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Research article

Development of an Assessment Model for Measuring Mechanical Engineering Companies' Circularity and Maturity Levels

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Abstract

The circular economy has gained significance in recent years due to its potential to achieve economic benefits and address ecological challenges. Mechanical engineering companies face the challenge of transitioning to a circular economy, which offers advantages like improved resource utilisation, reduced dependence on external suppliers, and enhanced production and supply chain efficiency. However, implementing circular economy principles proves difficult for manufacturing firms. Measuring circularity poses significant challenges, necessitating assessing methods' development, application, and validation. Industry-specific key indicators and data quality assurance are crucial in this regard. Existing models struggle to adapt to diverse contexts and industries. The outcome of this paper is the C-METRIC (Circular Manufacturing Evaluation and Rating for Industrial Circularity), an industry-specific method for assessing mechanical engineering companies' circularity and maturity level, developed using the Design-Science-Research Methodology. Based on the circular value chain, the method evaluates the maturity and circularity levels of the focused sector through 66 specific questions in 33 different areas of the company. The results are divided into the maturity and circularity levels of value-adding and strategic processes and are visualised using spider diagrams. The purpose of this model is to survey the circularity and circular economy maturity of mechanical engineering companies of specific regions and sectors.

Keywords: Circular Economy, Circular Business Models, Maturity Model, Assessment Model, Manufacturing

1. INTRODUCTION

The Circular Economy (CE) is an interdisciplinary concept of growing importance, demanding systemic and technological changes and cultural and behavioural adaptations. According to Kirchherr et al. (2017), the CE is "an economic system based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes." Potting et al. (2017) describe the core principles of the CE as the 9R imperatives (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover). These describe the circular economy from linear to increasingly circular. At the same time, they form the basis for national legislation like the Austrian circular economy strategy BMK (2022). Business models are one of the main enablers for these imperatives Kirchherr et al. (2017). In the context of CE, the enabling circular business models (CBM) can be divided into five main CBMs: Circular Inputs, Sharing Platforms, Product as a Service, Product use extension and Resource Recovery Lacy et al. (2020). Driven by environmental concerns and resource scarcity, the transition to a Circular Economy

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offers significant benefits. The circular economy is one way of decoupling economic growth from global resource consumption (The Ellen MacArthur Foundation, 2015), signifying a circular disruption that transitions from the 'take-make-use-dispose' model to a sustainable, resource-efficient approach through circular strategies Blomsma et al. (2023).

However, the circular economy not only offers benefits on a macro level, but companies perceive potential margin increases from more efficient resource use, reduced reliance on external suppliers, and overall supply chain and production efficiencies as drivers for implementing the CE principles Agyemang et al. (2019). Companies often perceive CE implementation as challenging due to limited awareness, risk-averse tendencies, and the necessity for substantial modifications in product design, business models, and supply chains. For a successful transition, the ability to measure and report on progress is crucial (Kristensen & Mosgaard, 2020; Uhrenholt et al., 2022).

Current tools for measuring progress towards a circular economy often lack a systemic and holistic approach (Rincón-Moreno et al., 2021) and focus too much on individual processes or phases in the product life cycle, production or product development (Ahmed et al., 2022). Many are still limited to resource efficiency, waste management and recycling rates (Parchomenko et al., 2019). An identified gap in current research is the integration of national strategies with standardised indicator sets that align with dominant industries and specific national circular economy strategies, such as Austria's circular economy strategy based on the 9R principles (Ahmed et al., 2022; BMK, 2022). Moreover, the absence of data-sharing exchanges or platforms using uniform indicators restricts sector-wide or national-level data collection capability (Ahmed et al., 2022). These gaps in current research were discovered during the search for a suitable tool to conduct a study across an entire industry and were, thus, the origin of the present research project. Addressing these gaps could enable a comprehensive evaluation of circularity and maturity across an entire sector.

This paper aims to develop an assessment model based on the available literature, the known strategies and business models of the circular economy and Austria's circular economy strategy. The development of the model is motivated by two primary objectives: firstly, to promote the circular economy at the micro level by enabling companies to determine their status, and secondly, to assess the circularity and maturity of the manufacturing mechanical and vehicle engineering sector in Austria. This sectoral classification is based on 'NACE Rev. 2', a European Community regulation that ensures comparability of economic activities (European Commission, 2006). The focus groups considered in the development were division 28, manufacture of machinery and equipment n.e.c., divisions 29 and 30, manufacture of motor vehicles, trailers and semi-trailers and other transport equipment. A regional focus was put on the Austrian circular economy strategy (BMK, 2022).

The following section (2 Requirements and Literature review) explains the requirements for the assessment tools and comprises an analysis of the existing literature related to the assessment of the circular economy based on these (2.2 Literature review). Section 3, Method, outlines the approach taken to develop the assessment tool. Section 4, Development of the assessment model, describes how the requirements have been met (4.1 Model Description), the result of the development process (4.2 Result), and the validation process (4.3 Model validation) of the model. A Perspective for the future (5.1) and limitations (5.2) are further discussed in Section 5 Discussion, and Section 6, Conclusion, provides the final remarks.

2. REQUIREMENTS AND LITERATURE REVIEW

The following section first describes the requirements for the assessment model and then summarises the resulting need for research and the current state of the literature.

2.1 Requirements of the Asssesment Model

In order to achieve the objectives described, the requirements for an evaluation model were already known before the research project. The aim was either to use a model from the specialist literature or

the grey literature or to derive a new evaluation model from this very literature. The requirements can be summarised as follows:

Conceptual and Strategic Alignment: The model must incorporate established definitions and principles of the circular economy (CE), circular strategies and business models, align with national CE strategies (Austria's 9R-based strategy in this case), and be mindful of industry-specific characteristics.

Comprehensive Assessment of the value chain and Reporting: The model should provide a systemic and comprehensive evaluation of CE implementation, encompassing all stages of a circular value chain. It should also offer robust measurement and reporting mechanisms to track progress towards CE implementation, emphasising stakeholder consideration at various levels within the sector.

Standardisation and comparability on a micro level: The model must facilitate data sharing and comparability across sectors. This may require uniform indicator sets and adherence to standardised classifications, including measures of circularity and maturity at the sector level.

Sectorial and Regional Applicability: The model must be designed with a specific sectoral focus and applied to a regional context.

2.2 Literature Review

To achieve a comprehensive overview of the existing literature concerning assessment models for the circular economy, the research process followed the process of Tranfield et al. (2003) and Watson & Webster (2020). To guarantee the most comprehensive and complete search possible at the time of the search, a final snowballing was also added, according to Wohlin (2014). Scopus, Web of Science, and Google Scholar were used for the search. In the snowballing process, Connected Papers was additionally used as a search tool to include literature not directly cited in the articles. The search was limited to assessment models for the circular economy; partially overlapping or related approaches such as sustainability-related topics, ecology, or environmental protection were excluded due to non-standard terminology and the associated imprecision of the concepts, which is detrimental to the application of the circular economy. Furthermore, applying such concepts could lead to conflicting information between circular economy approaches and sustainability-related approaches concerning assessment models, thus defeating the purpose of the research Kravchenko et al. (2019). The study deployed a sensitive search strategy, prioritising a broader, more comprehensive scope over region or company-specific valuation models. While yielding a larger pool of sources, this approach reduces the risk of missing crucial publications, ensuring comprehensive coverage of the research field Nightingale (2009).

