the key indicators for circularity readiness assessment, and how can they be identified?

Identifying the appropriate key indicators was crucial to operationalising the assessment tool. Dimensions and elements were selected based on a structured review of the literature and then refined using input from industry professionals to ensure relevance, completeness, and practical applicability within the aerospace context.

The dimensions and elements of circularity assessment tools provide guidance and cover the scope of the tool. The analysis of dimensions and elements of six key selected tools in the Appendix B could not provide a final set of dimensions and elements for **ENGREEN CRA** and had to use insights from GKN sustainability team professionals as a lens to refine the list of dimensions and elements as explained in Section 4.2.3.

As identified in the literature review section 2.4 very limited tools have been developed to measure circularity in the value chain, and no tool that is specially focused on the aviation industry is also a reason for the lack of dimension in the literature to cover the scope of **ENGREEN CRA**. "Regulatory & Compliance Readiness" and "Performance Measurement" are newly introducing to the taxonomy of circularity assessment dimensions through **ENGREEN CRA**. "Technology for Circular Design", "Circularity Responsibility Delegation", "KPI for Circularity", and "Employee-Led Circular Initiatives" introduce the taxonomy of elements by **ENGREEN CRA**. The introduction of a circular readiness assessment to the aviation industry is a new challenge and has introduced more elements to the framework, as highlighted by Esteban-Amaro et al. (2025).

It is very important to focus systematically on the selection and systematically structuring of these indicators, that is, the more involved process for the accuracy of the results of the CRA tools (Pigosso & McAloone, 2021). The method followed in this task shown in Figure 3.1 could capture a good set of dimensions and elements that cover all areas of the value chain and accepted by the users during the tests. Following a comment from the "Environmental Sustainability Lead" of one of the case company;

"The tool has covered a broad area in depth, impressive arrangement of the tool. The tool is pretty useful for circularity."

5.1.4 RQ4: How can a circularity readiness assessment support companies in collaborating across the value chain and enhance circularity performance?

One of the major focus of the study is to understand the practical value and broader impact of CRA in complex industrial context such as aerospace. Corsini et al. (2024) highlights such assessment tools can serve as an instrument for engaging value chain partners in the discussion of shared circular responsibilities and priorities. The **ENGREEN CRA** has developed to use as common tool with value chain partners as explained in Section 4.3. The weighting system of dimensions is working as parameter setup feature with enablers are common and very important for any value chain partners, and the importance of the implementer can vary from optional to critical based on the nature of the entity. Since the tool included elements to cover both upstream and downstream as explained in Section 4.2.2, an organisation can evaluate a good coverage of their value chain using the available expertise of the company without having a detailed and comprehensive analysis. And contractual agreements can be created with the help of internal departments for the handling customer and the supplier to share **ENGREEN CRA** between value chain partners. Then, as a collaborative effort, the circularity readiness of each value chain partner can be measured independently and that can be used to map the distribution of readiness across the value chain. The tool does not require quantitative measurement for evaluation. Therefore, external stakeholder engagement will not be an issue as highlighted by one of users that the tool's ability to work without sensitive data was seen as a benefit.

The study only covered two case companies due to the time limitation of the study and could not completely test the above mentioned new approach of measuring the circularity readiness of the value chain but the concept was commented on by experienced professionals from both case companies and explained in Section 4.5. The following are key reflections from the users.

ENGREEN CRA acts as a **structured platform** for shared understanding, to identify gaps, align priorities, and facilitated targeted collaboration within value chain partners. In addition, by clearly clarifying the roles, required capabilities, and necessary readiness levels, the tool supports effective coordination to implement circular practices within the value chain. In addition, the "progress over time" tab of the tool is facilitated to do a comparison of different stakeholder engagement and how it affects the organisation.

Initiating **cross-functional dialogue** is a must for the true function of the ENGREEN CRA within the value chain and active engagement of both internal and external stakeholders can create accurate result rather than isolation.

The ENGREEN CRA can supports companies to **strategically address** the collaboration weaknesses that directly affect circularity performance by exposing structural barriers such as fragmented ownership, unclear responsibilities, and lack of reverse logistics.

The features available within ENGREEN CRA also a deciding factor whether the assessment can support companies in collaborating across the value chain and enhance circularity performance. Having a tool is not enough, but the features of the tool are important. Survey results highlight the feature "progress over time" that can be used to track the progress of time, really helping to create a circularity journey. Although there are tools that use both weight assignment first and then assessment and wise-versa, the weight assignment at the beginning allowed the user to customise the tool to nature of the entity. This has been accepted by users as explained in Section 4.5, but further research is needed using different value chain partners to come to a better conclusion.

5.2 Other Tool Testing Interviews and Workshops Results

The comparison between the data from individual and group assessments in Section 4.5.1.1 highlights how collaborative evaluation can change the individual stance, enhance mutual understanding, and fill the knowledge gaps of different individuals. In addition, it reflects the value of joint reflection in generating more critical and balanced insights, which can be the correct representation of the circularity readiness value of an entity.

Gruenfeld et al. (1996) has shown that compositions of team are affecting to the performing differences and familiarisation; and may be effective at gathering, combining and sharing knowledge or data. Hence, as suggested by some participants to tool test activities, identification of correct and balance cross-functional team can be a good support factor for the successful circular journey for value chain partners.

The results of the tool tests, explained in Section 4.5, show inconsistent assessment results, particularly evident in Figures 4.12 and 4.13, where differences can be observed across individual responses as well as between individual and group assessments on current status. Pauliuk (2018) has explained that most circularity assessment tools offer a limited, context-specific view and should be seen as approximate and not as a precise result. But the ENGREEN CRA got good comments like *"The scoring was more reflecting of where we actually are"* and *"Real-world examples, which they know helped participants evaluate more accurately"*.

However, conducting the assessment with a well-balanced, cross-functional team comprising representatives from key departments such as design, production, procurement, and circularity can enhance the quality of reflections, promote mutual understanding, and lead to more accurate readiness evaluations by bridging knowledge gaps among participants.

The restricted weight assignment for enables was a common and highly concern from experts as well as tool testers from both companies. Feedback about that also collected from survey and most of the survey feedback highlighted user should have the freedom to select weights from 1-5. One tester was completely agreed with the restriction but suggested to mention the reason for the restriction as a note at the top of the tab to create a good first impression on a user. The weight assignment on "Organisation" is 5 for all the testers, and none of other dimensions has that trend, and it is clear acceptance as an enabler by both companies. More tests are required to confirm that "Business model & Strategy" and "product & service innovation" are enablers for all value chain partners.

The 5-stage Likert scale for current state analysis questions used for the tool received both positive and negative comments. It is a fundamental design aspect of the tool and is connected with the calculation, status comments, and recommendations. This scale represents the stages which a value chain partner can achieve for all the 40 elements highlighted in the tool. An expert commented that it is better to use a scale with 4 or 6 levels to avoid users' tendency to select the middle value. We had to keep that as a risk of tool failure and tested it. Based on the results, we can see that lack of tendency to select the middle value with the variations shown in the Figures 4.13 and 4.15. However, it is better to test the tool with more users and consider changing if necessary. Another common comment is that it is better to separate "No Action Taken / Exploring Possibilities" into two stages, because they are two different stages. All the 40 elements considered under the current status analysis need at least an initial discussion to start the circularity journey of an entity. Just after first use of the ENGREEN CRA, that company is in the stage of "Exploring Possibilities" because the tool is creating new discussions and opening new ways of thinking.

5.3 Improvement potentials for the two case companies

Except for one occasion, all other current status values for all three enablers are below 3.5 and the average is around 3 for both companies. This implies that aviation industry companies are still laying ground work for circularity principles, and top management involvement is more important. Case company one considered that "Production" dimension is not that much important for circularity, but their current status touching 5 while second case company has both priority and status as 5. This is a clear interpretation of the confidence that companies have about the efficient, lean and standardised production setups developed during past decades with help of the different production trends and need to keep it going for better circular performance also.

Another good observation is about "Supply chain & procurement" and all the testers considered that the importance is 3 or above for circularity, but the current status is less than 2.5. This was further analysed using individual questions and it could find that "Supplier Circularity Engagement" and "Mutually Beneficial Relationship" got the majority response as exploring possibilities and laying the groundwork. "Circular Procurement" is a bit high stage but still majority response are laying the groundwork and testing in practice. Hence, this area needs high attention from aviation companies because it is a highly important area for circularity as marked by the weight assigning with an average 4 value. "Customers, support & Maintenance" is opposite to the supplier side with above 4 weight assignment and above 3 current status. This can be due to the availability of the quality system with a very high customer focus in the aviation industry.

"Performance measurement" is a new dimension that has been introduced to circularity assessment taxonomy by this research work, providing a very important direction for the aviation industry value chain partners. All tool testers have identified this as a very important dimension for circularity by marking weight above 4 importance. But the current status is less than 3 is a significant difference. This has been further analysed using answers for the questions and revealed that "Life Cycle Assessment" is going very well in the aviation industry. But "Employee-Led Circular Initiatives" and "Material Circularity" are in exploring possibilities and laying the groundwork. As Dias et al. (2022) explained, half a million component of aircraft is a huge barrier to circularity in the aviation industry, and many aviation companies are still in the initial stages of measuring the circularity of material. The "Employee-Led Circular Initiatives" dimension is also in the laying groundwork stage. This is considered under the "Performance Measurement" especially to address the importance of assessment employee engagement to the CE.

6
Conclusion

By addressing the research questions that made up the basis of this thesis, the primary aim and objectives have been achieved successfully. The following conclusions are derived from the results and discussions.

The definition of circularity readiness identified through the research encompasses the alignment of strategies, resources, competencies, and collaboration mechanisms that enable an effective transition toward circularity of value chain.

Circular readiness is assessed through a variety of tools and frameworks found in both the academic literature and the grey literature. These tools typically fall into six objective categories and provide information about methodologies, structural frameworks, user interfaces, and best practices. Effective assessment requires a combination of established approaches and original contributions, with particular emphasis on user-friendliness and practical applicability.

Dimensions and elements define the scope of a circularity readiness assessment. Due to the limited availability of tools that address the circularity readiness of value chain, especially in the aviation sector, there is a lack of established indicators in the literature. This is the first time, to the best of the authors' knowledge, that a circular readiness assessment has been carried out in aviation companies considering a value chain perspective. This study contributes by identifying a comprehensive set of indicators and introducing two new dimensions "Regulatory & Compliance Readiness" and "Performance Measurement". The method applied in this study enabled the identification of a comprehensive set of dimensions and elements that effectively cover the entire value chain.

A CRA such as **ENGREEN CRA** supports companies by providing a structured platform that initiates cross-functional dialogue to identify collaboration gaps and encourages strategic alignment across the value chain. It enables organisations to evaluate their own readiness using internal expertise without relying on sensitive data, and to map readiness levels across partners by sharing and connecting values chain partners using the tool.

This study highlights several broader conclusions. Achieving a more accurate and meaningful assessment of circularity readiness requires the active participation of balanced cross-functional teams with expertise in different areas of the value chain. ENGREEN CRA provided realistic and positively acknowledged outputs, as reflected in user comments and relatable scoring. However, the results should still be interpreted as approximations, in line with the inherent limitations of most circularity assessment tools. The tool revealed a strong recognition of "organisational readiness" as a key enabler, but more testing is needed to confirm whether other dimensions such as "business model & Strategy" and "product & service innovation" hold similar importance across various value chain partners. "Procurement and supply chain" emerged as critical yet underdeveloped areas, with most responses indicating early-stage efforts such as groundwork and piloting. This reinforces the need for aviation companies to prioritise supplier engagement and circular procurement practices in their transition efforts.

6.1 Limitation of the Study and Recommendations for Future Development

The authors tested the tool's applicability in two manufacturing companies. Additional tests with more value chain partners in the aviation industry are needed. In the future, a web-based tool will be more convenient to use than an Excel-based tool if the organisation shares the tool with external value chain partners, considering its accessibility and the need to keep information in a centralised database. In addition, additional features can be integrated into the tool to deep dive and develop an action plan to improve the circularity of critical and underperforming dimensions.

The survey question regarding the best suitability of the tool with individual or group was marked as "Group" by all tool testers. Although group assessments offer valuable insights, it is crucial to acknowledge that these results may not fully reflect the true circular readiness of each company. The evaluations were conducted with relatively small groups of 3–6 participants, which, although beneficial in fostering discussion and reaching opinions, may not capture the complete complexity of circular practices throughout the organisation. To achieve a more accurate and comprehensive assessment, broader involvement from cross-functional teams, including representatives from all relevant departments and roles across the value chain, would be essential. Enhancing participation will ensure that various perspectives, operational details, and departmental distinctions are adequately reflected in the outcomes. Hence, the authors recommend this tool for team-based assessments.
Experts highlighted the potential for overlaps between certain dimensions in the tool, which could be explored in future versions to better reflect interdependencies. Furthermore, enhancing the output of the tool by providing actionable recommendations along with the assessment results was identified as a key improvement area, enabling users to better address identified gaps and implement targeted improvements within their organisations.

