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Research paper

Assessing Circular Economy Maturity and Circularity in Austria's Mechanical and Vehicle Engineering Sectors

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Abstract

The necessity of a sustainable economy has propelled the introduction and promotion of the concept of the circular economy worldwide. At both international and national levels, circular economy strategies, such as the EU Circular Economy Action Plan and the Austrian Circular Economy Strategy, have established ambitious objectives aimed at increasing circularity to reduce resource consumption. In this context, the transformation of industries into circular economy models is gaining increasing significance. Given the limited understanding of the current state within the manufacturing industry concerning the circular economy, this study aims to provide a comprehensive overview of the maturity and circularity levels within the Austrian mechanical and vehicle engineering sectors. The primary objective is to establish a foundational platform for a targeted transformation of this industry towards an economically successful circular economy. This study employs a specifically designed model for capturing maturity and circularity levels, which comprehensively assesses 10 different business domains using 66 distinct questions. 216 out of a total of 1854 companies within the industry actively participated in this survey. The findings offer profound insights into knowledge regarding the circular economy, its integration into corporate strategy, the adoption of circular business models and R-strategies, as well as environmental management practices.

Keywords: Circular Economy · Circular Business Models · Survey · Assessment Model · Manufacturing

1. INTRODUCTION

The circular economy is an economic system based on four basic principles, minimising the use of virgin material, maximising the number of successive cycles of use, diversifying reuse throughout the value chain and using uncontaminated material to increase efficiency while maintaining quality (The Ellen MacArthur Foundation, 2015). The implementation of this system is conducted through on circular business models and the 9R imperatives (Potting et al., 2017) that replace the traditional end-of-life concept of products and materials. It is applied at all levels of the economy and aims to promote sustainable development by fostering environmental quality, economic prosperity and social justice for present and future generations (Kirchherr et al., 2017). The growing recognition of the circular economy's role in mitigating the effects of resource scarcity and climate change has catalysed concerted efforts at both the supranational and national levels. The European Union and individual national governments are now aligning their strategies and policies to embrace this economic paradigm, reflecting its strategic importance for sustainable development (Hartley et al., 2020). Without targeted measures, primary material consumption is projected to double by 2060 (OECD, 2018), and waste generation will increase by 70% by 2050 (Worldbank, 2018). In its new action plan concerning the circular economy, the European Commission (2020) posits that transitioning from a linear to a circular economic model is pivotal for achieving climate neutrality by 2050. The fundamental aim of a circular economy is delineated as the disassociation of economic growth from resource utilisation. (European

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Commission, 2020). Similarly, Austria's national strategy on the circular economy articulates at the national level that the prevailing linear economic paradigm, characterised by a take-make-waste approach, contributes significantly to accelerated consumption growth and consequential environmental degradation (BMK, 2022). In both the EU Action Plan and the Austrian circular economy strategy, the manufacturing sector is highlighted explicitly for its role. Resource extraction and processing account for approximately 50% of greenhouse gas emissions and 90% of biodiversity loss and water stress (European Commission, 2020). The policy documents underscore the necessity of enhancing production processes without offshoring resource-intensive manufacturing steps. However, the impact of a circular supply chain is particularly high in resource-intensive industries. Minimising material, water and energy use, minimising inventory, maximising supply chain efficiency, minimising waste and wastage, maximising product life, and maximising product returns are all particularly beneficial for resource-intensive companies or products. (Vegter et al., 2023). A circular value chain augments economic resilience in resource-intensive industries by aligning with waste management laws, generating revenue through recycling and remanufacturing, improving material and energy efficiencies, and elevating product quality. These facets also mitigate supplier dependency and price volatility, thus enhancing global market competitiveness (Govindan & Hasanagic, 2018; Montag et al., 2021). To holistically promote these circular economy drivers, both the EU and Austrian strategies emphasise the importance of measuring progress towards a circular economy (BMK, 2022; European Commission, 2020). However, they utilise the EU's limited framework, focusing only on resource consumption and carbon footprints, neglecting micro-level perspectives (Eurostat, 2022). In academia, a similar approach has been taken to this day when measuring the macro or meso perspective. For example, a circularity rate and a circularity gap have already been collected for Austria, but this relates exclusively to material flows and waste and emissions statistics (Circle Economy & ARA, 2019; Jacobi et al., 2018). However, a successful transformation also requires a measurement of progress at the company level to be able to support improvements and planning at the meso or macro level based on this (Kristensen & Mosgaard, 2020). Accordingly, a holistic and systemic approach is needed that fully captures the multi-layered and complex value chain to identify opportunities for improvement, systematically explores interactions and trade-offs, and supports quantitative and qualitative decision-making (Avraamidou et al., 2020). Given the observed gaps in both academic literature and national and supranational governmental data, the study aims to evaluate the status of the Austrian mechanical and vehicle engineering sector regarding the circular economy. The sector was chosen for investigation due to its potential for implementing a comprehensive range of R strategies (Potting et al., 2017), the efficacy of its product life extension measures (Fontana et al., 2021), and its inherent resource intensity—factors that align with the strategic objectives of both Austrian and EU policy frameworks. In this paper, therefore, the following research questions are answered:

- RQ1: How circular and mature is the Austrian machinery and vehicle industry?
- RQ2: What strategic prerequisites for the circular economy have already been implemented in the Austrian mechanical and vehicle engineering industry?
- RQ3: Which strategies, services and business models are currently dominant in the implementation of the circular economy?