Utilising various search terms, nine unique queries were generated and applied across multiple databases. The search strings were created iteratively of the following keywords:

- “circular economy” was used in each query,
- "maturity", "readiness", "capability", and "progression" covered the assessment part
- and "models", "assessment", "evaluation" and "measurement" covered the assessment model part.

All steps, shown in Figure 1, were manually performed, from selecting relevant publications to analysing existing valuation models. Potential sources were collected, and irrelevant ones were eliminated based on the title, abstract, and full text. The inclusion criteria were the following:

- Assessment models in the circular economy
- Analysis of assessment models in the circular economy
- Business-critical areas, success factors and KPIs for the assessment of the circular economy
- German or English language
- Available online

The exclusion criteria were:

- Lack of reference to the circular economy
- Meso- or macroeconomic perspective of assessment
- Non-industry references outside of the manufacturing industry
- Not publicly available

The goal was to analyse literature presenting or analysing valuation models, identifying performance metrics, or proposing recommendations based on the evaluation. From the initial pool of publications, 24 were chosen, encompassing the aforementioned areas.

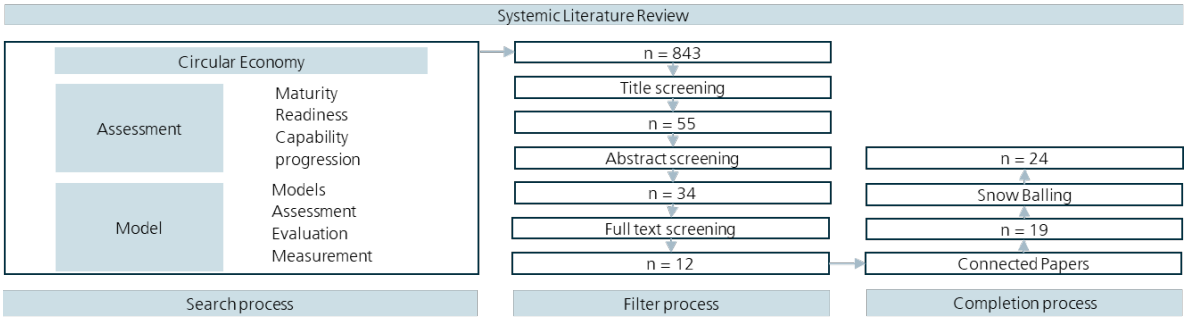

Figure 1. Summary of the Literature Review

2.2.1 Results of the Review

In total, 24 papers were analysed according to the requirements described in section 2.1; 21 of those papers presented assessment models, whereas 3 presented existing meta-analyses of assessment models.

The extent to which the models are conceptually and strategically adaptable to the Austrian circular economy strategy (9R model)[a], the extent to which the entire value chain of manufacturing companies on a micro level is analysed[b] and whether they are tailored to industry- and region-specific requirements[c] and the overall usability for the application[d] were evaluated accordingly. The summary of this analysis can be seen in Table 1.

Table 1. Summary of the Literature Analysis and Key Factors for Developing an Assessment Model

Source	Concept[a]	Value Chain[b]	Industry[d]	Total[e]
(Shevchenko et al., 2022)	◑	○	◑	◔
(Kayikci et al., 2022)	◔	○	◕	◔
(Aguiar & Jugend, 2022)	◔	○	◕	◔
(Bressanelli et al., 2021)	○	○	●	◑
(Sacco et al., 2021)	◑	●	◕	◕
(Elia et al., 2017)	○	●	○	◑
(Pigosso & McAloone, 2021)	◑	●	◕	◕
(Baratsas et al., 2022)	○	◔	●	◑
(Averina et al., 2022)	○	◔	◕	◔
(Montag et al., 2021a)	◕	◕	◑	◑
(Solidforest, 2018)	○	○	○	◔
(CircularTRANS, 2020; Urain et al., 2022)	◔	◑	◑	◑
(The Ellen MacArthur Foundation, 2020)	◕	◔	◑	◑
(Inèdit, 2020)	○	○	○	○
(The Ellen MacArthur Foundation, 2017)	◕	◔	◑	◑
(Tecnun, 2017)	◑	◔	◑	◑

(Franco et al., 2021)	●	◕	◕	◕
(Cayzer et al., 2017)	◕	○	◑	◔
(Garza-Reyes et al., 2019)	◕	◔	◑	◑
(wbcsd, 2020)	◔	◔	◑	◑

○ No fulfilment of the requirement
◔ low level fulfilment of the requirement
◑ moderate level fulfilment of the requirement
◕ high level fulfilment of the requirement
● complete fulfilment of the requirement

None of the 21 models evaluated aligns with the objectives specified in Section 2.1. Valls-Val et al. (2022) corroborate this, noting increased yet non-harmonised circular assessment tools, with result variability based on tool selection. This was also why the requirement on standardisation and comparability was neglected in Table 1, as this will be a requirement to be fulfilled by the new tool.

Several of the examined tools exhibit a conceptual focus that is not aligned with the 9R strategies. For example, Urain et al. (2022) present an assessment model that has adapted the CE to management systems,. Bressanelli et al. (2021) presents a model for the assessment of readiness that also does not consider R-strategies. Elia et al. (2017) and Garza-Reyes et al. (2019) presents a model for the assessment of progress based on requirements and actions that also does not include R-strategies. The Circulytics tool, developed by The Ellen MacArthur Foundation (2020), focuses on company operations and addresses only 6 out of the 9 R-strategies, specifically in the context of material flows.". Valls-Val et al. (2022) also substantiate this finding about the R-strategies depicted in existing assessment models. Looking at the mapping of the value chain in existing assessment models, it is noticeable that some focus strongly on material and resource flows (Baratsas et al., 2022; Tecnun, 2017; The Ellen MacArthur Foundation, 2017) , individual products (Aguiar & Jugend, 2022; Cayzer et al., 2017; Shevchenko et al., 2022; Solidforest, 2018), business models (Averina et al., 2022) or the supply chain (Kayikci et al., 2022; Montag et al., 2021a; wbcsd, 2020) , which excludes adaptability. The focus of the existing valuation models is generally on manufacturing companies, but none of them look at specific sectors in greater depth (Valls-Val et al., 2022).

2.2.2 Theoretical Framework

Despite the limitations of the current literature, the analysis identified three models as best aligned with the intent, namely:

- **CM-Flat** (Sacco et al., 2021)**:** presents a holistic view of the value chain, facilitated by prior work by Vinante et al. (2021), which introduced a comprehensive circular value chain (cVC) framework based on 365 indicators and Porter's value chain. This model aligns with 7 of 9 Eurostat circular economy indicators, enabling superior statistical evaluation compared to other tools (Valls-Val et al., 2022). It is designed explicitly to accommodate various industries, adapting to the specific focus industry, and specifically emphasizes take-back systems, which are crucial for comprehensively addressing the 9R imperatives.
- **MATChE** (Pigosso & McAloone, 2021) stands out for its broad representation of stakeholders during the survey and model development. It considers numerous circular strategies and 6 of 9 R-strategies. A strong emphasis on product and service innovation covers the unaddressed Rs R0 and R1 (Valls-Val et al., 2022). As such, this model facilitates alignment with the Austrian circular economy strategy and targets manufacturing companies.
- The evaluation model named **"Morphological matrix interconnection value proposition, circularity strategic choices and C-Indicators"** (Franco et al., 2021) is remarkable for its explicit weighting of R strategies and their linkage to indicators. Furthermore, it incorporates drivers, such as stakeholders, business models, and other circular strategies. It facilitates the

integration of models to map specific sectors within the manufacturing industry and their value chains with the Austrian circular economy strategy or the 9R imperatives.