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A

Appendix 1

Table A.1: Circular Economy Tools, Adapted from (Keita Sekijima, 2024), with substantial additions and modifications by the authors

#	Tool name	Developer	Year	Level of circularity	Outputs	Method	Interface	Objective Category	References
1	CD-Tool	Kaunas University of Technology	2024	Product	Qualitative	Self assessment	Web-base	Circular Product Design & Development	(Dagilienė et al., 2024)
2	CE indicator prototype (CEIP)	University of Bath	2017	Product	Quantitative & Qualitative	Self assessment	Excel	Circularity Performance Measurement	(Cayzer et al., 2017)
3	Checklist for Life Cycle Design Strategies Pursuit Evaluation (ICSxToolkit)	LeNSlab, Polimi, Politecnico di Milano	2024	Product	Quantitative & Qualitative	Self assessment	Excel	Circular Product Design & Development	(LeNSlab Polimi team, 2024)
4	Circular Design Rules (CDR)	Institute of Design Research Vienna	2023	Product	Quantitative	Self assessment	Web-base	Circular Product Design & Development	(Institute of Design Research Vienna, 2023)
5	Circular Economy Toolkit (CET)	University of Cambridge	2013	Product	Qualitative	Self or Group Assessment	Web-base	Circular Product Design & Development	(Cambridge UK, 2013)

#	Tool name	Developer	Year	Level of circularity	Outputs	Method	Interface	Objective Category	References
6	Circular Pathfinder	IDEAL&CO Explore, ResCoM project	2017	Product	Qualitative	Self assessment	Web-base	Circular Product Design & Development	(IDEAL&CO Explore & ResCoM project, 2017)
7	Circular Product Readiness	TU Delft	2022	Product	Quantitative	Self or Group Assessment	Excel	Circular Product Design & Development	(Boorsma et al., 2022)
8	Circular Transition Indicators (CTI)	WBCSD, Circular IQ	2024	Company	Quantitative	Self assessment	Web-base	Circularity Performance Measurement	(WBCSD, 2023, 2024)
9	Circularity Assessment Tool V.4	CIRCit NORDEN	2020	Product	Quantitative	Self or Group Assessment	Excel	Circular Product Design & Development	(CIRCit NORDEN, 2020)
10	Circularity Calculator	IDEAL&CO Explore, ResCoM project	2022	Product	Quantitative	Self assessment	Web-base	Circular Product Design & Development	(IDEAL&CO Explore, 2022)

#	Tool name	Developer	Year	Level of circularity	Outputs	Method	Interface	Objective Category	References
11	Circularity Index	INDEED Innovation	2024	Company & Region	Qualitative	Self assessment & External benchmarking	Canvas	Industry-Specific Circularity Assessment	(Indeed, 2024a)
12	Circularity Indicators Advisor (CIA)	Université Paris-Saclay	2019	Product & Company	Quantitative & Qualitative	Self assessment	Excel	Circularity Performance Measurement	(Université Paris - Saclay, 2019)
13	Circularity Potential Indicator (CPI)	Université Paris-Saclay	2018	Product	Quantitative	Self assessment	Web-base	Circularity Performance Measurement	(LGI Circular Economy & Université Paris Saclay, 2018)
14	Circularity Toolset for Benchmarking	TU Delft, Sony	2024	Product	Quantitative & Qualitative	Self assessment & External benchmarking	Canvas	Circularity Performance Measurement	(Sekijima et al., 2024)
15	Circulytics 2.0	EMF	2020	Company & Industry	Quantitative & Qualitative	Self assessment	Web-base	Circularity Performance Measurement	(Ellen MacArthur Foundation, 2020)

#	Tool name	Developer	Year	Level of circularity	Outputs	Method	Interface	Objective Category	References
16	Cradle to Cradle Certified - Version 4.1	Cradle to Cradle Products Innovation Institute	2024	Product	Qualitative	Self assessment	Web-base	Business Strategy & Circular Economy Implementation	(Cradle to Cradle Products Innovation Institute, 2024)
17	Current State Overview	EcoDesign Circle	2022	Company	Qualitative	Self assessment	Canvas	Circularity Performance Measurement	(EcoDesign Circle, 2022d)
18	Ecodesign Assessment Product	EcoDesign Circle	2022	Product	Quantitative	Self assessment & External benchmarking	Canvas	Business Strategy & Circular Economy Implementation	(Eco Design Circle, 2022a)
19	Ecodesign Audit	EcoDesign Circle	2022	Product	Quantitative	External Assessment	Canvas	Circular Product Design & Development	(Eco Design Circle, 2022b)
20	Ganbatte - Circularity Assessment Tool	Circle Economy	2022	Product & Company	Quantitative & Qualitative	Self assessment	Web-base	Circularity Performance Measurement	(Ganbatte, 2025)

#	Tool name	Developer	Year	Level of circularity	Outputs	Method	Interface	Objective Category	References
21	GREen TArgets (GRETA)	SUPSI, CircThread project	2024	Product & Company	Quantitative	Self assessment	Web-base	Industry-Specific Circularity Assessment	(SUPSI & CircThread project, 2024)
22	ISO59020 - Measuring and assessing circularity performance	ISO standards	2024	Product & Company	Quantitative & Qualitative	External Assessment	Web-base	Circularity Performance Measurement	(Hans Kröder, 2024)
23	Making the Transition to a Circular Economy (MATChE)	DTU	2021	Company	Quantitative & Qualitative	Self or Group Assessment and External Benchmarking	Web-base	Circular Economy Maturity Assessment	(Pigosso & McAloone, 2021)
24	Material Circularity Indicator (MCI)	EMF	2015	Product & Company	Quantitative	Self assessment	Excel	Circularity Performance Measurement	(Ellen MacArthur Foundation, 2015)

#	Tool name	Developer	Year	Level of circularity	Outputs	Method	Interface	Objective Category	References
25	Product & Actant Journey	EcoDesign Circle	2022	Company & Value Chain	Qualitative	Self or Group Assessment	Canvas	Circular Value Chain & Resource Management	(Eco Design Circle, 2022c)
26	Self-Check Circular Readiness Level	Fraunhofer CCPE	2021	Product	Quantitative & Qualitative	Self assessment	Web-base	Circular Product Design & Development	(CCPE, 2025)
27	ready2LOOP	Technical University of Denmark	2024	Company & Value Chain	Quantitative & Qualitative	Self or Group Assessment and External Benchmarking	Web-base	Circular Value Chain & Resource Management	(DTU researchers, 2025)
28	CircularStart	Spanish National Agency for International Education	2021	Product & Company	Quantitative & Qualitative	Self assessment	Excel	Business Strategy & Circular Economy Implementation	(Prospektiker et al., 2021)

#	Tool name	Developer	Year	Level of circularity	Outputs	Method	Interface	Objective Category	References
29	Compass Circular Economy	cooperation with the Circular Economy Forum Austria, the Vienna University of Technology, the Institute of Management Sciences, and the Resource Forum Austria	2023	Product & Company	Quantitative & Qualitative	Self assessment	Web-base	Circular Economy Maturity Assessment	(Circular Economy Forum Austria et al., 2023)
30	circular assessment of suppliers (CAoS)	Institute of Management and Sustainability and Climate Interdisciplinary Center, Italy	2024	Company & Value Chain	Quantitative & Qualitative	Self assessment	Excel	Circular Value Chain & Resource Management	(Corsini et al., 2024)

B
Appendix 2

Table B.1: Key Tools - Dim and Elements analysis

(Circular Economy Forum Austria et al., 2023; Corsini et al., 2024; DTU researchers, 2025; Ellen MacArthur Foundation, 2020; Ganbatte, 2025; Prospektiker et al., 2021)

Tool Name	Dimension	Element
CE Readiness Assessment	Energy	Energy flows, Energy input, Energy production, Energy reduction targets, Renewable energy input, Renewable energy production
	External Engagement with Stakeholders	Circular Economy initiatives, Customer Engagement, Engage with suppliers for circular sourcing, Fair business relationships, Local partners and suppliers
	Operations	IT and digital systems to support CE, Plant, property and equipment assets, Processes to support CE, Regeneration of ecosystems
	People & Skills	CE competences of staff, Human well-being/fundamental needs, Local jobs/wealth
	Plant, Property & Equipment	Circular Procurement - End of functional life, Circular Procurement - Long Use, Circular Procurement - Second hand assets, PPE assets, Recirculation of PPE
	Products & Materials I	Circular Design for long use, Circular Design for second life, Product/material flows along life cycle, Support customers to improve CE performance
	Products & Materials II	Direct GHG emissions, Emissions to air/water/soil, Hazardous substances, Indirect GHG emissions, Material input, origin, output, Other emissions, Renewable materials, Waste/by-products not recirculated
	Products & Materials IV	Recirculation, Reuse of products

Tool Name	Dimension	Element
CE Readiness Assessment (cont.)	Services	Circular Services - Consultancy and business support, Eliminate waste and pollution, Recirculation, Regenerate natural systems, Services using products, Software, Keep products/materials in use, Support CE
	Strategy & Innovation	CE related opportunities, Innovative solutions, Measurable CE targets, Mission / Vision / Values
	Water	Closing water cycle, Recovering valuable products from wastewater, Reduction of water demand, Wastewater - destination and treatment, Water flows, inflow, origin/source, outflows
Circular Assessment of Suppliers (CAoS)	Environmental Criteria	Compliance with critical environmental standards, Evaluation of environmental performance
	Supplier Internal Circularity	Circular business models within the supplier, Internal reuse and recycling processes, Use of secondary or renewable materials
	Supplier Relationship Circularity	Integration of circular principles in the partnership, Level of collaboration on circular practices

Tool Name	Dimension	Element
Circulytics	Energy	Renewable energy production, Renewable energy use
	External Engagement	Circularity advocacy, Customer engagement, Financier engagement, Policymaker engagement, Supplier engagement
	Finance	CE investment screening, Circular finance allocation
	Innovation	CE innovation strategy, Circular R&D investment, Scaling circular innovations
	Operations	Circular infrastructure investment, Circular tracking systems, Operational circularity
	People and Skills	CE training and awareness, Circular skills development, Internal collaboration
	Plant, Property, and Equipment Assets	Asset lifetime optimization, Circular asset decommissioning, Circular asset procurement
	Products and Materials	Circular material inputs, Circular product design, Material recirculation, Waste circularity
	Services	Circular business models, Customer circularity enablement
	Strategy and Planning	CE in strategy, Circular governance, Resource allocation for circularity initiatives , Circularity monitoring
	Water	Sustainable water discharge, Water recirculation, Water reduction targets, Water tracking

Tool Name	Dimension	Element
Compass Circular Economy	Design	Avoidance of critical/hazardous materials, Design for recyclability or biodegradability, Durable, modular, upgradeable, and repairable product design, Use of bio-based/recycled materials
	Knowledge & Communication	Environmental impact monitoring across lifecycle, Internal/external CE communication, Circular R&D investment, Use of standards/certifications
	Logistics	Product return systems, Reuse after return, Storage/transport optimization, Sustainable packaging, Use of digital tools to reduce travel
	Organization & Strategy	Assigned CE responsibilities, Market monitoring, Employee engagement/training, CE financial evaluations, Resource efficiency strategy
	Partnerships	Collaboration to reduce resource use, CE expectation communication, Industrial symbiosis participation, Product labeling for material transparency
	Procurement	Extension of asset lifetime, Purchase of refurbished assets, Critical material risk assessment, Partner CE development support, Sustainable procurement, Value chain CE checks
	Production	Monitoring of processes, Efficiency improvements, Material flow/waste evaluation, Reuse/recycling of residues, Use of renewable energy, Waste reduction
	Services	Customer repair training, Data strategies, Maintenance/re-manufacturing, Upgrade offerings, Provision of spare parts/materials, Use of digitalization

Tool Name	Dimension	Element
Ganbatte Circularity Assessment Tool	NO DIMENSIONS	Business model innovation, Collaborative value creation, Digital integration, Future-ready design, Knowledge development, Lifetime extension, Regenerative resources, Waste as resource
Ready2Loop	Manufacturing & Value Chain	Circular supply chain, Collaborative partnerships, Industrial symbiosis, Sustainable materials
	Organisation	Business case development, Capability development, Processes and tools, Risk and investment planning
	Policy & Market	Co-development market, Market innovation, National/international policies, Second-life markets, Sector-specific policies
	Product & Service Innovation	Design for longevity, End-of-life design, PSS models, Sharing-oriented design
	Strategy & Business Model Innovation	Resource planning, Revenue model innovation, Strategic communication, Strategic planning, Value proposition innovation
	Take-back & End-of-Life Strategies	Recycling, Re-manufacturing, Take-back systems
	Technology & Data	Tech for longevity, Usage monitoring
	Use, Support & Maintenance	Repair services, Sharing platforms, Support services

C

Appendix 3

C.1 Interview Questions – Circular Economy at GKN : 21-02-2025

1. Circularity Goals & Strategy
   1.1. What is GKN's main circularity and sustainability goals?
   1.2. How do regulations and industry standards affect your circular economy strategy?
   1.3. What future trends or innovations is GKN exploring in circularity?
2. Measuring & Tracking Circularity (Current)
   2.1. How does GKN track circularity in its operations and value chain?
   2.2. What key metrics are used to measure circularity?
   2.3. What challenges do you face in tracking and improving circularity?
   2.4. Are there gaps in data collection or supplier engagement?
   2.5. What technology limitations affect circularity assessment?
3. Materials & Waste Management
   3.1. What are the key raw materials used in production?
   3.2. Which materials are most critical for circularity, and how are they managed?
   3.3. How does GKN monitor material flow and lifecycle?
   3.4. What steps are taken to reduce material waste?
   3.5. Are there any remanufacturing or refurbishment programs?
   3.6. How does GKN handle scrap and by-products?
   3.7. How are non-recyclable materials disposed of?
4. Product Design & Circularity Strategies
   4.1. How are products designed to be more circular (durable, repairable, recyclable)?
   4.2. Are products designed for modularity, reusability, or recyclability?
   4.3. What strategies are in place for remanufacturing, recycling, or waste reduction?
   4.4. How does GKN manage end-of-life product recovery and reverse logistics?
   4.5. How are obsolete or damaged products handled?
   4.6. What are the services GKN provides?
   4.7. How does GKN manage product & service?
5. Stakeholder Engagement & Collaboration
   5.1. How involved are suppliers, customers, and partners in circularity efforts?

   5.2. Does GKN collaborate with industry groups, universities, or policymakers?
   5.3. What are the biggest challenges in engaging stakeholders in circularity?
   5.4. How much investment is available for circular economy initiatives?
6. Tools & Systems for Monitoring Circularity
   6.1. What tools or systems does GKN use to track circularity?
   6.2. How well can materials and products be traced across the value chain?

C.2 Extracted Key Points from GKN Interview for Circularity readiness assessment tool

C.2.1 Defining the objective of the solution

1. The main challenge identified in the interview is the lack of structured circularity tracking, particularly for material flows, end-of-life products, and supplier engagement.
2. GKN has some circularity-related goals, like waste reduction (95% landfill diversion) and water consumption control, but no formal framework for assessing circularity.
3. There is no in-house material loop, and metal recycling is handled externally, making it difficult to track whether recycled materials return to aerospace.
4. The lack of end-of-life visibility makes it unclear how much material is actually recycled or reused.
5. Packaging waste is a focus area, with efforts to replace plastic wraps with recycled cardboard.

C.2.2 Development of Design Objectives

1. Understand the Current State (Assess Readiness) - GKN tracks waste by weight but lacks visibility into circularity across the supply chain.
2. Identify Barriers (Challenges) - Regulatory compliance varies by region, making it hard to standardise circularity efforts globally.
3. Develop Circularity Strategies (Readiness Score) - No formal re-manufacturing strategy, but some repair methods exist (mainly for blades and structural components).
4. Implement Monitoring & Improvement (Conceptual Model) - GKN uses an ERP system for traceability, but this does not track circularity metrics.

C.2.3 Development of Design Requirements

Assessment Areas and Key Findings from Interview
1. Material Circularity - Metal chips are recycled, but no closed-loop tracking.
2. End-of-Life Management - No direct involvement in dismantling. (GKN is Assuming the materials are recycled, but no visibility for them)

3. Supplier & Stakeholder Engagement - Supplier portal exists but only for quality tracking, not circularity.
4. Design & Production Circularity - Additive manufacturing reduces waste but is not yet optimised for circularity.
5. Regulatory Compliance - Different regulations across global sites make standardisation difficult.