This study distinguishes itself primarily through its methodological approach. Unlike existing surveys, it aggregates multiple micro-perspectives into a unified macro-perspective, thereby providing a more comprehensive understanding of the complexities inherent to the circular economy. This novel viewpoint enables the identification of targeted interventions at various levels to advance the circular economy.

2. THEORETICAL BACKGROUND

The subsequent section provides an overview of the core circular principles guiding this paper (2.1), discusses methods for evaluating progress in the circular economy (2.2), and concludes with a definition of the mechanical and vehicle engineering industry in relation to the circular economy (2.3).

2.1 Circular Economy

Interest in the circular economy has grown steadily since 2015, largely driven by more stringent international regulations, which are themselves influenced by concerns over resource scarcity, consumerism, and population growth (Sassanelli et al., 2019). Additionally, the circular economy has seen heightened focus in sustainability and sustainable supply chain research since 2018 (Amofa et al., 2023). The circular economy replaces traditional end-of-life (EoL) approaches for products with a set of guidelines known as the 9R Imperatives, aimed at preserving value:

Circular Economy

Smarter use and manufacturing of products	R0 Refuse	Make product redundant by abandoning ist function or by offering the same function with a radically different product
	R1 Rethink	Make product use more intensive (e.g. by sharing product)
	R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
Extending the lifetime of products and product parts	R3 Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfills ist original function
	R4 Repair	Repair and maintenance of defective product so it can be used with ist original function
	R5 Refurbish	Restore an old product and bring it up to date
	R6 Remanufacture	Use parts of discarded product in a new product with the same function
	R7 Repurpose	Use discarded product or ist parts in a new product with a different function
Effective valorisation of materials	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9 Recover	Incineration of material with energy recovery

Linear Economy

Figure 1. 9R-Framework Adapted from Potting et al. (2017)

These guidelines not only underpin the concept of the circular economy but also form the basis of Austria's circular economy strategy (BMK, 2022) and the evaluation at hand. Circular business models facilitate the implementation of these strategies (Geissdoerfer et al., 2020). Although the literature offers various interpretations of these models, this paper utilizes the framework by Lacy et al. (2020), which outlines five fundamental business models:

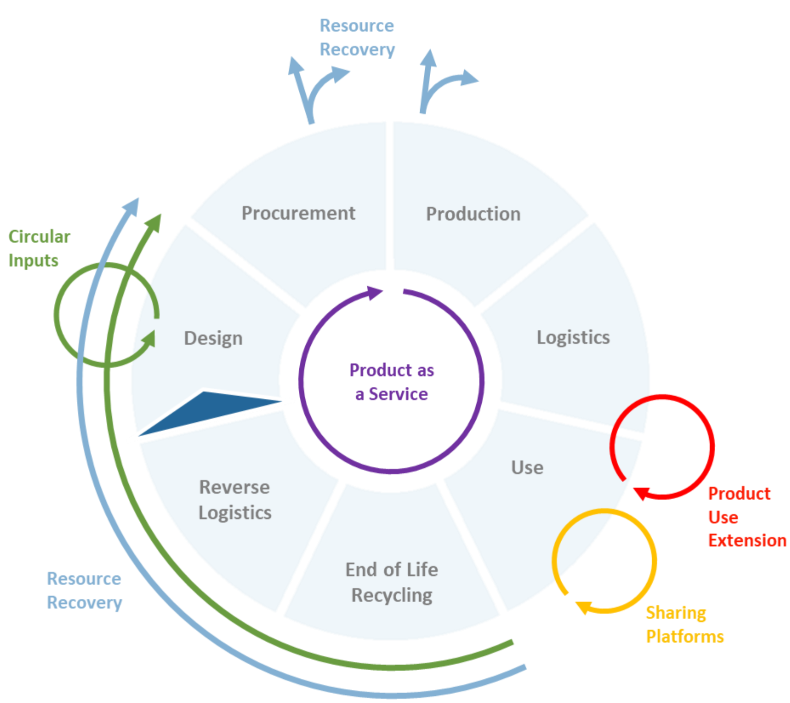

Figure 2. Circular Business Models Adapted by Lacy et al. (2020)

2.2 Methods and Challenges in Assessing Circular Economy Progress

Despite widespread acknowledgment from academia and strategic decision-makers about the necessity for transitioning to a circular economy, actual implementation remains insufficient. One contributing factor is the absence of standardized metrics for assessing enterprise circularity (Tan et al., 2022). Hence, a unified, holistic measurement approach is viewed as essential for driving circular economy progress (Uhrenholt et al., 2022).