3. METHOD

As already described in Section 1, the motivation for this research project was to conduct a study using an assessment model across an entire sector in Austria. To this end, specific requirements were defined for this evaluation model as described in section 2.1. This project is, therefore, an objective-centred development project. The Design Science Research Method (DSRM) with an objective-centred entry point was chosen to carry out this development project systematically.

This method was chosen as the principal framework for this work because of its capacity to yield a valuable artefact (an assessment model for evaluating industry-wide circularity and maturity) (Peffers et al., 2007). The conceptualised assessment model aims to bundle insights and knowledge from different companies in the focus industries and thus, on the one hand, to survey the status quo in these industries and, on the other hand, to evaluate critical strategies and methods that significantly influence the realisation of a circular economy in specific industry sectors. The process model by Peffers et al. (2007) serves as the basis for the research procedure to ensure a systematic approach and adherence to the design science guidelines. The nominal process consists of six activities and five transition activities, as shown in Figure 2. Starting with the entry point, working outwards step by step is recommended, whereby the order is generally irrelevant (Peffers et al., 2007).

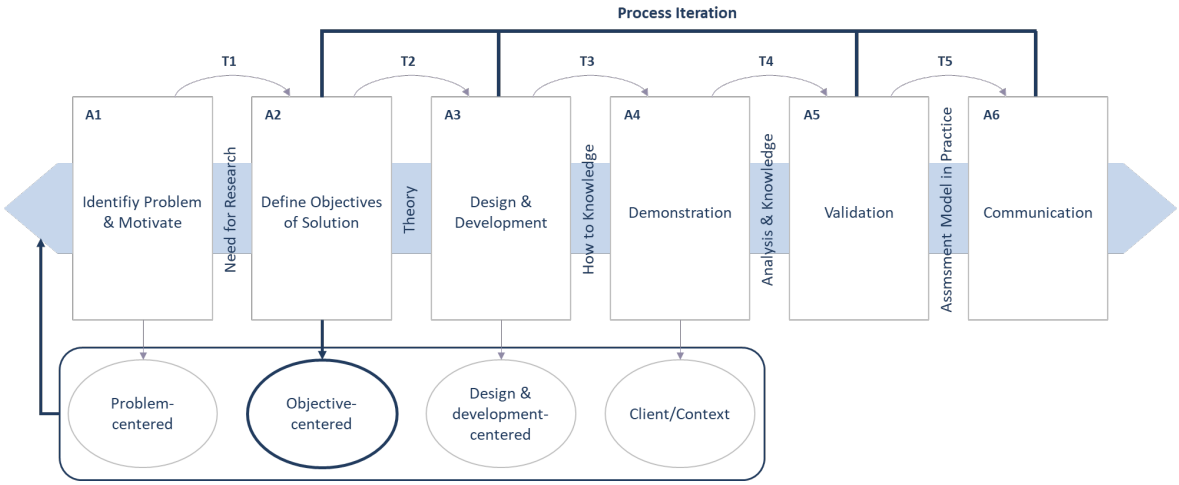

Figure 2. Process Model Adapted from Peffers et al. (2007)

In this case, the goal and the solution were already defined before the development process, but the way must be clarified. The objectives and requirements were specified again in section 2.1 (A2). As a result, the problem was identified based on a literature search: no assessment model satisfactorily fulfils all requirements, which also motivated the development process (A1, T1). Based on the same literature research, a theoretical framework for developing the new tool was also defined in section 2.2.1, whereby the existing tools that came closest to the requirements were filled in (T2). The development process and the extent to which the defined requirements are achieved are described in section 4 (A3). Chapter 4.2 then demonstrates the result of the development process, explains its use and subsequently validates it in a targeted manner (A4, T3, T4). According to Cloquell-Ballester et al. (2006) (A5), the validation follows three steps. Finally, the evaluation model is published and used for further research (A6, T5). Table 2 provides an overview of the procedure and what is essential in the individual development steps.

Table 2. Summary of the DSRM Adapted from (Peffers et al., 2007)

Steps from Peffers et al. (2007)	Implementation
Problem identification and motivation	Current assessment tools for circular economy lack a systemic approach and do not integrate with national strategies, limiting their scope to individual processes and restricting sector-wide data collection.
Defining a goal for a solution	Development of an assessment model, in line with the 'NACE Rev. 2' classifications and Austria's circular economy strategy, designed to measure the degree of circularity and maturity within Austria's machinery, motor vehicles, and other transport equipment manufacturing sectors.
Designing and developing	Development of the assessment model based on existing maturity models, considering the specific requirements of the focus industry, the 9R imperatives and a statistical evaluability of entire industries.
Demonstrating	Demonstration of the assessment model at a company of the focus group
Evaluating and Publishing	Evaluation of the model in three steps, according to Cloquell-Ballester et al. (2006): i) Self-Validation, ii) Expert-Validation and iii) Company-Validation and a subsequent publication.

4. Development of the Assessment Model

4.1 Model Description

To meet these requirements, the evaluation models selected in Section 2.3. were chosen, and a thorough analysis of their basic concepts, strategies, business models, industry focuses, measurement mechanisms, indicators, and classifications was conducted. The questionnaires, indicators, and classifications were pooled, and the basic circular economy concepts were summarised. The selected literature from Sacco et al. (2021), Pigosso & McAloone, (2021) and Franco et al. (2021) yielded 142 survey items, encompassing 84 specific questions and 58 indicators with associated R-strategies, metrics, and motivations, thus facilitating easy question generation. This pool of survey items was used to address the requirements explicitly set. This was accomplished through a 66-item self-diagnostic questionnaire. The survey design was influenced by transitions from broad qualitative questions about the company and basic facets of the circular economy to more specific quantitative inquiries. This structure boosts participant engagement, enhancing the validity of their responses (Groves, 2009, S. 250–253). Quantitative questions employ ordinal and rational scales, optimising statistical and correlational analyses (Baker & Baker, 1991, S. 145–150). This mixed-methods approach enriches our findings and offers flexibility, facilitating diverse interpretations of the data (Creswell & Plano Clark, 2018, S. 50–53).

4.1.1 Conceptual and Strategic Alignment

A contextually congruent assessment model was selected for the surveyed industry in alignment with national strategies. Selected micro-scale models cater to manufacturing firms, excluding nano, meso, or macro perspectives. R-imperatives were essential for coherence with the Austrian circular economy strategy. The explicit integration of circular business model inquiries was predicated on Lacy et al. (2020) foundational circular business models, serving as the basis for specialised models. This was crucial due to the need for comprehensive R-imperatives and strategies in the evaluated valuation models, including the foundational ones (Valls-Val et al., 2022). However, Franco et al. (2021) R-imperative indicators facilitated the integration of additional inquiries into the assessment model. Based on Franco et al. (2021) framework, all 9R imperatives were addressed by at least two distinct R-indicators, totalling 32 R-indicators.

Additionally, per Lacy et al. (2020) delineation, each of the five business models was featured at least four times in the model, yielding a cumulative count of 34 inquiries across diverse contexts. To manage the diverse business models, Chen (2020) classification was adopted for Sharing Platforms and Product as a Service, while Ertz et al. (2019) segmentation was employed for Product Use Extension.