C.2.4 Development of Conceptual Model

1. Assess Circularity Readiness - Evaluate material flow tracking, supplier engagement, re-manufacturing potential, and waste management.
2. Score Maturity Levels - Develop a readiness scale based on current processes vs. best practices.
3. Identify Barriers - Highlight regulatory gaps, supply chain limitations, and technological constraints.
4. Recommend Circularity Strategies - Provide guidelines for supplier engagement, re-manufacturing potential, and improved material tracking.

C.2.5 Key Takeaways for Tool Development

1. Lack of structured circularity tracking - The tool must introduce material traceability across the value chain.
2. No formal end-of-life assessment - The tool should include an evaluation of dismantling and recycling transparency.
3. Supplier engagement in circularity is weak - A readiness score for supplier involvement should be included.
4. Regulatory complexity makes standardisation difficult - The tool must account for regional compliance variations.
5. Circularity in design is not a focus - The tool should assess potential for design improvements to enhance circularity.

D

Appendix 4

D.1 Expert discussion output

D.1.1 First expert (Exp1) - (08/04/2025 - 10.00 - 11.00)

Comment	**Actions / changes**
The options under Weights1 (enabler), specifically "very critical" and "extremely critical," are not recommended. The "extreme critical" option is at the far end of the scale and can lead to misunderstandings, so the users may feel like it is better to avoid selecting extreme critical.	Waited for other experts feedbacks also. There were no any comments from others. We further improved the clarity of the hints to support the user
The question regarding the organization and elements (resources) is challenging to answer. It encompasses a broad range of factors, and different departments have varying levels of resource implementation.	Waited for other experts comments also. Did small change in the question to add “e.g.,” with given examples to make it clear for user. Later added pop-up notes with our own definitions for key terms
Regarding Weights2 tab, Regulation dimension: Adhering to regulations and compliance is essential. However, measuring compliance levels does not seem to make sense.	Agreed. Since the focus of the tool is about readiness, we alter the question by checking the proactiveness/ reactiveness on regulations”
User could not initially identify the drop-down list available within dashboard. Suggested to add instruction about that drop-down list in the methodology section.	Add instructions to the methodology, further improve the appearance of the drop-down list to make it eye catchy.
The tool’s name is somewhat complex.	Did not take any action

D.1.2 Second expert (Exp2) - (10/04/2025 – 9.00 - 10.00)

Comment	**Actions / changes**
The weight1 with only scale 4 & 5 is restricting the freedom of user and forcing the user to select higher value.	Since we found these 3 dimensions (weight1) are in most of the assessment tool and some of the developer's emphasise the importance of these we considered they as enablers and need to keep the importance with high weights. Hence no changes but will be evaluated during tool testing.
Weight 1 & Weight2 questions related Likert-scale is bit distracting the users. Better to update keep similar wording within a question.	Agreed. Updated scale to keep the consistency of wording within one dimension.
Check for constancy of Assessment questions with common Likert scale.	Agreed. Updated all the questions to align with the common Likert scale.
More descriptive questions can be introduced that may help the user.	Not changed. To keep the balance in every aspect, we developed the questions as it is with bit open ended questions.
It is better to add a guide in methodology whether this tool should be used as a Group or individually.	This is one of the areas we going to test. Based on the workshop results this will considered.
There may be overlap on dimensions and it can change the overall readiness value (inter connection scores).	With the way the tool conceptual framework developed, we considered only 10 independent dimensions. There can be some overlap but not considered with calculations and tool definitions. Can be include as future development of the tool.

D.1.3 Third expert (Exp3) - (11/04/2025 – 10.10 - 10.50)

Comment	**Actions / changes**
Tool is considered only for the internal company value chain.	The scope of the tool was prepared in a way that tool can be used by a manufacturing entity as a representation of the value chain and trough the expertise of that entity the value chain can be measured. Dimensions and elements selected with that basis.
Explore other companies (suppliers, stakeholders, other shareholders).	Other than above comment, the tool can be shared between value partners and the results of the assessments can be utilised to track the overall readiness value.
Include all 9R factors (Reduced, refurbished, re-think, refurbished, three groups).	Already incorporated in the tool under different dimensions and elements.
If few factors considered within one weight, then add them as examples for clarity.	Agreed. Changed accordingly
The Likert scale is good to have 4 or 6 to avoid users' tendency to select middle value.	This is bit difficult change we can introduce to the tool because it is a fundamental design aspect of the tool which can change all the tabs of the excel file. Too much work to change it. We can keep this as a risk of tool failure but we can test the results using workshops and discuss about that.
Think about how to support the design team using this tool.	The tool is with a broader set of applicable departments and not deep diving on circularity in product design only. But the tool already included main elements which can represent the design aspects of circularity. Hence reflection on "How the output of this tool can be used for future product design?" will be discussed in the report.
Colours, colour codes, overall user friendliness is very good	Noted

D.1.4 Fourth expert (Exp4) - (24/04/2025 – 8.00 - 8.50)

Comment	Actions / changes
It is better if the user has the capability to skip weight assignment with default weight assignment.	A possible option and introduced before the planned tool testing.
Weight1 (Enablers) questions are like the tool developers have taken decisions on behalf of user when only has option to select level 4 & 5 only.	Since we found these 3 dimensions (weight1) are in most of the assessment tool and some of the developer's emphasise the importance of these we considered they as enablers and need to keep the importance with high weights. Hence no changes but will be evaluated during tool testing.
Since the tool has a section to collect user information, a personal data disclosure should be available.	We developed the tool with the point of view that the tool will be a part of organization function. Then the user information is not a problem. But all the data collection during tool testing will be included personal data disclosure.
Weight1 & 2 questions better to prepare to evaluate past activities instead of futuristic imaginary situations.	All the users may not have the same necessary experiences and then the user is in a more tense situation. But if the tool is going to use as a team, then this is a possible change.
When reading the questions under weigh assigning parts user may feel like we need to prioritise all the dimensions.	No change. These scenario-based questions were formulated to get more practical response from the users. Since weights for target setting, the high values are not affected the overall readiness results.
Big yes for 40 questions to assess current status with structure, simplicity, and clarity.	Noted.
User may not have good idea about some terms in those 40 questions and can be use option like "Pop-up" notes on cells to give tool developer own definitions.	Agreed. Pop-up notes were added for all 40 elements with developer own definitions.
The dashboard is a bit noisy with colours and better to improve with single colour gradient.	All others were impressed with the dashboard and accepted the colour codes. Hence did not change.

E
Appendix 5

E.1 Individual Survey Form

Table E.1: Survey Response Table

#	Questions	1	2	3	4	5
Section 1: Perceived Value of the Assessment						
1	The Circularity Readiness Assessment helped me better understand our department's current position regarding circularity					
2	The assessment highlighted specific areas where collaboration with other departments or external partners could improve circularity					
3	The tool made it clear how different parts of the value chain impact circularity and sustainability					
4	Insights from this assessment will help identify specific actions that departments can take to improve circularity					
5	Applying the assessment regularly could help our company track and improve circularity readiness over time					
Section 2: Impact on Collaboration and Circularity						
6	Collaboration within the aerospace value chain can be strengthened by using this assessment tool					
7	Using the tool can support better communication and alignment with suppliers, customers, and other stakeholders					
Section 3: Final thought						
8	Any other feedback you would like to share about the tool?					

F

Appendix 6

F.1 Individual Tool testing workshops

F.1.1 First tester (Ind-T1) - (05/05/2025 - 9.00 - 10.00)

- Took 18 minutes to complete the assessment using the tool (9.07AM-9.25AM)
- Tool arrangement and structure is good.
- Likert scale in questions: not action taken, and exploring possibilities have two meanings and at two levels. Can not be put into one level. exploring possibilities is closer to the laying ground works and better to combine those.
- Weights2: The structure is very good and very interested about it.
- Weights1: User should have more flexibility to set the priority level.
- In the Generated report, if the image of the dashboard can be moved to the first or second page and it can give good idea to reader of report.
- Recommendations field in the tool dashboard: Current recommendations are in basic level. Expect more details and action in place in the recommendation. Also, he agreed that keeping the balance between very specific vs General is very hard when develop such broad tool for broader users' group.
- External stakeholder engagement: Without the support of customers, suppliers, and internal teams, the tool has limited value. The hard part is to get it accepted in and out of the organisation. Once accepted by customer, suppliers, different parts of the organisation it can be very useful. If it is only me using the tool, our customers or suppliers will not care. Then the effort needs to be on selling the tool first, before it can be used to improve.

F.1.2 Second tester (Ind-T2) - (05/05/2025 - 10.00 - 11.00)

- Took 22 minutes to complete the assessment using the tool (10.10AM-10.32AM)
- Weight1: Add a note reasoning why you chose only two options. That can give the user a first impression and it can avoid ambiguity.
- Questions and weights: Add an option to see previous assessment results to remind what they had done during last run and a place to comment/self-note cell if someone needs to highlight the reason why he/she selected that scale/value.
- Good to have an individual profile maintained for the tool
- Q9: regulatory compliance: It is a must for aerospace. Not any other option except 5. And although a company has issues, they may put as 5 to avoid unnecessary external issues.

- Q10 (Performance Measurement - KPI for circularity): add some examples to the question
- Q10 (Performance Measurement - Employee-Led Circular Initiatives): the question is not clear for me.
- Q8 (Technology and data): Some questions are not aligned with the Likert scale. Need to refine the questions
- Overall: the tool has covered a broad area in depth, impressive arrangement of the tool. The tool is pretty useful for circularity.

F.1.3 Third tester (Ind-T3) - (05/05/2025 - 13.00 - 14.00)

- Took 29 minutes to complete the assessment using the tool (1.06PM-1.35PM)
- The initial impression by looking at the tool was that this tool is some promotional tool or whether the students developed it.
- Q3 (Product and Service Innovation): When answering about product service systems, he had a doubt whether he needed to pick commercial aircraft side or fighter aircraft side because GKN has full ownership on fighter products but not for commercial products. When he answering he kept focused on the commercial side.
- He is Ok with tool and happy about not having too many questions.
- Overall, he is happy about the tool but less comments from him.

G

Appendix 7

G.1 Group Survey Form

Table G.1: Participant Feedback Survey - Group

#	Questions	1	2	3	4	5
Section 1: Participant Information						
1	Name:					
2	Department (Check all that apply): ❏ Manufacturing ❏ Procurement ❏ Design ❏ Circularity / Sustainability Team ❏ Other:					
Section 2: General Experience						
3	The overall tool was easy to use and understand					
4	The step-by-step structure helped me to navigate the tool efficiently					
5	The Excel format was practical and user-friendly					
6	The tool gave me a clear picture of our current circularity readiness					
7	The team discussion during the group assessment was valuable					

#	Questions	1	2	3	4	5
8	Which mode of use do you think is more suitable for this tool? (Check all that apply): ❑ Individual ❑ Group ❑ Both are equally useful ❑ Depends on the context – Please explain					
9	Please explain if you selected "Depends on the context" above:					
Section 3: Tool Methodology & Steps - Feedback						
10	The introduction (Methodology & Key Terms) of tool helped me understand the circular economy context					
11	The user info section was simple and clear					
12	The dimension weighting questions were helpful					
13	The assessment questions were easy to understand and answer					
14	The dashboard / recommendation interface was clear and useful					
15	Reassessing periodically using this tool would be valuable					
16	Do you agree with separating the dimensions into Enablers and Implementers? ❑ Yes – It adds clarity ❑ No – Treat all dimensions the same ❑ I do not know / No opinion					
17	Should users be allowed to set any level (1–5) for priority? ❑ Yes – Users should have flexibility ❑ No – Enablers should have high priority ❑ I do not know / No opinion					
Section 4: Final Thought						
18	This tool can improve collaboration across the value chain (e.g., with suppliers, customers, partners)					

#	**Questions**	**1**	**2**	**3**	**4**	**5**
19	This tool is suitable for use by external value chain partners (e.g., suppliers, service providers)					
20	How could this tool help inform or support team-level planning and improvement initiatives?					
21	Did the tool help you identify any new ideas or opportunities for improving circularity in your area? Please explain:					
22	What specific action(s) do you recommend for GKN to take based on this assessment?					
23	What was the most useful feature of the tool? Why?					

H

Appendix 8

H.1 First Group Tool Testing Workshop : Group-T1

The insights that could be captured from the circularity readiness assessment tool testing workshop with the first case company are listed below.

H.1.1 Tool Use Phase

- The tool's structure supports circularity readiness assessment through a weight & score approach.
  - "The tool, first you assign weights... and then we assess how we're actually good at that, more bad."
  - "It looks at different areas that can enable our company to be more circular."
- Real-world examples which they known helped participants evaluate more accurately.
  - "The biggest example, always the metal Swarf... is always a very good example for that in practice."
- The participants interpreted some questions differently, leading to varied scoring.
  - "I interpret the question differently than you do."
  - "Could be different ways of interpreting the questions."
- End-of-life responsibilities and outcomes are poorly understood internally.
  - "We assume that someone is recycling our products at the end of life."
  - "That is not really a priority, that is quite low"
- Economic drivers dominate circular decisions.
  - "Of course, we always put money first... if we don't make money, we won't go for it."
  - "Circularity is secondary."
- Repair practices are well established and valued.
  - "Everything in repair is circular."
  - "We have a whole repair organization... it is part of our strategy."
- The tool triggered deep team reflection and dialogue.
  - "It is better to continue this discussion... your ideas. That is the main thing for our research."
- Circular thinking exists, but is not explicitly framed as 'circularity'.

  - “We do not talk about circularity… we must have used that word.”
  - “Circularity is just something on the side in a lot of cases.”
- The use phase was perceived as less emphasised during the assessment, despite being covered in the tool.
  - “We talked a lot about customers and end of life… but the in between is not so much”
- Digital technology is seen as a future enabler, but not yet justified by circular goals alone.
  - “Investing in technology for the sake of becoming more circular… I don’t find very likely right now.”
- Weakness in training and awareness about circularity.
  - “We are laying the groundwork… but we are not really there where everybody has to know the basics.”
- Data systems are unreliable for tracking circular metrics.
  - “We don’t really have the input… we don’t have a system that is reliable and standardised.”
- Participants struggled to assess procurement and supply chain due to limited visibility and involvement.
  - ”Quite bad that they were going to supply chain procurement, yeah… also because we don’t really work with it”.

H.1.2 Dashboard Review Phase

- Visualising the gaps between performance and importance supports strategic alignment.
  - “The goal could be to have both lines aligned… not necessarily to reach five… but to not have too big gaps.”
- Discrepancies reveal where performance is high, but importance is rated low.
  - “We believe we’re already so good at it… we’re not putting a lot of emphasis on making that even better.”
- End-of-life stands out as a critical weakness.
  - “That can’t be a surprise, because a lot of the questions about end of life we answered with like one or two.”
- Dashboard highlights organisational blind spots.
  - “It’s what the tool thinks is your weakness that you can improve.”
- Weighting step is validated through gap visualisation.
  - “The black line is based on the weights… what’s important for us.”
  - “Because we’re doing good… we focus more on that.”