4.1.2 Comprehensive Assessment and Reporting

Upon analysing the 24 publications presented in Table 1, 88 distinct measurement categories, company areas or activities subject to measurement were identified. These 88 areas were grouped according to Porter's and Eisenreich et al. (2022) value chain model to ensure a comprehensive analysis. The grouping was carried out by using these models as codes. Subsequently, the 88 categories were assigned, and similar elements were summarised. The original company activities were then revised based on the areas and activities documented in the literature. Consequently, 10 core areas emerged, further delineating into 23 sub-areas. In total, these represent 33 assessed company areas. The classification of these areas is detailed in Table 3.

Table 3. Summary of the Assessment Categories

Core Area / Activity	Sub Areas / Activity	Source
Strategic Infrastructure	Strategy & Vision Business Model Investment, Cost, Incomes	(Bressanelli et al., 2021; Cagno et al., 2019; Eisenreich et al., 2022; Urain et al., 2022; Vinante et al., 2021)
Operational Infrastructure	Environmental Management Cooperation, Industrial Symbiosis (Industrial Symbiosis) & Stakeholder (Governance) Legislative	(Cagno et al., 2019; Eisenreich et al., 2022; Prieto-Sandoval et al., 2018; Urain et al., 2022; Vinante et al., 2021)
Innovation, Technology & Design	Durability Ecodesign / Design For X	(Bressanelli et al., 2021; Cayzer et al., 2017; Eisenreich et al., 2022; Garza-Reyes et al., 2019; Uhrenholt et al., 2022; Urain et al., 2022; Vinante et al., 2021)
Hr-Management	Training Employee Satisfaction & Participation Culture	(Bressanelli et al., 2021; Cagno et al., 2019; Eisenreich et al., 2022; Montag et al., 2021b; Uhrenholt et al., 2022; Vinante et al., 2021)
Marketing, Sales & Communication	Commercialisation Consumption	(Cayzer et al., 2017; Eisenreich et al., 2022; Prieto-Sandoval et al., 2018; Vinante et al., 2021)
Procurement	Supplier Selection & Auditing Material Sourcing Packaging Energy	(Baratsas et al., 2022; Cagno et al., 2019; Eisenreich et al., 2022; Garza-Reyes et al., 2019; Prieto-Sandoval et al., 2018; Uhrenholt et al., 2022; Vinante et al., 2021)
Inbound & Outbound Logistics		(Baratsas et al., 2022; Eisenreich et al., 2022; Garza-Reyes et al., 2019; Prieto-Sandoval et al., 2018; Vinante et al., 2021)
Operations	Resource Consumption Waste Management Efficiency, Emissions, Spillages and Discharges	(Baratsas et al., 2022; Bressanelli et al., 2021; Cayzer et al., 2017; Eisenreich et al., 2022; Garza-Reyes et al., 2019; Montag et al., 2021b; Prieto-Sandoval et al., 2018; Uhrenholt et al., 2022; Urain et al., 2022; Vinante et al., 2021)
Service	After Sales Service	(Cayzer et al., 2017; Eisenreich et al., 2022; Montag et al., 2021b; Prieto-Sandoval et al.,

		2018; Urain et al., 2022; Vinante et al., 2021)
Reverse Logistics	Sorting Disassembly Recovery	(Bressanelli et al., 2021; Cayzer et al., 2017; Eisenreich et al., 2022; Garza-Reyes et al., 2019; Montag et al., 2021b; Vinante et al., 2021)

In the development of the assessment tool for implementing the Circular Economy (CE), a comprehensive review of literature was conducted to identify key stakeholders. This review guided the thematic consideration of various stakeholder groups and their perspectives, although these stakeholders were not directly surveyed. The identified stakeholders, detailed in Table 4 (Eisenreich et al., 2021; Govindan & Hasanagic, 2018; Jakhar et al., 2018; Urain et al., 2022) encompass both primary and secondary categories, aligning with the essential elements of CE implementation. Their inclusion, along with their critical CE considerations, ensures a comprehensive encapsulation of relevant points for the surveyed companies and a holistic mapping of an entire sector, including external influences.

Table 4. Summary of Stakeholders and Their Most Important Factors for the Implementation of the Circular Economy

Type of Stakeholder	Key points for circular economy implementation

Primary Stakeholders
• Internal:
  ○ Employees
  ○ Shareholders / Investors
• Supply Chain:
  ○ Customers / Clients / Consumers
  ○ Suppliers
  ○ Resource recovery partners
  ○ Cross-sector partners
	• Commitment to environmental / CE principles is needed from employees at all levels
	• Alignment of CE and financial sustainability is essential for profit-driven shareholders.
	• Active participation of customers in the take-back process is needed
	• Customer scepticism concerning used products needs to be addressed
	• An increase in customer responsibility is needed
	• An eco-efficient supply chain is needed
	• Inter-company cooperation is needed to maximise resources and minimise pollution
	• Product and process innovation is needed
	• Use of modern technology is needed to optimise supply chains

Secondary Stakeholders
• Societal stakeholders:
  ○ Research institutes
  ○ NGOs
  ○ Press and social media
• Regulatory stakeholders
	• Growing population and resource demand drive support for CE initiatives
	• Promise of job growth serves as motivation for CE adoption
	• Laws and policies act as key drivers or barriers for companies
	• Governmental organisations are crucial for financial support
	• Press and social media are key in customer relations, increasingly important in CE
	• The work of NGOs and research is a key driver for the promulgation of CE principles
	• Education and training are necessary to implement circular economy practices

In developing the assessment tools, insights about the described range of stakeholders are considered either within the questionnaire itself or during the validation process. This consideration allows the tools to capture better the multi-layered nature and the complexity of CE implementation. Figure 3 illustrates a consolidated overview of the assessment areas, their interrelationships, and the stakeholder network pertinent to the Circular Economy (CE). This representation is derived from the circular value chain model as conceptualized by Eisenreich et al. (2022). The diagram serves as a visual synthesis of the dynamic interplay between various CE components and the stakeholders engaged in the value chain.

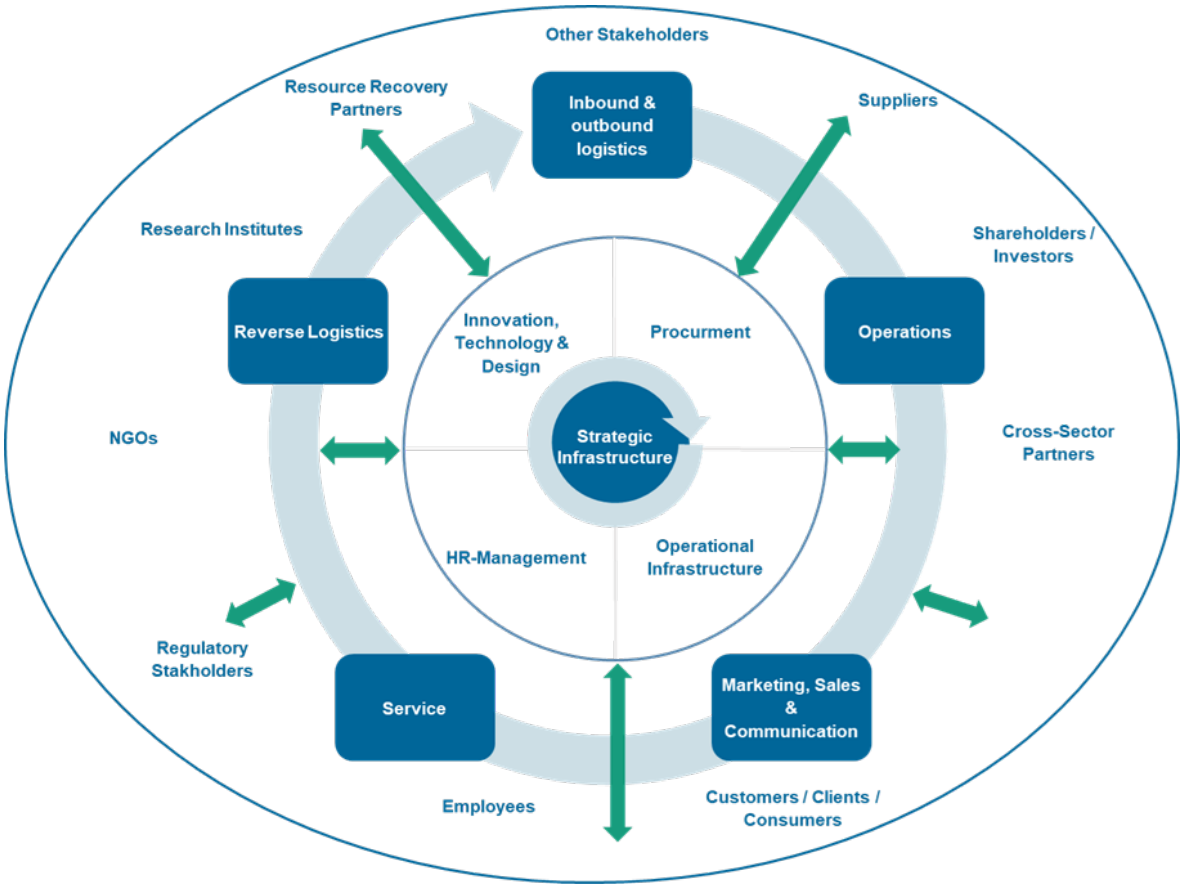

Figure 3. Summary of the Circular Value Chain and the Stakeholder Network

4.1.3 Standardisation and Comparability

The questionnaire ensured comparability by aligning with NACE Rev. 2 industries, specifically limiting it to C28 (manufacture of machinery and equipment n.e.c.), C29 and C30 (manufacture of motor vehicles, trailers, and semi-trailers and other transport equipment). The selection of base valuation models was carefully conducted to guarantee their intrinsic suitability for statistical analysis. For instance, the evaluation model from Sacco et al.(Sacco et al., 2021) stands out for its extensive representation of Eurostat Circular Economy Indicators (Eurostat, 2022; Valls-Val et al., 2022). Conversely, the MATChE tool (Pigosso & McAloone, 2021; Valls-Val et al., 2022) evaluates organisational strategies, allowing it to align well with the Eurostat and R-strategy indicators presented by Franco et al. (2021). Ordinal variables categorize attributes in a specific order without implying equal spacing between categories, while ratio variables are quantitative measurements that have a true zero point; both were utilized in devising a questionnaire, with Likert scales applied to assess the ordinal variables (Groves, 2009; Joshi et al., 2015). To ensure the comparability of responses, quantitative questions were prioritised. For questions not directly quantifiable by companies, ordinal variables were employed to characterise progress towards the circular economy incrementally (Baker & Baker, 1991, S. 145–150). Conversely, ratio variables were utilised for indicators quantifiable with specific figures to optimise data precision, statistical validity and analysis of correlations (Hill & Lewicki, 2006). Building upon this optimisation, in the existing evaluation model, the described areas are assessed using the distinction between maturity and circularity provided by Sacco et al. (2021)

Maturity: This term refers to the level at which measurement and management practices reflect their appropriateness in alignment with strategic goals and responsiveness to environmental changes (Bititci et al., 2015). It encompasses the systematic and documented implementation of activities and practices that establish the foundation for introducing the circular economy (Sacco et al., 2021).

Circularity: This term is defined in current literature as a quantifiable metric. Circularity relies on various units and indicators, all of which emphasise measurability (Bocken et al., 2017; Linder et al., 2017). In the context of the present evaluation model, circularity represents the actual measurable degree of a company's existing performance in comparison to the maximal achievable circular performance (Sacco et al., 2021).

Austria's Circularity Report underscores 'circularity' and 'maturity' differentiation. While strong in recycling rates, a 'circularity' metric, the nation lags in strategic circular economy aspects (Circle Economy & ARA, 2019). Austria's Circular Economy Strategy, aligning with Potting et al.'s 9R imperatives, emphasises comprehensive strategic planning beyond recycling, highlighting the 'maturity' aspect (Potting et al., 2017).

Table 5 presents the variables derived from extant literature, classified according to their foundational type, and categorised into either maturity or circularity for the purposes of the model. As a result, these variables formed the basis for the questionnaire to be developed from which specific questions and answer options were developed for the ordinal questions, which then represent the complete evaluation model and, at the same time, the questionnaire for the industry-wide survey.

Table 5. Summary of Variables

No.	Variable	Circularity / Maturity	Type of Variable
1	Extent of company acquaintance with the circular economy concept	Maturity	Ordinal
2	Extent of company collaboration with circular economy organisations	Maturity	Ordinal
3	Extent of integration of circular economy in corporate strategy	Maturity	Ordinal
4	Extent of dissemination of circular economy knowledge within the company	Maturity	Ordinal
5	Extent of employee recommendation consideration	Maturity	Ordinal
6	Extent of specialised circular economy training programs	Maturity	Ordinal
7	Extent of new employee recruitment attributed to the implementation of a circular economy concept	Maturity	Ordinal
8	Percentage of annual revenue attributed to circular business models	Circularity	Ratio
9	Percentage of annual revenue derived from product life extension services	Circularity	Ratio
10	Extent of company collaboration with external partners in circular economy activities	Maturity	Ordinal
11	Extent of industrial symbiosis implementation	Maturity	Ordinal
12	Extent of supplier selection process based on circular economy criteria	Maturity	Ordinal
13	Percentage of suppliers selected based on performance in circular economy	Circularity	Ratio
14	Percentage of suppliers audited for circular economy practices	Circularity	Ratio
15	Extent of company collaboration with customers in circular economy activities	Maturity	Ordinal
16	Percentage of sold products taken back from customers	Circularity	Ratio
17	Extent of planned measures for products taken back from customers	Maturity	Ordinal
18	Percentage of all taken back products reused through R-strategies	Circularity	Ratio
19	Percentage of annual revenue derived from R-strategies	Circularity	Ratio
20	Extent of company involvement in the implementation of reverse logistics systems	Maturity	Ordinal
21	Percentage of transport loading utilisation	Circularity	Ratio
22	Extent of usage of strategies or technologies for transportation optimisation	Maturity	Ordinal
23	Extent of company communication regarding circular economy information	Maturity	Ordinal
24	Extent of environmental management policies	Maturity	Ordinal
25	Percentage of waste utilisation	Circularity	Ratio
26	Extent of waste reduction strategies implemented within the company	Maturity	Ordinal
27	Percentage reduction in waste intensity	Circularity	Ratio
28	Percentage of energy consumption derived from renewable energy sources	Circularity	Ratio
29	Extent of energy consumption control within the company	Maturity	Ordinal

30	Percentage reduction in energy intensity	Circularity	Ratio
31	Extent of material consumption control within the company	Maturity	Ordinal
32	Percentage reduction in material intensity	Circularity	Ratio
33	Extent of eco-design/circular design implementation	Maturity	Ordinal
34	Percentage of application of eco-design/circular design for circular objectives	Circularity	Ratio
35	Percentage of material usage covered by specific materials	Circularity	Ratio
36	Percentage of material output covered by specific materials	Circularity	Ratio
37	Percentage of specific material flows comprised of hazardous substances	Circularity	Ratio
38	Extent of innovation activities	Maturity	Ordinal
39	Percentage of annual revenue spent on research and development within the company	Maturity	Ratio
40	Percentage of annual revenue generated from innovations	Maturity	Ratio
41	Extent of process innovation	Maturity	Ordinal
42	Extent of eco-innovation	Maturity	Ordinal

4.1.4 Sectorial and Regional Applicability

The customised assessment model for regional relevance strongly incorporates the Austrian circular economy strategy, aligned with Potting et al.'s 9R principles, emphasising critical transformation aspects like research and innovation, the Ecodesign Regulation, and the European Green Deal (BMK, 2022). The model was adapted to the engineering sector's unique characteristics, considering success factors from Yuik et al. (2020), such as leadership commitment and workforce training. Notably, product life extension services, tailored by product type, were identified as advantageous (Fontana et al., 2021). This led to surveys on managerial alignment, employee engagement, training, and product support services.