H.1.3 Final Reflection & Discussion Phase

- Group use is more reflective than individual scoring.
  - “The tool for me sparked interesting discussion in a group.”
  - “The scoring was more reflecting of where we actually are.”
- Participant diversity improves representativeness.

  - "We'd probably get some other answers as well... diversified group gives better output."
- The tool is most effective at business area or value stream level.
  - "I feel like it's the right level—the engines level."
  - "Value stream and business area... not site level."
- Role/perspective (OEM vs commercial) influences responses.
  - "Some questions are really depending on from which perspective you think... we are the OEM ourselves."
- Need to balance specificity vs generality in recommendations.
  - "Very general... it's hard to do something real with it. Super specific... might not apply for all."
- Use phase (between customer and end-of-life) is under represented in tool.
  - "It was our customers and end of life... the in between is not so much."
- Tool not fully suitable for global / corporate assessment.
  - "If you put the global team in front of that tool, would they also manage to work with it?"
  - "It's quite operational."
- Question clarity needs improvement.
  - "Some topics are just prone to discussion."
  - "We could consider if the wording could be improved."

H.1.4 Additional Insights

- Tool language and question wording need to be clearer.
  - "Maybe the feedback is that the question is not super clear."
  - "The wording of the scale is a little bit tricky."
- The tool acts as a learning and awareness raising mechanism.
  - "I should know this, or I should have got that."
  - "The search is manual, typically, or difficult to find."
- Cultural framing of circularity is missing.
  - "We don't talk about circularity... we must have used that word."
- Industry context naturally encourages some circular practices.
  - "No one wants to lose a part... the material is so expensive that nobody wants to scrap anything."
- Best application level is business area or value stream.
  - "Engines level... value stream is probably the lowest I would go."
- Visualisation helps prioritise improvement areas.
  - "It's what the tool thinks is your weakness that you can improve."

H.2 Second Group Tool Testing Workshop : Group-T2

The insights that could be captured from the circularity readiness assessment tool testing workshop with the second case company are listed below.

H.2.1 Tool Use Phase

- Leadership and organizational commitment were considered extremely important for circular transition
  - "For me it's extremely critical to have a strong support. So I think that's really 5."
- Case company team has identified the importance of to decide on the evaluation scope before assigning the weight.
  - "When we're doing this assessment, is this from like a sub perspective as a whole or looking at a specific project."
- Customer demands were identified as a major driver of circularity.
  - "Very customer driven company. Definitely."
- Participants felt their company was proactive with regulation.
  - "Because everything is so slow in our industry, we have to be."
- Digital investments are well-supported when aligned with economic or innovation goals.
  - "Yeah, I think it's just a strong sport. We have a lot of ETU programs on planes."
- Circularity is embedded in business operations, but not always explicitly framed as such.
  - "There are a lot of circularity-positive things which are already integrated to our business models, although we might not speak about it in the circularity context."
  - "But of course, with take backs and reparation and maintenance and building on on existing platforms to make them better. That's definitely a part of our business model."
- Some circular activities are technically advanced but not strategically labelled.
  - "Principles in our business models that this is in circularity, but it doesn't say it outside the company. You know our maintenance operations we have."
- Feedback suggested separating questions on recyclability, optimisation, and hazardous material usage in Design for Resource Conservation or Users were in doubt that use of not-hazardous material in products helps design for resource conservation.
  - "You should maybe have these questions divided in three questions."
  - "I struggle a bit to to put it in in the context of the alternatives"
  - "We do a lot of considerations in our processes when we do designing... but our products are not 100
  - "So that is a to be the footnote of this question, But if you look at our Product portfolio, we do a lot of work to see what we can do"
- Waste minimization and hazardous material handling were seen as highly integrated.
  - "We definitely take action... I would say it's fully integrated."
- The company has limited engagement in mutually beneficial relationships across the value chain, highlighting a need to explore collaborative circularity opportunities.

  - "I have no knowledge of this, but I could imagine we were very low on this too. . . "
  - ". . . because we don't charge so much resource for add or companies."
  - ". . . because of like the nature of our products. . . "
  - "Yeah, yeah. Explore possibilities, I think."
- • Reverse logistic is a similar word for take back. The case company only families with take back.
  - "Yeah, not reverse or If we look at the definition."
  - "Like taking take back programs'"
  - "we do have some take back schemas we installed in train simulation in navigation services and also in dynamics. We have a take back programs."
- Initial uncertainty shifted to recognition of partial involvement in end-of-life material recovery with given context guidance.
  - "Is that that we as a company recover material or that could it be that someone else recovers the material?"
  - "OK. Because we do guide our customers if they're going to. Do some end of fly for the products. We do sell some products to recycling facility facilities."
- Re-manufacturing and refurbishment activities exist but are not strongly developed.
  - "We do a lot of refurbish. . . you can set the number 2 here."
- End-of-life responsibilities are often delegated to customers
  - "Our customer owns our products. . . we don't have the producer responsibility."
- There are resources and technology but the circularity perspective design is at the level of laying the ground work.
  - "But we look at the other ways, technical performance, optimizing of the products, but not for certainly designed to do, yeah"
- There are resources and technology but the circularity perspective in service assessment is at the level of No Action Taken / Exploring Possibilities.
  - : "Yeah, we don't do it for a circular economy approach. We do it for other things"
  - "Yeah, we do. We do have a big data, we working with digital twins where IoT for GRIP and other systems. But not for circularity approach."
- But the team was very impressive about the questions in Technology and because they gave new way of thinking.
  - "That's a good questions. I like it."
- Several assessments revealed that circularity practices are being explored, but not yet formalised.
  - "That's a nice way of saying we're not doing this. I like exploring possibilities as like a phrase."
- Delegation in the point of view of Circular Economy responsibilities was very new to the team which handling regulations and compliance.
  - "Mm hmm. Yeah, we do some delegation, but not in this way. I think it is one or two. Do you think team?."

  - “But then of course we have. I mean disposal. How to dispose everything and how to to take care of it at the end of life and so on. But it’s not specifically. Named Circular economy.”

H.2.2 Dashboard Review Phase

- Participants confirmed the dashboard realistically reflected their maturity.
  - "I would say it’s realistic. I mean, we’re working with all of these parts or most of them, but still in the laying, the ground works in in a lot of perspectives."
- The tool helped identify both strong and weak dimensions.
  -
- Use at business unit (BU) level was strongly recommended
  - "We should do this on a more granular level within the company."
- The tool was praised for efficiency and ease of use.
  - "It took us how long? 20,25 minutes to go through this, of course. Now we didn’t go very deeply... but still we got through it."
- Value in training prioritisation was noted and it is part of regulation.
  - " Score show Wellness about circularity. So we know how much train you should do for your employees."
  - “Yeah, I think that’s the important thing to know because we are aware about the legislation, regulations and so on”
- The tool’s ability to work without sensitive data was seen as a benefit.
  - "That could be a sensitive topic for some to share data or or provide evidence... This is more like what do you think of your status right now."
- Sharing with partners in the value chain was supported.
  - "Very good thing to see your status and your partnership ’cause we have supplies. We’re very good at this."
- The tracking feature was seen as helpful for long-term readiness development.
  - "You can come back in another three months time and you can do the same assessment for your company and you can see the track."
- Participants emphasised progress tracking over absolute scoring
  - "It’s the progress and the next time you do it, have you improved from the ones before."
- Long-term changes in circularity take time in the aerospace context.
  - "Going from a Step 3 to a Step 4 for our industry and our company... could be done in a time frame of, like, several years."
- A more granular scale could improve visibility of change.
  - : "We would benefit from a more granular scale with smaller steps if we want to see progress."

H.2.3 Final Reflection & Discussion Phase

- Possibility to use the tool with value chain partners were accepted

  - “ I think so. Very good thing to see your status and your partnership because we have supplies. We’re very good at this.”
  - “Hmm. I think it’s a. It’s a good thing that it doesn’t require any data to to do the assessment. That could be a sensitive topic for some to share data or or provide evidence."
- The tool is valued more for tracking progress over time than for its absolute scores, emphasising continuous improvement in circularity readiness.
  - “A good way to qualitatively measure exactly what you said you should do. Measure your circularity readiness. And I mean in this kind of exercises, I’m thinking that it’s not the actual value that you get at four or five on that scale. That’s the important one. It’s the progress and the next time you do it, have you improved? From the ones before?”
- Suggested refinement: differentiate clearly between “no action” and “exploring possibilities.
  - "I would really like to separate those two because no action taken. That’s like, no, we haven’t done anything. But then in the next chapter at least, you have started looking at it."
- The tool was praised as a method for internal evaluation and planning.
  - "Very nice way to set your status... I will use it internally."
- Tool’s potential to support strategy development was recognised.
  - "We should do this for on on BU level to know like we’re developing our circularity strategy right now."
- Strong overall feedback was received
  - "Good job really. You should be very happy with your thesis work."

H.2.4 Additional Insights

- More wider team need to answer to the questions.
  - “All the participants did not know to answer about new revenue models but guess a value.”
  - When answering to the Circular Innovation and Collaboration - “It probably varies a little bit throughout the companies as we’re so big”
- Participants acknowledged the value of transforming the Excel-based tool into a secure, shareable web-based version for broader use across value chain partners.

I
Appendix 9

I.1 ENGREEN CRA Tool

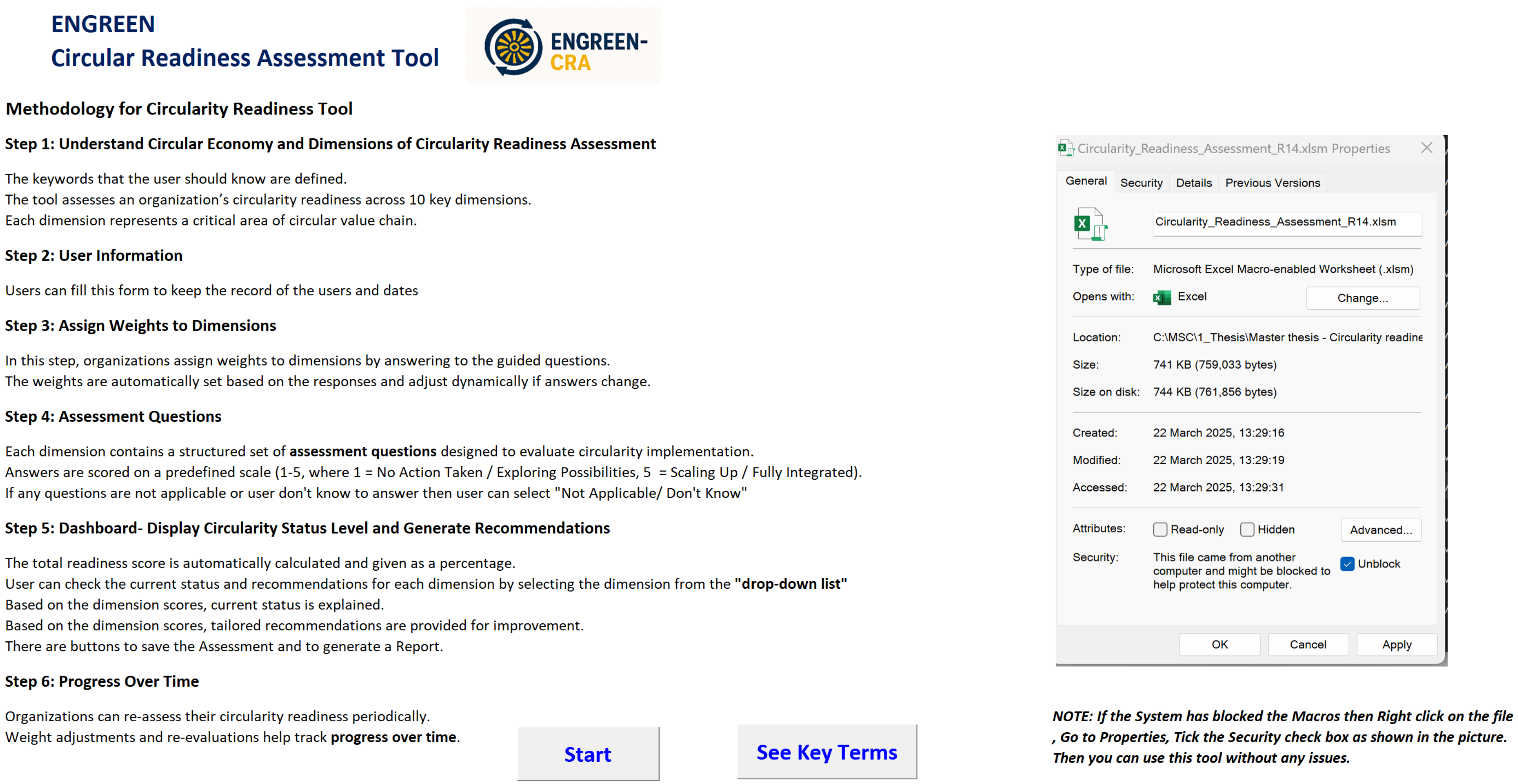


Figure I.1: Tool methodology

Key Terms & Definitions:

Circular Economy	An economic system that focuses on closed cycles aimed at eliminating waste and promoting resource efficiency through the integration of supportive policies, renewable energy and sustainable practices (E.g.: reuse, remanufacturing, and recycling, etc) (9)
Circularity Readiness in Value Chain	The extent to which a company's value chain is psychologically and structurally prepared to transition to circular economy principles (1) (10)
Value Chain	The full range of activities required to bring a product or service from conception to end-of-life, including design, production, distribution, use, and disposal including flows of information, goods, money and shared values(5).
Circularity Assessment	The evaluation of how well a company implements circular strategies across its value chain (7).
Circular Business Model	A business approach that integrates circular principles, such as closed-loop supply chains, product-as-a-service models, and resource efficiency (1).
Reverse Logistics	The process of returning products, materials, or components for reuse, refurbishment, or recycling (4).
Circular Design	Product development strategies that consider durability, modularity, and recyclability to support circularity (3).
End-of-Life	The final stage of a product's lifecycle, where it is disposed of, recycled, remanufactured, or repurposed to minimize waste (9).
Life Cycle Assessment (LCA)	A method for evaluating the environmental impact of a product or process from raw material extraction to end-of-life (9).
Material Circularity	A measure of how efficiently materials are kept in use through reuse, recycling, and closed-loop systems instead of being wasted (2)

Dimensions

The tool assesses an organization's circularity readiness across 10 key dimensions:

Organisation	Examines company culture, leadership commitment, governance structures, skills, resources, and internal collaboration necessary to drive circular practices.
Business Model & Strategies	Assesses how well the company's business model and strategic initiatives integrate circular principles, such as circular value propositions and partnerships.
Product & Service Innovation	Measures the company's ability to design and innovate products/services that are modular, durable, reusable, repairable, or recyclable.
Production	Evaluates how circularity is embedded into production processes, including resource efficiency, waste minimization, and sustainable manufacturing practices.
Supply Chain & Procurement	Assesses supply chain management and procurement strategies for circularity, emphasizing supplier collaboration and circular material flows.
Customers, Support & Maintenance	Reviews company approaches to customer engagement, including maintenance, repair, overhaul, education, and circular service provision.
Reverse Logistics & End-of-Life Strategies	Evaluates processes and infrastructure for product takeback, reverse logistics, refurbishment, remanufacturing, recycling, and disposal.
Technology & Data	Assesses implementation and maturity of enabling technologies (e.g., IoT, AI, blockchain) and data management supporting circular economy strategies.
Regulatory & Compliance Readiness	Measures preparedness and responsiveness toward regulatory changes, compliance standards, and certifications related to sustainability and circular economy.
Performance Measurement	Examines the establishment of metrics, indicators, and reporting frameworks to track and improve circularity performance.