4.2 Result

The online assessment tool, meeting specified criteria, was developed using LimeSurvey. The 66 questions presented in Table 6 were implemented across five pages within the online survey tool. The initial section solicits participants to provide company data such as industry classification according to NACE Rev. 2, employee count, and primary business affiliations, which distinguish the participating firms. This is succeeded by 62 questions assessing circularity and maturity. Upon completion, economic success factors such as turnover, earnings before interest and taxes (EBIT), net working capital (NWC), return on capital employed (ROCE), and contact details are collected for benchmarking after the broader industry survey concludes, though providing these details is voluntary. Conformity with the GDPR was ensured throughout the process. Once the assessment model is finished, companies receive a six-page evaluation referencing circular value chain areas from section 4.1.2, illustrated with spider diagrams and relevant term definitions. Progress towards the circular economy is evaluated within the categories delineated in section 4.1.2 through a quantitative assessment of maturity and circularity, which is presented to the companies. This evaluation utilises a continuous scale ranging from 0 to 1, where 1 signifies the optimal realisation of a circular economy in each area, and 0 denotes adherence to a conventional linear economy.

Table 6. CE Maturity and Circularity Dimensions and Questionnaire of the Assessment Model

Categorisation	Questions / Circularity or Maturity
General Questions	
Please indicate the (main) industry of your company.	
Please indicate the total number of full-time equivalent (FTE) employees in your company.	
What is the main business relationship pursued by your company?	
Strategic Infrastructure	Circularity and maturity of “Strategic Infrastructure" assess an organisation's strategic and operational roadmap, emphasising the integration of business models, strategies, and services (Eisenreich et al., 2022; Vinante et al., 2021).
Circularity	

Please indicate the percentage of annual revenue attributable to the following business models.[a] (Franco et al., 2021; Pigosso & McAloone, 2021; Sacco et al., 2021)	
What is the percentage of total revenue generated by the following services per year, expressed as a percentage?[b,] (Franco et al., 2021; Pigosso & McAloone, 2021; Sacco et al., 2021)	
Maturity	
To what extent is the circular economy anchored in your corporate strategy? (Pigosso & McAloone, 2021; Sacco et al., 2021)	
Is any further use foreseen for returned products (e.g., remanufacturing, resale, rental, etc.)? (Pigosso & McAloone, 2021)	
Operational Infrastructure	Circularity and maturity of "Operational Infrastructure" assess the internal business capabilities of your company to integrate cooperative relationships, environmental stewardship, and foundational structures that prioritise the principles of the circular economy. (Eisenreich et al., 2022; Vinante et al., 2021)
Maturity	
To what extent is your company familiar with the concept of the circular economy? (Pigosso & McAloone, 2021; Sacco et al., 2021)	
Is your company in contact with one or more organisations in the circular economy sector? (Sacco et al., 2021)	
To what extent is your company active in collaboration with external partners for the circular economy? (Pigosso & McAloone, 2021; Sacco et al., 2021)	
Does your company belong to an industrial cluster of companies aiming at industrial symbiosis (e.g., sale of industrial waste, use of shared facilities, etc.)? (Pigosso & McAloone, 2021; Sacco et al., 2021)	
To what extent is industrial symbiosis implemented in your company? (Pigosso & McAloone, 2021; Sacco et al., 2021)	
To what extent is your company actively working with customers for the circular economy? (Sacco et al., 2021)	
Which of the following are included in your company's environmental management policy? (Sacco et al., 2021)	
HR-Management	Circularity and maturity of "HR-Management" evaluate the company's capabilities to cultivate a workforce skilled in circular economy principles and to foster a corporate culture that embodies environmental and sustainable values. (Eisenreich et al., 2022; Vinante et al., 2021)
Maturity	
How is knowledge about the circular economy shared within your company? (Sacco et al., 2021)	
Does your company have a system for collecting employee recommendations? (Sacco et al., 2021)	
Does your company have special training programs on the topic of circular economy? (Pigosso & McAloone, 2021; Sacco et al., 2021)	
Has your company succeeded in recruiting new employees thanks to implementing a circular economy concept? (Sacco et al., 2021)	
Inbound & outbound logistics	Circularity and maturity of “Inbound & Outbound Logistics” gauge the internal operational capabilities of your organisation to efficiently manage the flow of goods, both incoming and outgoing. This ensures timely product delivery, optimised inventory levels, and alignment with sustainable and circular business models, strategies, and services. (Eisenreich et al., 2022; Vinante et al., 2021)
Circularity	
What is the average percentage of truck loading? (Sacco et al., 2021)	
Does your company carry out product transports itself (i.e. transports are not outsourced to a logistics service provider)?	
Does your company have control over the transport processes? (Sacco et al., 2021)	
Does your company have strategies or technologies to optimise transport routes? (Sacco et al., 2021)	
Innovation, Technology & Design	Circularity and maturity of “Innovation, Technology & Design” gauges the internal business capabilities of the company to integrate innovative solutions, technological advancements, and sustainable design principles, essential for the successful adoption of Circular Economy concepts. (Eisenreich et al., 2022; Vinante et al., 2021)
Circularity	
What percentage of material usage is covered by the following materials?[d] (Franco et al., 2021; Pigosso & McAloone, 2021; Sacco et al., 2021)	
What percentage of the material output is covered by the following materials?[d] (Franco et al., 2021; Sacco et al., 2021)	
What percentage of the following material flows consist of hazardous materials? (Franco et al., 2021; Sacco et al., 2021)	
What percentage of annual revenue is spent on research and development in your company? (Franco et al., 2021)	
What percentage of annual revenue is generated with innovations? (Franco et al., 2021)	
Has your company implemented process innovations in the last two years? (Franco et al., 2021)	
How many eco-innovations has your company produced in the last two years? (Franco et al., 2021)	
How many patents does your company own related to circular economy? (Franco et al., 2021)	
Maturity	
What kind of process innovations has your company implemented? (Pigosso & McAloone, 2021)	
Has your company implemented eco-innovations in the last two years? (Pigosso & McAloone, 2021)	