Go To User Information

Figure I.2: Key terms & definitions

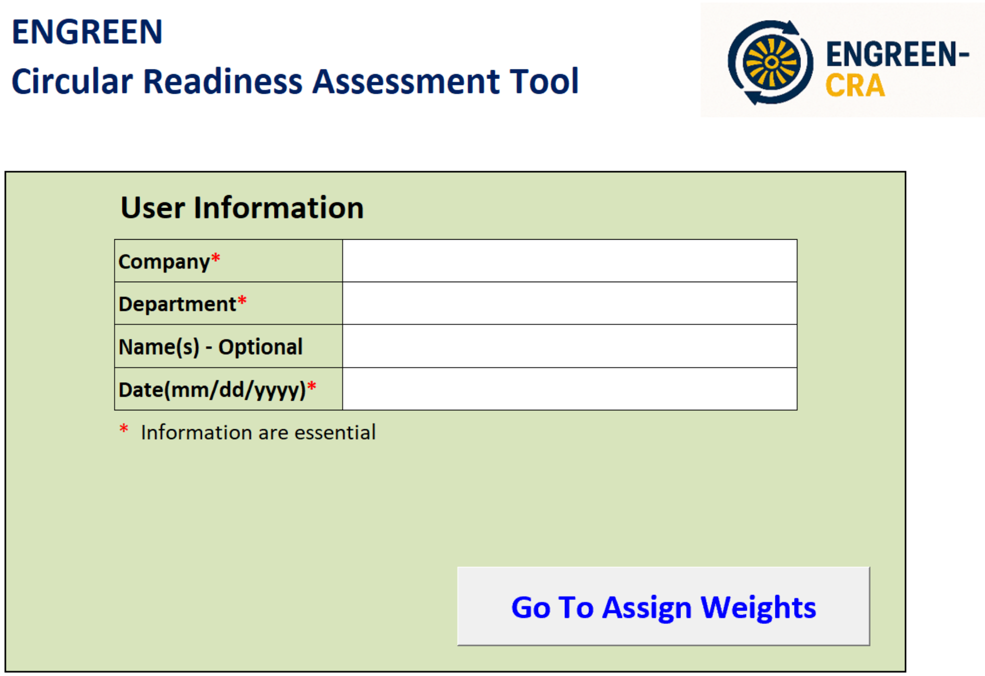


Figure I.3: User information

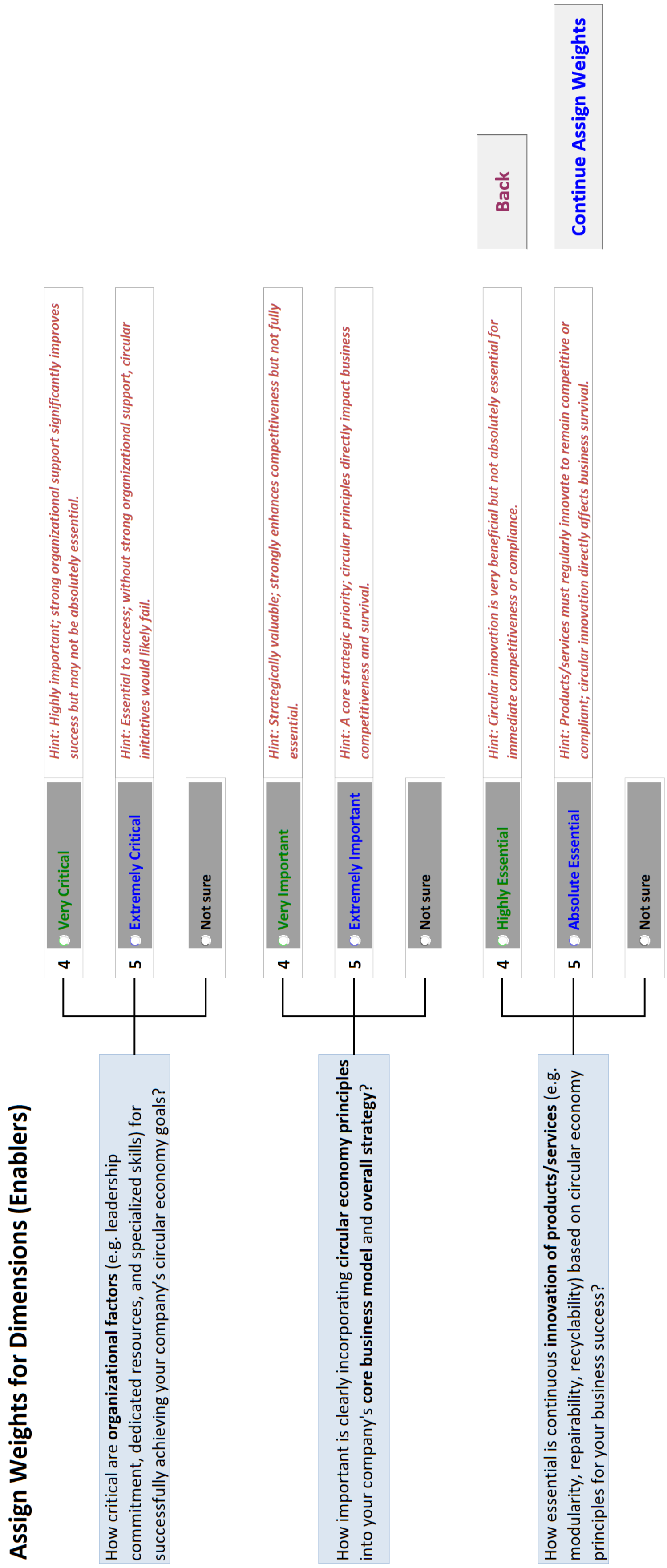


Figure I.4: Assign Weights for Dimensions (Enablers)

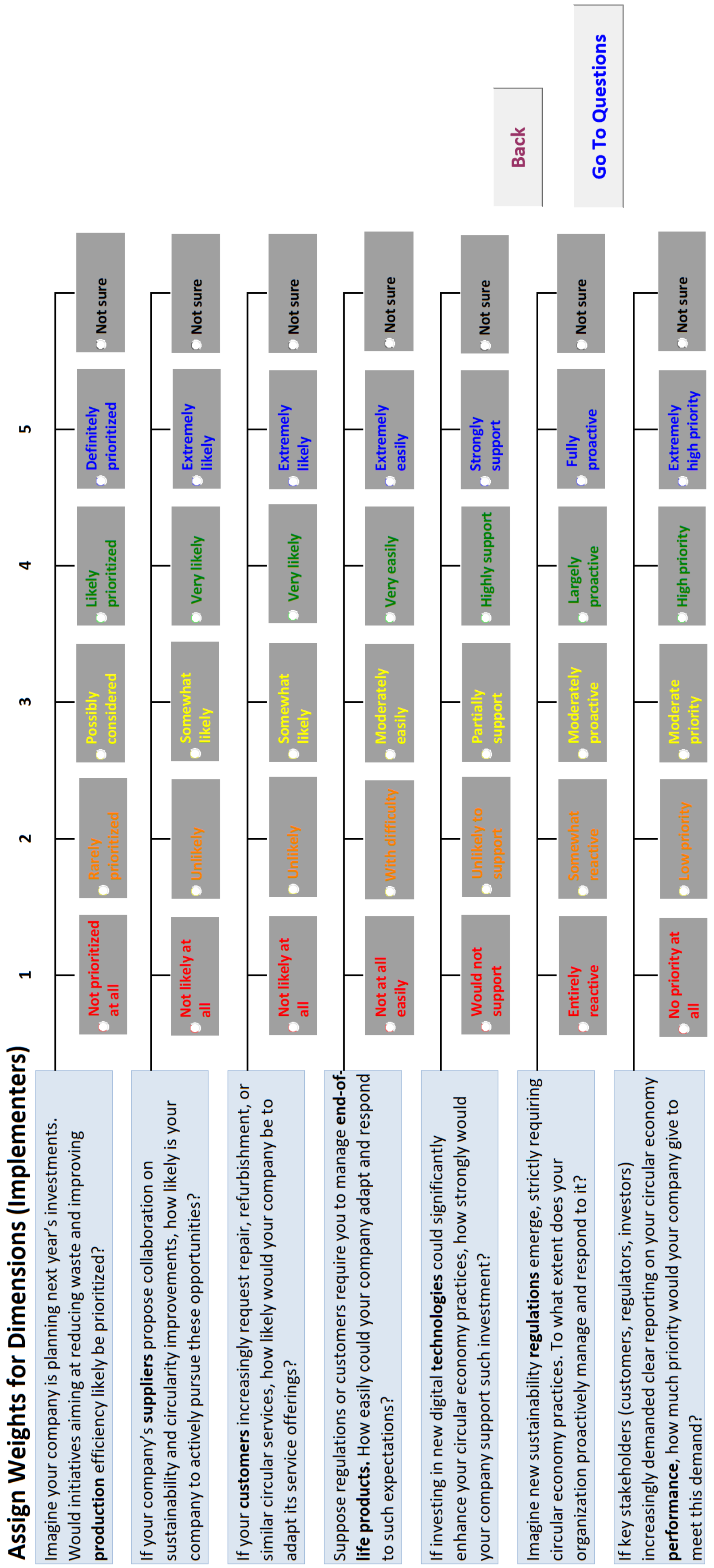
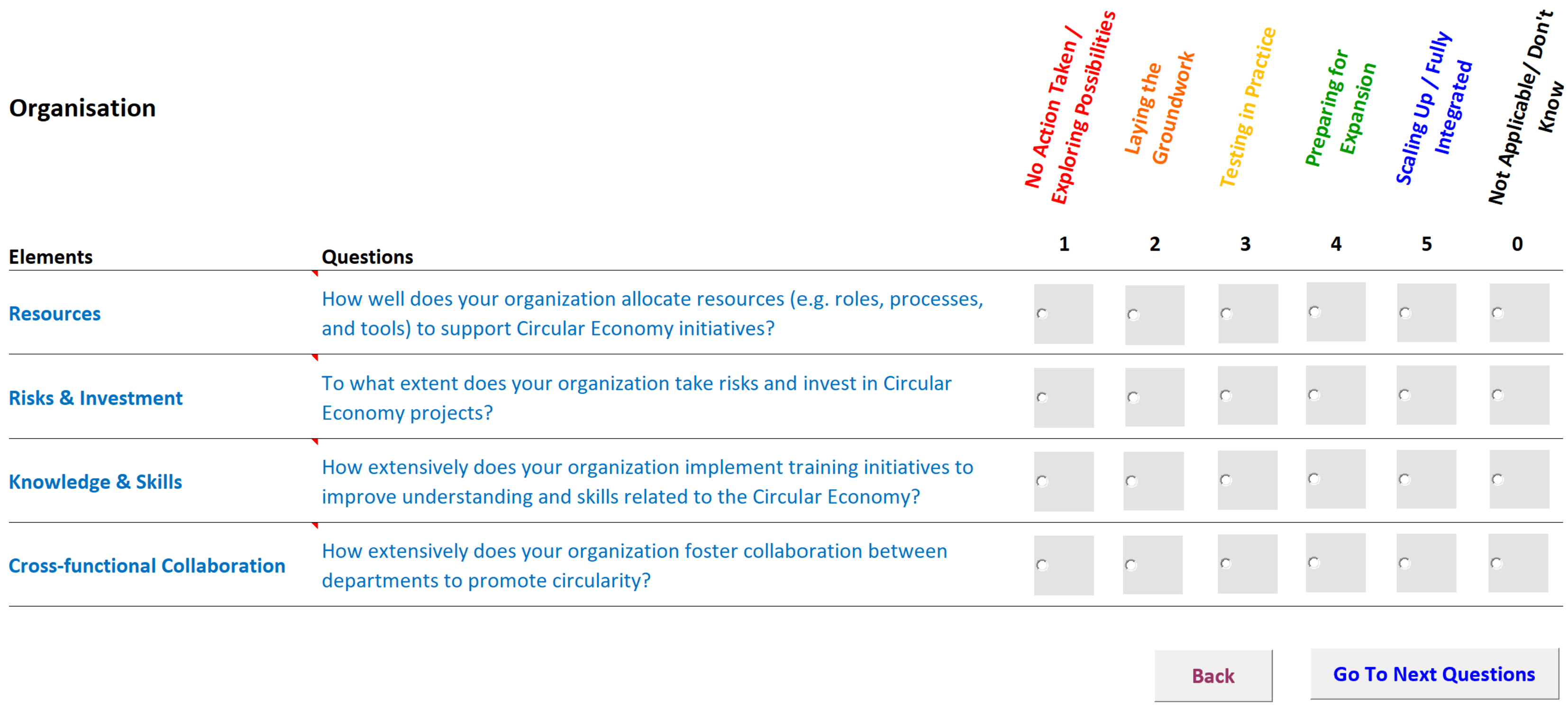


Figure I.5: Assign Weights for Dimensions (Implementers)



Organisation

Elements	Questions	No Action Taken / Exploring Possibilities 1	Laying the Groundwork 2	Testing in Practice 3	Preparing for Expansion 4	Scaling Up / Fully Integrated 5	Not Applicable/ Don't Know 0
Resources	How well does your organization allocate resources (e.g. roles, processes, and tools) to support Circular Economy initiatives?						
Risks & Investment	To what extent does your organization take risks and invest in Circular Economy projects?						
Knowledge & Skills	How extensively does your organization implement training initiatives to improve understanding and skills related to the Circular Economy?						
Cross-functional Collaboration	How extensively does your organization foster collaboration between departments to promote circularity?						

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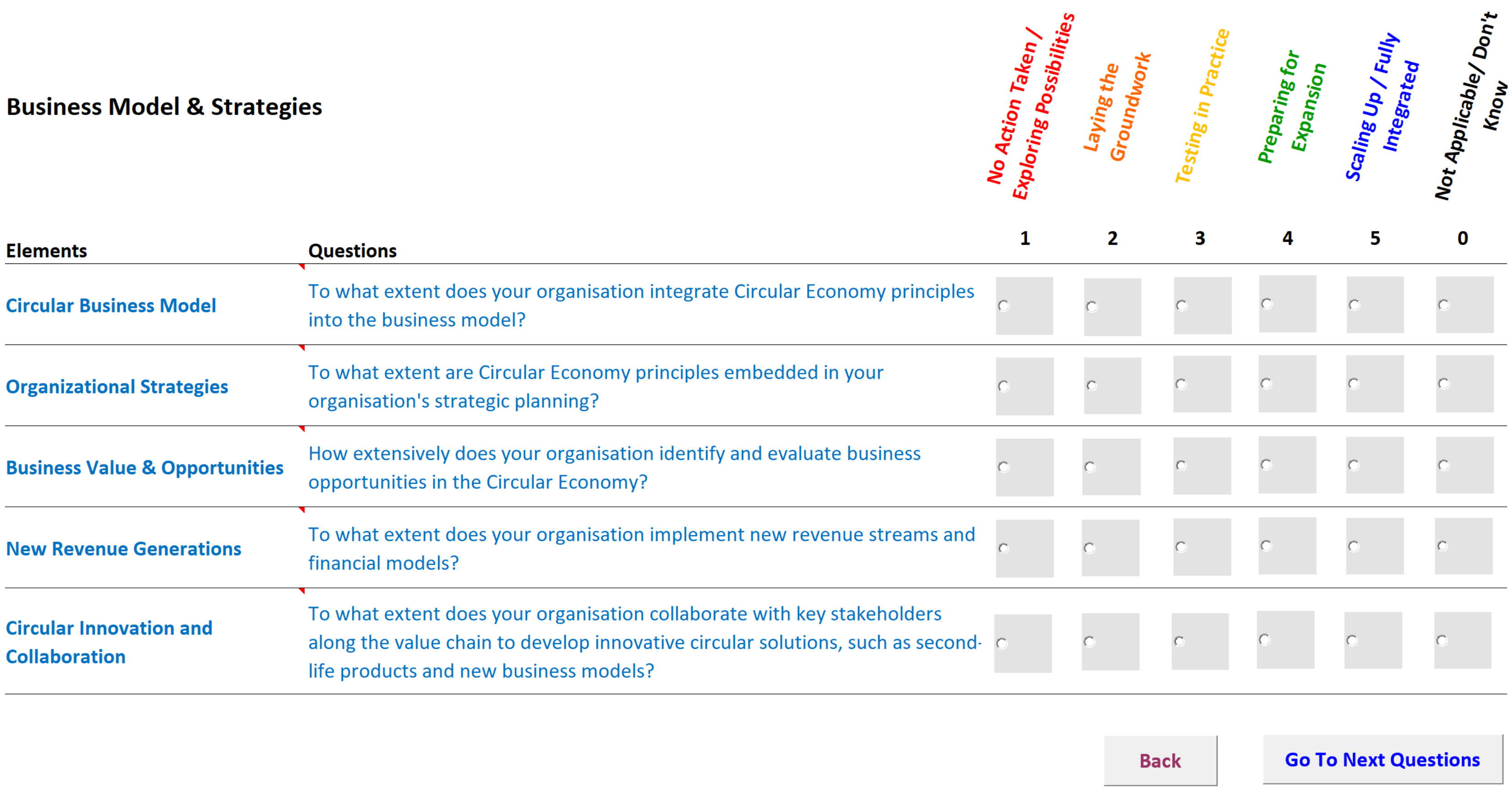
Figure I.6: Questions - Organization



Business Model & Strategies

Elements	Questions	No Action Taken / Exploring Possibilities 1	Laying the Groundwork 2	Testing in Practice 3	Preparing for Expansion 4	Scaling Up / Fully Integrated 5	Not Applicable/ Don't Know 0
Circular Business Model	To what extent does your organisation integrate Circular Economy principles into the business model?						
Organizational Strategies	To what extent are Circular Economy principles embedded in your organisation's strategic planning?						
Business Value & Opportunities	How extensively does your organisation identify and evaluate business opportunities in the Circular Economy?						
New Revenue Generations	To what extent does your organisation implement new revenue streams and financial models?						
Circular Innovation and Collaboration	To what extent does your organisation collaborate with key stakeholders along the value chain to develop innovative circular solutions, such as second-life products and new business models?						

Figure I.7: Questions - Business Model & Strategies

Product & Service Innovation

Elements	Questions	1 No Action Taken / Exploring Possibilities	2 Laying the Groundwork	3 Testing in Practice	4 Preparing for Expansion	5 Scaling Up / Fully Integrated	0 Not Applicable/ Don't Know
Product & Service-Systems	To what extent does your organisation develop and implement a product as a service (e.g. component leasing, life cycle management solutions, additive manufacturing solutions)?	○	○	○	○	○	○
Design for Life Extension	How extensively does your organisation develop products and services with an extended lifetime (e.g. design for maintenance, modularity, and spare parts replaceability)?	○	○	○	○	○	○
Design for End-of-Life	How extensively does your organisation develop products and services that effectively address End-of-Life considerations (e.g. design for disassembly, remanufacturing, recycling, etc.)?	○	○	○	○	○	○
Design for Resource Conservation	To what extent does your organisation use recyclable, optimized, non-hazardous materials in products?	○	○	○	○	○	○
Efficient Manufacturing Design	To what extent does your organisation integrate waste elimination, energy efficiency, and reuse of manufacturing waste into product design?	○	○	○	○	○	○

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Figure I.8: Questions - Product & Service Innovation

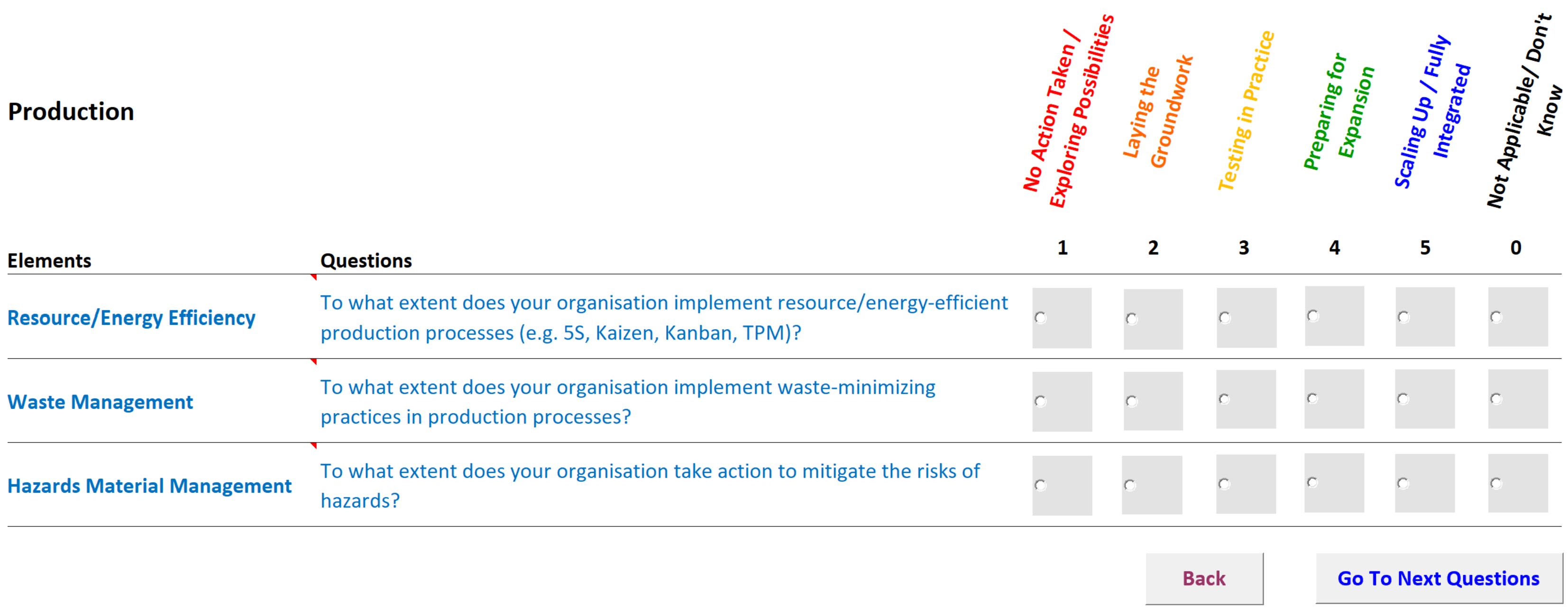
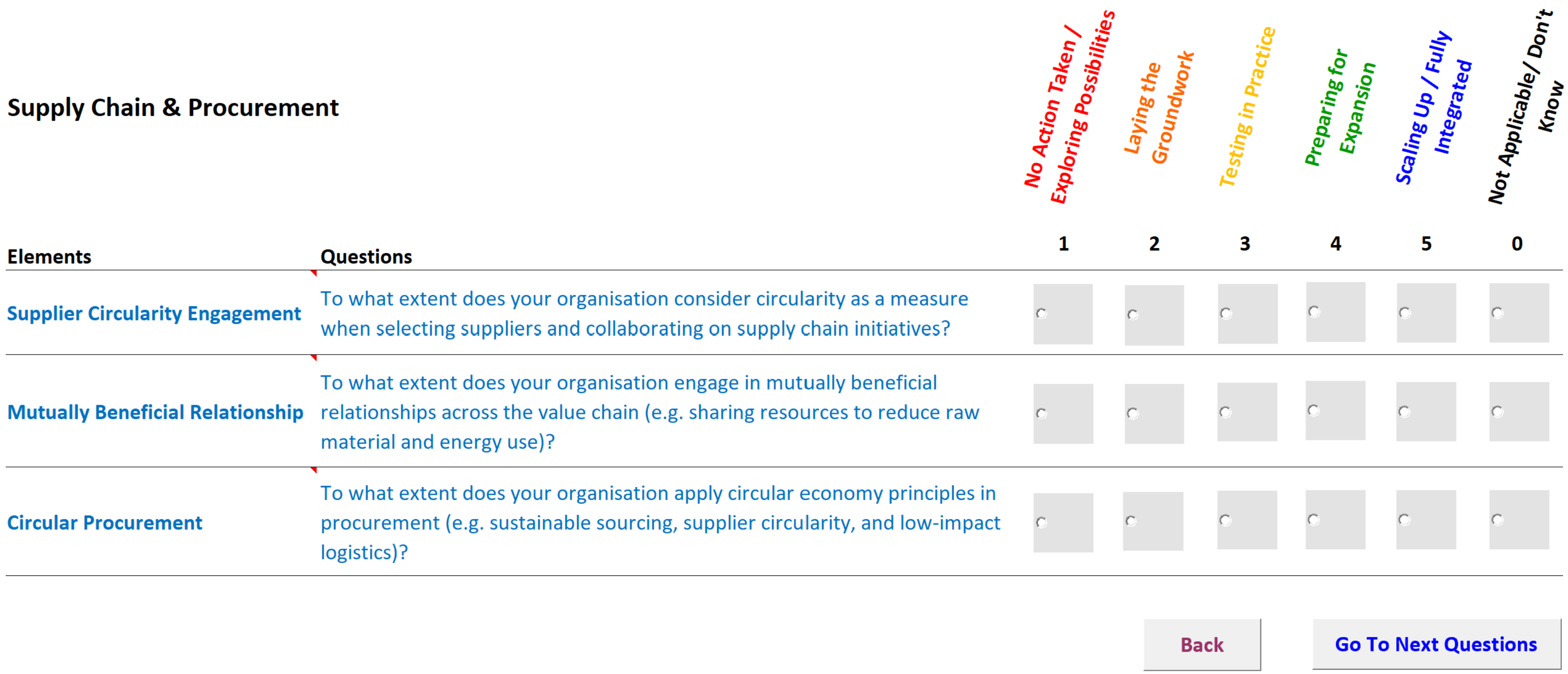


Figure I.9: Questions - Production



Supply Chain & Procurement

Elements	Questions	No Action Taken / Exploring Possibilities 1	Laying the Groundwork 2	Testing in Practice 3	Preparing for Expansion 4	Scaling Up / Fully Integrated 5	Not Applicable/ Don't Know 0
Supplier Circularity Engagement	To what extent does your organisation consider circularity as a measure when selecting suppliers and collaborating on supply chain initiatives?						
Mutually Beneficial Relationship	To what extent does your organisation engage in mutually beneficial relationships across the value chain (e.g. sharing resources to reduce raw material and energy use)?						
Circular Procurement	To what extent does your organisation apply circular economy principles in procurement (e.g. sustainable sourcing, supplier circularity, and low-impact logistics)?						

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Figure I.10: Questions - Supply Chain & Procurement

Customers, Support & Maintenance

Elements	Questions	1 No Action Taken / Exploring Possibilities	2 Laying the Groundwork	3 Testing in Practice	4 Preparing for Expansion	5 Scaling Up / Fully Integrated	0 Not Applicable/ Don't Know
Customer Awareness	To what extent does your company provide educational resources or initiatives to help customers understand product usage and extend the lifecycle of your products or services?						
After Service	To what extent does your organisation offer support and services throughout the product life cycle (e.g. maintenance, consultancy, advice, etc.)?						
Repair	How extensively are products repaired by your organisation to prolong their lifespan?						
Circularity-driven Services	To what extent does your organisation offer circularity-driven services to improve product longevity and customer engagement (e.g. sharing platforms, component pooling, modular upgrades, digital platforms, etc)?						