Does your company have patents related to the circular economy? (Sacco et al., 2021)	
Marketing, Sales & Communication	Circularity and maturity of “Marketing, Sales & Communication " measures the internal business capabilities of your company to effectively communicate the value of circular products and services. (Eisenreich et al., 2022; Vinante et al., 2021)
Maturity	
Does your company actively share circular economy information through its communication channels? (Pigosso & McAloone, 2021; Sacco et al., 2021)	
To what extent does your company communicate information about the circular economy? (Sacco et al., 2021)	
Operations	Circularity and maturity of “Operations” assess the internal business capabilities of your firm, with a spotlight on production processes. It's pivotal in determining if key pillars of CE, notably Resource Consumption and Resource Recovery, are achieved. (Eisenreich et al., 2022; Vinante et al., 2021)
Circularity	
What is the percentage of all returned products that are reused through R-Strategies?[c] (Franco et al., 2021; Pigosso & McAloone, 2021)	
What is the share of total sales generated by R-Strategies per year, expressed in %?[c] (Franco et al., 2021; Pigosso & McAloone, 2021)	
What percentage reduction in waste intensity was achieved after implementing the waste reduction strategies? (Franco et al., 2021; Sacco et al., 2021)	
What percentage of energy consumption comes from renewable energy sources? (Franco et al., 2021; Sacco et al., 2021)	
What percentage reduction in energy intensity was achieved after implementing energy management strategies? (Franco et al., 2021; Sacco et al., 2021)	
What percentage reduction in material intensity was achieved after implementing strategies to manage material consumption? (Sacco et al., 2021)	
Maturity	
What measures are planned for the retracted products? [c] (Pigosso & McAloone, 2021)	
To what extent has your company implemented waste reduction strategies? (Sacco et al., 2021)	
To what extent is energy consumption controlled in your company? (Sacco et al., 2021)	
To what extent is material consumption controlled in your company? (Sacco et al., 2021)	
Procurement	Circularity and maturity of “Procurement” measures the internal business capabilities of your company, emphasising the sourcing and acquisition of goods and services, focussing on reducing waste, raw material procurement, and energy consumption. (Eisenreich et al., 2022; Vinante et al., 2021)
Circulartiy	
What percentage of your suppliers are selected based on their performance in the circular economy? (Pigosso & McAloone, 2021; Sacco et al., 2021)	
What percentage of your suppliers are audited for their circular economy practices? (Pigosso & McAloone, 2021; Sacco et al., 2021)	
Maturity	
To what extent is your supplier selection process based on circular economy criteria? (Sacco et al., 2021)	
Reverse Logistics	Circularity and maturity of “Reverse Logistics” measures the internal business capabilities of your company, emphasising the introduction of reverse logistics and recovery processes, stakeholder collaboration, and the traceability of products. (Eisenreich et al., 2022; Vinante et al., 2021)
Circularity	
What percentage of your company's solid waste is recycled for internal or external processing?[e] (Franco et al., 2021; Pigosso & McAloone, 2021; Sacco et al., 2021) (in % of total solid waste)	
What percentage of your company's liquid industrial waste is recycled for internal or external processing?[e] (Franco et al., 2021; Pigosso & McAloone, 2021; Sacco et al., 2021) (in % of total liquid waste)	
How much of your company's industrial waste gases are recovered for internal or external processing?[e] (Franco et al., 2021; Pigosso & McAloone, 2021; Sacco et al., 2021) (in % of total waste gases)	
Maturity	
Does your company take back used products and/or products from customers after the use phase? (Pigosso & McAloone, 2021; Sacco et al., 2021)	
To what extent is your company active in the implementation of take-back systems (i.e. reverse logistics)? (Pigosso & McAloone, 2021; Sacco et al., 2021)	

[a]The following business models are asked: Leasing or rental, Product-as-a-Service, Sharing, Sale of used/remanufactured products, Dematerialization, Sale of industrial waste (Industrial symbiosis), Maintenance, repair, upgrading and product support.
[b]The following services are asked: Inspection and/or cleaning of the products, Products maintenance, Repair of products, Upgrade and modernisation of products, Monitoring the condition and performance of the products and Warranty extension.

[c]The following R-principles are asked: Refuse, Reuse, Refurbish, Repurpose
[d]The following types of materials are asked: Certified Materials and Recyclable Materials
[e]The following R-Strategies are asked: Reuse, Recycle and Recover

4.2 Model Validation

In the following section, we succinctly describe the validation process for the designed assessment model. It is carried out in three steps following the proposed procedure of Cloquell-Ballester et al. (2006):

i. **Self-validation:** This stage unfolds in two phases. Initially, individual validation is undertaken, wherein each development team member independently evaluates the questionnaire for clarity, relevance, comparability, and measurability. Subsequently, collective validation occurs, where initial results are examined in a workshop setting, accompanied by the execution and analysis of preliminary pseudo-pilot tests. This validation process reaffirmed the alignment of the assessment model with the Austrian Circular Economy Strategy, incorporating all corresponding strategies. Moreover, each question and indicator were allocated to specific circular value chain areas, ensuring an exhaustive and rigorous evaluation.

ii. **Expert validation**: Three university and research institutes experts were interviewed to obtain feedback and define change measures. The main objective of this step was to ensure objectivity through independent expert judgments. This validation step made it possible to optimise questions and adapt definitions and examples to improve participants' understanding and dependencies between questions. After the expert validation, the wording of questions was standardised (e.g., Eco / Green / Circular), definitions were slightly adapted and made more comprehensible, missing definitions were added, comprehensibility was increased through more examples, and the B2C sector was also given more significant consideration.

iii. **Companies validation:** A multi-stage test run was carried out at a company from the focus industry to obtain the highest possible transparency of the tool and test its usefulness and usability with end users. The questionnaire was administered twice, initially after the first two validation steps and subsequently after integrating feedback from the initial response. This process mitigated strategic discrepancies between theoretical models and actual practice. Questions were refined to prevent inquiries about practices already implemented outside the circular economy context. This held especially true for queries on product design and innovation, which were accordingly adjusted. For this purpose, the branch logic was adapted accordingly, and the assigned scaling of the scores was also adapted to actual conditions.

Figure 4 delineates the validation steps alongside their corresponding development outcomes. It illustrates the continuous development process that extends from an initial Excel-based questionnaire to a finalised online version with automated evaluation.

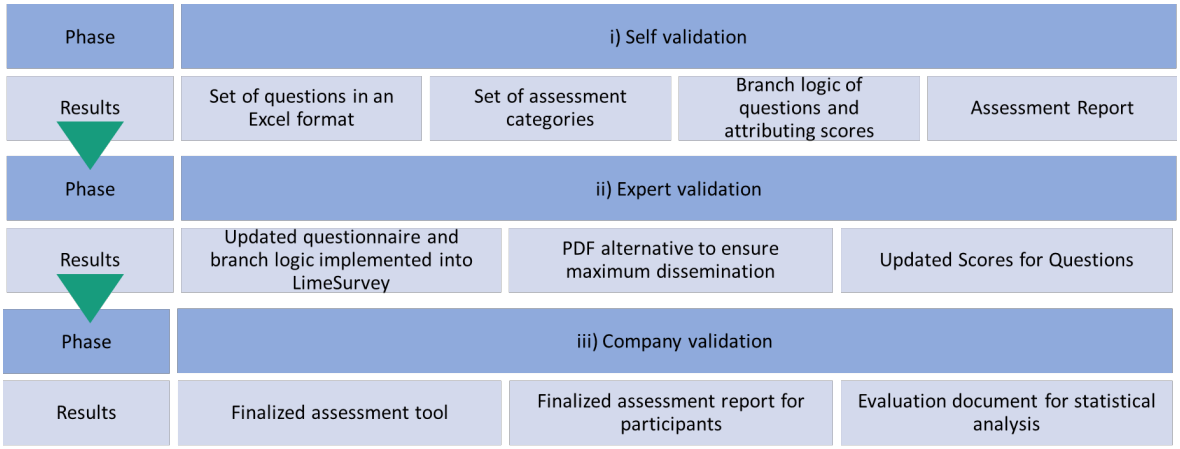

Figure 4. Summary of the Validation Phase

5. DISCUSSION

Effectively realising a circular economy necessitates an in-depth comprehension of the prevailing conditions within organisations. Understanding at both the micro-level, specific to individual companies, and the macro-level, pertinent to governments and policymakers, is paramount. The Circular Economy Assessment Tool has been devised in response to this need. Its dual purpose is to foster awareness among businesses and facilitate a sector-wide overview to guide targeted initiatives to advance the circular economy. This tool integrates existing models to provide comprehensive insight into the present status of organisations and industries. As emphasised by Pigosso & McAloone (2021) in their work, integrating and utilising the synergistic effects of current tools can sustain the transition to a circular economy over time. The development of this tool embodies this approach, resulting in an instrument attuned explicitly to the Austrian circular economy strategy, encompassing the entire circular value chain, and engaging a broad spectrum of stakeholders. Table 7 below summarises the essential characteristics that distinguish the developed tool from the three foundational tools.