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Figure I.11: Questions - Customers, Support & Maintenance

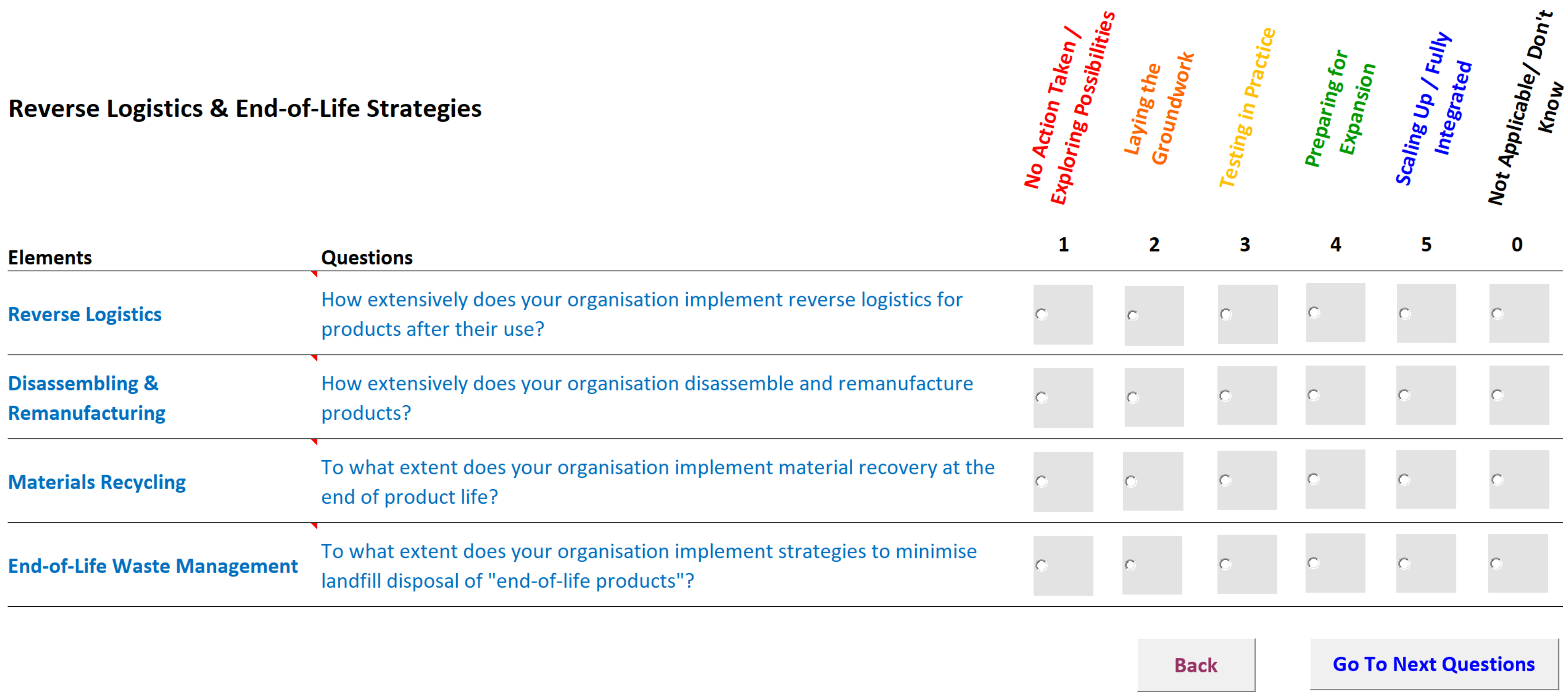
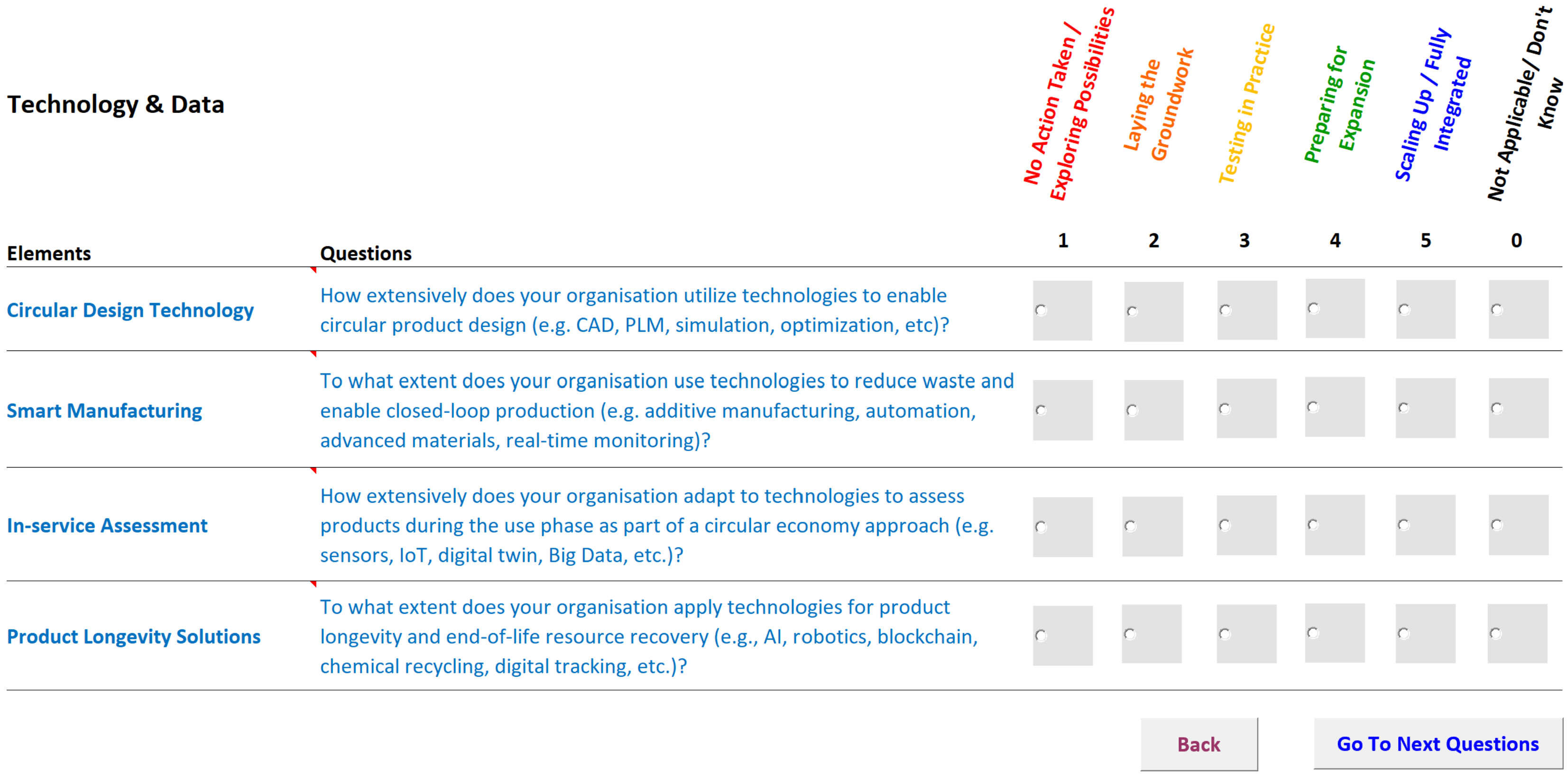


Figure I.12: Questions - Reverse Logistics & End-of-Life Strategies



Elements	Questions	1	2	3	4	5	0
Circular Design Technology	How extensively does your organisation utilize technologies to enable circular product design (e.g. CAD, PLM, simulation, optimization, etc)?						
Smart Manufacturing	To what extent does your organisation use technologies to reduce waste and enable closed-loop production (e.g. additive manufacturing, automation, advanced materials, real-time monitoring)?						
In-service Assessment	How extensively does your organisation adapt to technologies to assess products during the use phase as part of a circular economy approach (e.g. sensors, IoT, digital twin, Big Data, etc.)?						
Product Longevity Solutions	To what extent does your organisation apply technologies for product longevity and end-of-life resource recovery (e.g., AI, robotics, blockchain, chemical recycling, digital tracking, etc.)?						

Figure I.13: Questions - Technology & Data

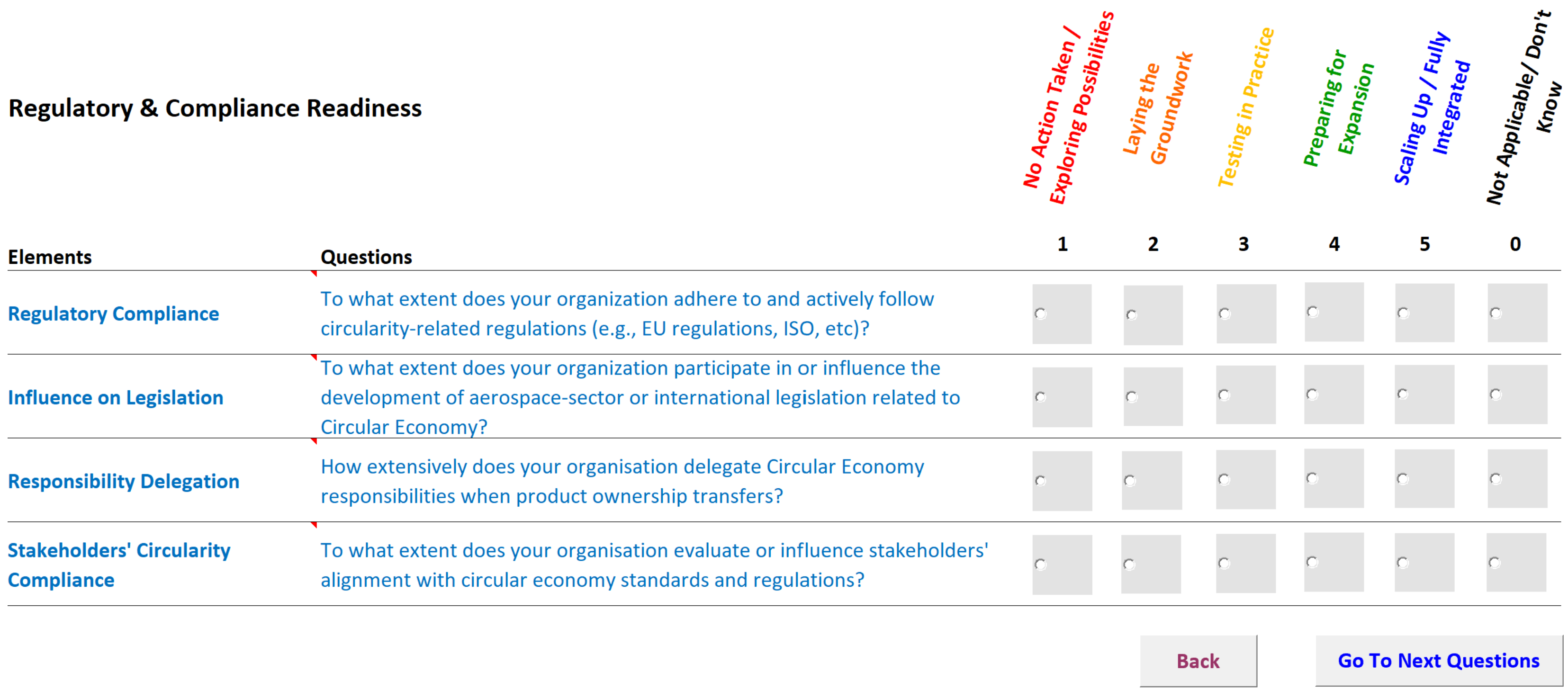


Figure I.14: Questions - Regulatory & Compliance Readiness

Performance Measurement

Elements	Questions	No Action Taken / Exploring Possibilities 1	Laying the Groundwork 2	Testing in Practice 3	Preparing for Expansion 4	Scaling Up / Fully Integrated 5	Not Applicable/ Don't Know 0
KPI for Circularity	To what extent does your organisation incorporate circularity-related measurements for KPIs?						
Life Cycle Assessment	To what extent do your organization's life cycle assessments (LCA) identify circularities within the value chain?						
Employee-Led Circular Initiatives	To what extent does your organization assess employee engagement in circular economy initiatives?						
Material Circularity	How extensively does your organisation develop and implement a reliable and standardised material circularity measurement system?						

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See Readiness Score

Figure I.15: Questions - Performance Measurement

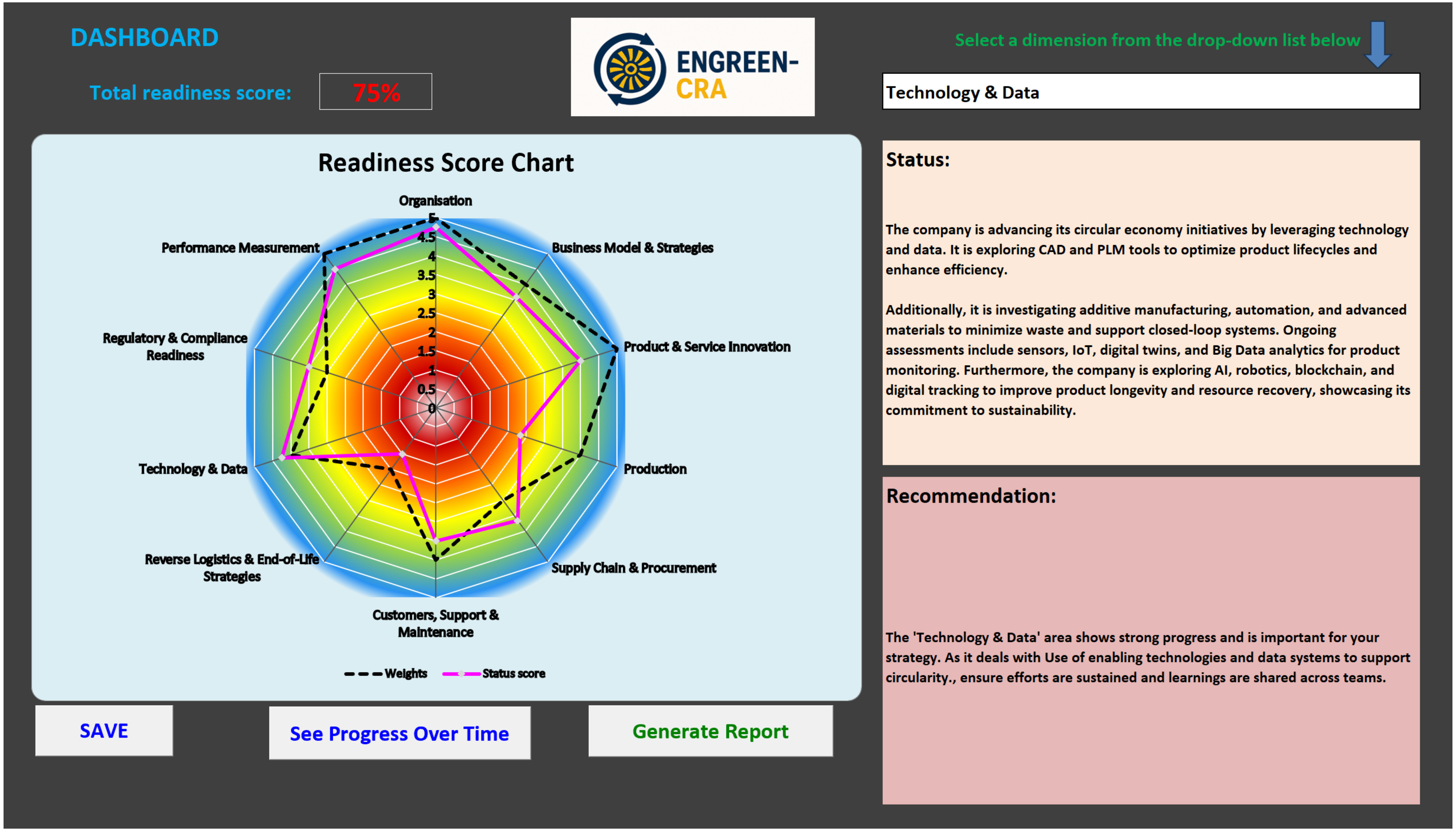

Figure I.16: Overall results - Dashboard

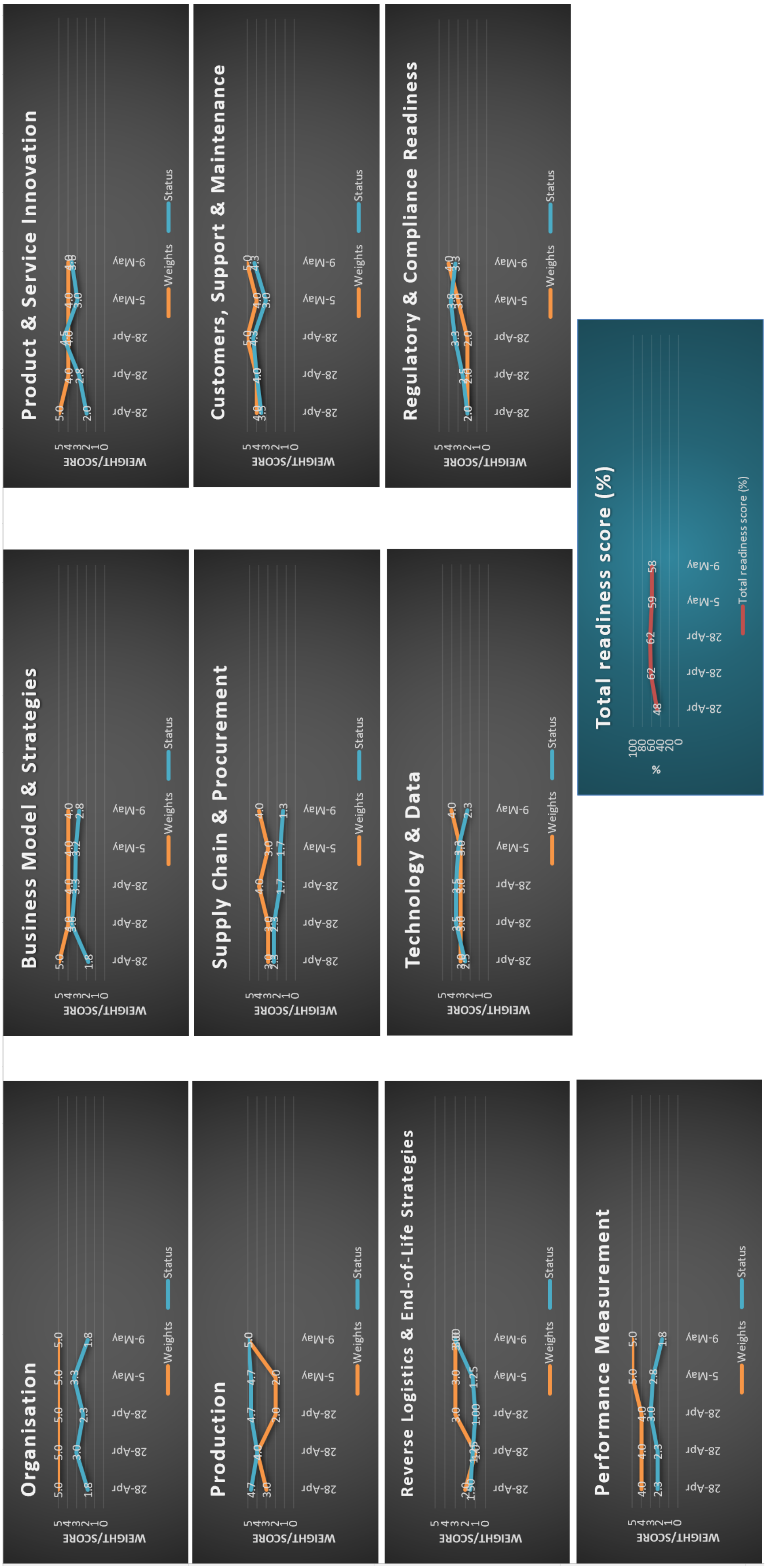

Figure I.17: Progress over time

J

Appendix 10

J.1 Macro Codes of the ENGREEN CRA Tool

See Key Terms, Go to User Information

```
Attribute VB_Name = "Module1"
Sub GoToNext()
    Dim ws As Worksheet
    Set ws = ActiveSheet
       Worksheets(ws.Index + 1).Activate
End Sub
```

Back

```
Attribute VB_Name = "Module9"
Sub GoToBack()
    Dim currentSheet As Worksheet
    Dim previousSheet As Worksheet

    Set currentSheet = ActiveSheet
    Set previousSheet = Sheets(currentSheet.Index - 1)

    previousSheet.Activate
End Sub
```

Delete Data

```
Attribute VB_Name = "Module12"
Sub DeleteData()
    Range("A10:Y32").ClearContents
End Sub
```

Start

```
Attribute VB_Name = "Module3"
Sub ResetAllCommmandButtons()
     Dim ws As Worksheet
    Dim ctrl As OLEObject
     Dim sheetName  As Variant

    ' List the sheet names you want to reset controls on
    Dim targetSheets As Variant
    targetSheets = Array("Weights1", "Weights2", "Q1", "Q2", "Q3", "Q4", "Q5", "Q6", "Q7", "Q8",
"Q9", "Q10") ' <-- Change sheet names here

    ' Loop through each listed sheet
    For Each sheetName In targetSheets
        Set ws = ThisWorkbook.Sheets(sheetName)

        For Each ctrl In ws.OLEObjects
            Select Case TypeName(ctrl.Object)
                Case "CheckBox", "OptionButton"
                    ctrl.Object.Value = False
                End Select
        Next ctrl
    Next sheetName

     ' Clear content in range D3:D6 on the "User Info" sheet
    Sheets("User Info").Range("D3:D6").ClearContents

    ' Clear values in column P for Weights1 & Weights2
    For Each sheetName In Array("Weights1", "Weights2")
        Sheets(sheetName).Range("R:R").ClearContents
    Next sheetName

    ' Clear values in column J for Q1 - Q10
    For Each sheetName In Array("Q1", "Q2", "Q3", "Q4", "Q5", "Q6", "Q7", "Q8", "Q9", "Q10")
        Sheets(sheetName).Range("J:J").ClearContents
    Next sheetName

End Sub
```

User Info

```
Attribute VB_Name = "Module10"
   Sub Userinfo()
   Dim ws As Worksheet
  Dim isEmpty As Boolean
    Dim cell As Range

    ' Set the active sheet
    Set ws = ActiveSheet
    isEmpty = False

   ' Check if any cell in the range J4:J7 is empty
        For Each cell In Range("D3, D4, D6")
        If Trim(cell.Value) = "" Then ' Corrected function usage
            isEmpty = True ' Set flag if an empty cell is found
            Exit For ' Exit loop immediately
        End If
    Next cell

    ' If all cells are filled, move to the next sheet
    If Not isEmpty Then
        ws.Next.Activate ' Move to the next sheet without checking availability
    Else
        MsgBox "Enter all necessary information. Check again.", vbExclamation, "Incomplete
Answers"
    End If

End Sub
```

Go to Next - Weights1

```
Attribute VB_Name = "Module7"
Sub ThreeW()
    Dim ws As Worksheet
    Dim cell As Range
    Dim isEmpty As Boolean

     ' Set the active sheet
    Set ws = ActiveSheet
    isEmpty = False

    ' Check if any cell in the range J4:J7 is empty
    For Each cell In ws.Range("R4:R6")
        If Trim(cell.Value) = "" Then ' Corrected function usage
            isEmpty = True ' Set flag if an empty cell is found
            Exit For ' Exit loop immediately
        End If
    Next cell

    ' If all cells are filled, move to the next sheet
    If Not isEmpty Then
        ws.Next.Activate ' Move to the next sheet without checking availability
    Else
        MsgBox "You have not answered to all questions. Check again.", vbExclamation,
"Incomplete Answers"
    End If

End Sub
```

Go to Next - Weights2

```
Attribute VB_Name = "Module8"
Sub SevenW()
    Dim ws As Worksheet
    Dim cell As Range
    Dim isEmpty As Boolean

     ' Set the active sheet
    Set ws = ActiveSheet
    isEmpty = False

    ' Check if any cell in the range J4:J7 is empty
    For Each cell In ws.Range("R4:R10")
        If Trim(cell.Value) = "" Then ' Corrected function usage
            isEmpty = True ' Set flag if an empty cell is found
            Exit For ' Exit loop immediately
        End If
    Next cell

    ' If all cells are filled, move to the next sheet
    If Not isEmpty Then
        ws.Next.Activate ' Move to the next sheet without checking availability
    Else
        MsgBox "You have not answered to all questions. Check again.", vbExclamation,
"Incomplete Answers"
    End If

End Sub
```

Go to Next - Q1, Q6, Q7, Q8, Q9, Q10

```
Attribute VB_Name = "Module4"
Sub FourQ()
    Dim ws As Worksheet
    Dim cell As Range
    Dim isEmpty As Boolean

     ' Set the active sheet
    Set ws = ActiveSheet
    isEmpty = False

    ' Check if any cell in the range J4:J7 is empty
    For Each cell In ws.Range("J4:J7")
        If Trim(cell.Value) = "" Then ' Corrected function usage
            isEmpty = True ' Set flag if an empty cell is found
            Exit For ' Exit loop immediately
        End If
    Next cell

    ' If all cells are filled, move to the next sheet
    If Not isEmpty Then
        ws.Next.Activate ' Move to the next sheet without checking availability
    Else
        MsgBox "You have not answered to all questions. Check again.", vbExclamation,
"Incomplete Answers"
    End If

End Sub
```

Go to Next - Q2, Q3

```
Attribute VB_Name = "Module5"
Sub FiveQ()
    Dim ws As Worksheet
    Dim cell As Range
    Dim isEmpty As Boolean

     ' Set the active sheet
    Set ws = ActiveSheet
    isEmpty = False

    ' Check if any cell in the range J4:J7 is empty
    For Each cell In ws.Range("J4:J8")
        If Trim(cell.Value) = "" Then ' Corrected function usage
            isEmpty = True ' Set flag if an empty cell is found
            Exit For ' Exit loop immediately
        End If
    Next cell

    ' If all cells are filled, move to the next sheet
    If Not isEmpty Then
        ws.Next.Activate ' Move to the next sheet without checking availability
    Else
        MsgBox "You have not answered to all questions. Check again.", vbExclamation,
"Incomplete Answers"
    End If

End Sub
```

Go to Next - Q4, Q5

```
Attribute VB_Name = "Module6"
Sub ThreeQ()
    Dim ws As Worksheet
    Dim cell As Range
    Dim isEmpty As Boolean

     ' Set the active sheet
    Set ws = ActiveSheet
    isEmpty = False

    ' Check if any cell in the range J4:J7 is empty
    For Each cell In ws.Range("J4:J6")
        If Trim(cell.Value) = "" Then ' Corrected function usage
            isEmpty = True ' Set flag if an empty cell is found
            Exit For ' Exit loop immediately
        End If
    Next cell

    ' If all cells are filled, move to the next sheet
    If Not isEmpty Then
        ws.Next.Activate ' Move to the next sheet without checking availability
    Else
        MsgBox "You have not answered to all questions. Check again.", vbExclamation,
"Incomplete Answers"
    End If

End Sub
```

Generate Report

```
Attribute VB_Name = "Module11"
Sub CreatePDFfromSelectedSheets()
    Dim ws As Worksheet
    Dim pdfName As String
    Dim pdfPath As String
    Dim printArea As String

    ' Set the PDF file name and path
    pdfName = "Circular Readiness Report.pdf"
    pdfPath = ThisWorkbook.Path & "\" & pdfName

  ' Define the sheets to be printed
    sheetNames = Array("User Info", "Dashboard", "Weights1", "Weights2", "Q1", "Q2", "Q3",
"Q4", "Q5", "Q6", "Q7", "Q8", "Q9", "Q10", "Q2", "Computation")

    ' Loop through each specified sheet and set the print area
    For i = LBound(sheetNames) To UBound(sheetNames)
        Set ws = ThisWorkbook.Sheets(sheetNames(i))
        ' Check if the sheet has a print area set
        If ws.PageSetup.printArea <> "" Then
            ' Set the print area
            printArea = ws.PageSetup.printArea
            ws.PageSetup.printArea = printArea
        End If
    Next i

    ' Create a new collection of selected sheets
    Set SelectedSheets = Sheets(sheetNames)

    ' Add page numbers in the footer
    With ws.PageSetup
        .CenterFooter = "Page &P of &N" ' &P = Current Page, &N = Total Pages
    End With

    ' Export the selected sheets to a single PDF
    SelectedSheets.Select
    ActiveSheet.ExportAsFixedFormat Type:=xlTypePDF, Filename:=pdfPath, Quality:
=xlQualityStandard, _
        IncludeDocProperties:=True, IgnorePrintAreas:=False, OpenAfterPublish:=True

    ' Notify the user
    MsgBox "PDF created successfully at " & pdfPath
End Sub
```

Save

```
Attribute VB_Name = "Module2"
Sub SaveResultsToSheet()
    Dim wsResults As Worksheet
    Dim ws1 As Worksheet, ws2 As Worksheet, ws3 As Worksheet
    Dim lastRow As Long
    Dim i As Integer

    ' Define sheets
    Set wsResults = Sheets("Progress Over Time")  ' Destination Sheet
    Set ws1 = Sheets("User Info")  ' Source Sheet 1
    Set ws2 = Sheets("Computation")  ' Source Sheet 2

    ' Find the next empty row in Results sheet
    lastRow = wsResults.Cells(wsResults.Rows.Count, "A").End(xlUp).row + 1
    If lastRow < 10 Then lastRow = 10 ' Make sure it starts at A5

    ' Copy data from different sheets to Results sheet
    With wsResults
        .Cells(lastRow, 1).Value = ws1.Range("D6").Value ' Extract Date
        .Cells(lastRow, 2).Value = ws1.Range("D3").Value ' Extract Company
        .Cells(lastRow, 3).Value = ws1.Range("D4").Value ' Extract Department
        .Cells(lastRow, 4).Value = ws1.Range("D5").Value ' Extract Name

        ' Loop to copy values from C4:C13 to E:N (Columns 5 to 14)
    For i = 0 To 9
        wsResults.Cells(lastRow, 5 + i).Value = ws2.Cells(4 + i, 3).Value ' C4:C13 -> E:N
    Next i

    ' Loop to copy values from D4:D13 to O:X (Columns 15 to 24)
    For i = 0 To 9
        wsResults.Cells(lastRow, 15 + i).Value = ws2.Cells(4 + i, 4).Value ' D4:D13 -> O:X
    Next i

    ' Copy total readiness score from different sheet1 to Results sheet
        .Cells(lastRow, 25).Value = ws2.Range("F15").Value ' Extract total readiness score

    End With

    MsgBox "Results have been saved successfully!", vbInformation
End Sub
```

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