Table 7. Comparison Between Developed and Foundational Assessment Tools

Assessment Model	**C-METRIC**	**MATChE**	**CM-Flat**	**Franco et al.**
Number of questions	66	39	45	58 Indicators
Alignment with Circular Economy Principles	10/10 R-strategies considered	5 R-strategies considered	5 R-strategies considered	10/10 R-strategies considered
Alignment with specific industry needs	Consideration of the specific needs of the mechanical and vehicle engineering sector	Designed for manufacturing companies	Designed to be used by as many companies as possible	Not considered
Adaptability to industries	Adaptable to other industries	Adaptable to other industries	Adaptable for any company	Not considered
Comprehensive assessment and reporting	10 core areas: Strategic Infrastructure; Operational Infrastructure; Innovation, Technology & Design; HR-Management; Marketing,	8 areas: Organisation; Strategy & Business Model; Product & Service Innovation; Manufacturing &	16 areas: strategy & vision; Business model; Environmental management; Cooperation & industrial symbiosis; Training; Employee satisfaction &	9R Framework as a basis

	Sales & Communication; Procurement; Inbound & Outbound Logistics; Operations; Service; Reverse Logistics + 23 sub-areas	Value Chain; Technology & Data; Use, Support & Maintenance; Takeback & End-of-life; Policy & Market	participation; Ecodesign; Supplier selection & auditing; Direct logistics; Reverse logistics; Resource consumption; Waste management; Resource recovery; Marketing & communication; Green products performances; Post-sales services	
Consideration of circular business models	5/5 CBMs considered	3/5 CBMs considered	5/5 CBMs considered	5/5 CBMs considered
Regional applicability	Adapt to the Austrian circular economy strategy	Danish sectors assessed	Not considered	Not considered
Integration and Utilization of Existing Models	3 Assessment tool / frameworks, 11 paper for categorisation	Comparison with 1 assessment tool	Indicator set as a foundation	9R framework
Standardisation and comparability	Consideration of industry standards, focus on quantitative questions, differentiation between circularity and maturity.	Only qualitative Question	Focus on quantitative questions differentiation between circularity and maturity.	Set of Indicators

By using this tool, companies can achieve a comprehensive understanding of their current practices and conditions in the circular economy, both at a micro-level specific to their operations and at a macro-level relevant to broader industry practices. This enhanced awareness fosters strategic insights, enabling businesses to identify areas for improvement and align their strategies more closely with circular principles. Consequently, this leads to sustainable business growth and heightened environmental responsibility, as companies become more attuned to the dynamics of the circular economy.

5.1 Perspectives for the Future and Future Research

The proposed evaluation model enables the assessment of circularity and maturity levels across entire industries in comprehensive studies. This allows for examining the current state and prevailing strategies within these sectors. Therefore, this assessment model provides the basis to survey circularity, maturity and dominant strategies in the Austrian division of manufacture of machinery and equipment n.e.c., manufacture of motor vehicles, trailers and semi-trailers and manufacture of other transport equipment. By gauging the companies' circularity and maturity, the model also provides a benchmarking opportunity within industries, thereby fostering and quantifying sustainable advancements in the circular economy. This complements existing studies highlighting a lack of publicly accessible and quantifiable corporate goals in the circular economy (Schöggl et al., 2021) and underscores the need for increased knowledge about the circular economy, specific companies, and industries to overcome implementation barriers (Huber-Heim & Kronenberg, 2021). Future research could focus on exploring how this model can be adapted to various manufacturing sectors and regions, assessing its scalability across diverse manufacturing processes and supply chains. This would include validating its applicability in different operational scales, from small enterprises to multinational corporations, and establishing comparisons with other industries and countries. Additionally, such research could examine the long-term impacts of the model on environmental sustainability and economic viability in the manufacturing sector, providing critical insights for continuous improvement and effective policy formulation.

5.2 Limitations of the Work

The current assessment tool, designed principally for sectors 28 (manufacture of machinery and equipment n.e.c.), 29 and 30 (manufacture of motor vehicles, trailers, and semi-trailers and other

transport equipment), can be adapted for the broader manufacturing industry, subject to a separate validation process. Limitations exist for raw material producers and service providers. Explicitly developed in alignment with the 9Rs and the Austrian circular economy strategy, the tool's compatibility with individual companies is evident, though it may pose challenges for divergent national strategies. An additional limitation is the practical validation of the tool. Although the tool was validated with a company from the industries in question, this phase of the DSRM process focused heavily on experts from research and science. However, the aim of the model is to carry out regular studies and, thus, a long-term iterative development process in which the tool is refined in the long term with practical relevance. A notable limitation is the tool's practical validation. While it was validated with a company from the targeted industries, the focus during this phase of the DSRM process was mainly on research and science experts. The model's goal is to conduct regular studies, initiating a long-term, iterative development process for the tool and ensuring its continual refinement with practical relevance.

6. CONCLUSION

Developing the current assessment model for the circular economy aimed to analyse the status within the focus sector. The objective was to develop a model that offers both value and thorough analysis for companies, along with comprehensive data on circularity, maturity, strategies, business models, and product life extension measures, all in alignment with the Austrian circular economy strategy (9R strategies). In pursuit of this goal, a thorough examination of existing circular economy assessment models was undertaken. Despite identifying tools that covered some areas, it became clear that even the most suitable options did not fully satisfy the following requirements: Conceptual and Strategic Alignment with national strategies and industry-specific needs, ensuring flexibility and customisation to various sectors. Comprehensive Assessment and Reporting must provide robust tracking across all value chain stages and standardised indicators for cross-sector comparability. Emphasis on Regional Applicability tailors the model to specific geographical contexts. Overall, the developed C-METRIC tool is expected to synergise strategic alignment, comprehensive evaluation, standardisation, and regional relevance, all geared toward practical application within the industry.

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AUTHOR CONTRIBUTIONS

Fabian Holly: is a research assistant at the Institute of Management Sciences and the initiator of the scientific work. He is significantly responsible for the preparation of the paper.
Clemens Schild: is a student assistant at the Institute of Management Sciences and provided intensive support for the scientific work.
Sebastian Schlund: provided scientific support for the work.

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Data availability The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

Ethics approval and consent to participate All the participants signed a form to confirm they agreed to participate in the survey and their consent to publish the results. The data protection officer of TU Wien approved the study and its research methods. The research was carried out following the guidelines of the TU Wien. Due to the nature of the project, the data protection officer determined that the project didn't require approval from the ethics committee.

Competing interests The authors declare that they have no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.

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