At the micro-level, companies employ various strategies to address this issue, ranging from quantitative methods like Life Cycle Assessment (LCA) and Material and Energy Flow Analysis (MFA) to qualitative approaches such as multi-criteria decision-making tools and simulations (Sassanelli et al., 2019). To assess CE-progress holistically it is crucial to extend the scope beyond material-related and internal issues to include the entire value chain and all stakeholders (Negri et al., 2021). Based on a systematic literature search conducted in Spring 2023 (Holly et al., 2023b), it becomes evident that these limitations are particularly pronounced at macro level. Here, qualitative aspects have been entirely neglected, with assessments focusing solely on material flows (Holly et al., 2023b). Although existing studies offer quantifiable metrics on circularity rates (Circle Economy & ARA, 2019; Jacobi et al., 2018), they fail to provide micro-level insights, thereby impeding the identification of dominant strategies or areas requiring enhancement.

In addition to internal quantitative and qualitative methods, external assessment models, such as maturity or readiness assessment models, offer a third avenue for evaluating the current state of the circular economy (Sassanelli et al., 2019). These external models serve as an intermediary approach, bridging the gap between internal enterprise metrics and broader, sector-specific indicators. They have the potential to facilitate information sharing, monitor progress, and provide decision-making insights, thereby influencing both circular economy and business strategies (Roos Lindgreen et al., 2020).

2.3 Manufacturing, Mechanical Engineering, Machinery and Vehicle Engineering in the Context of CE

The study is aimed at three specific groups identified within the NACE Rev.2 classification by the European Union, encompassing sectors pivotal to mechanical engineering and manufacturing (European Commission, 2006):

- **NACE Code 28, Manufacture of Machinery and Equipment n.e.c.:** Encompasses the manufacture of general-purpose machinery, including engines and turbines, fluid power equipment, pumps, and compressors, along with other machinery for various industrial applications such as metallurgy, mining, and food processing.
- **NACE Code 29, Manufacture of Motor Vehicles, Trailers, and Semi-trailers:** Focuses on the production of complete motor vehicles and their parts, including bodies, coachwork, trailers, semi-trailers, and specific vehicle components like electrical and electronic equipment.
- **NACE Code 30, Manufacture of Other Transport Equipment:** Covers a range of products from the building of civilian and military ships and boats, manufacture of railway locomotives and rolling stock, to the production of air and spacecraft, and includes manufacturing of military vehicles and other specialized transport equipment like motorcycles and bicycles.

The current literature on the circular economy in mechanical engineering and related industries is relatively limited (Fontana et al., 2021). Pieroni et al. (2021) identify premature wear of main components and low productivity due to improper operation and complexity as key causes of structural waste in these sectors. They advocate for digital service management to enhance maintenance, productivity, and sustainability. (Fontana et al. (2021) also underscore the value of product-related services in the industry, which is also confirmed by Pieroni et al. (2021) noting the potential for optimization through digital platforms . Moreover, Yuik et al. (2020) highlight the critical role of leadership commitment and employee training in managing the complexity of products in this context.

3. METHODS

3.1 Survey Development / Maturity Model

A survey was executed using the C-Metric assessment tool specifically designed for sector-wide analysis. This assessment model was tailored to align with the Austrian 9R-framework for circular economy, optimized for statistical assessment, and adapted to the specific characteristics of the mechanical and vehicle engineering sector (Holly et al., 2023b). The assessment model is based on a questionnaire that contains a total of 66 qualitative and quantitative questions and was made available online for survey participants.

3.2 Survey Development

The maturity model developed by Holly et al. (2023b) was used for the survey of company participants. This industry-specific method was developed to assess the circularity and maturity of production companies, particularly in the mechanical engineering and automotive industries, about the circular economy. It is based on the circular value chain and assesses the maturity and circularity of the focused sector based on 66 specific questions in 33 different sub-sectors of companies. The results are divided into the maturity and circularity levels of the circular processes that are already quantifiable and the strategic processes that serve as a prerequisite for CE implementation. The aim of this model is to capture the maturity level of the circular economy in mechanical engineering and vehicle manufacturing companies in specific regions and sub-sectors. Part of the maturity model is also a comprehensive introduction to the circular economy to ensure that participants are familiar with the terminology used in the model. The questionnaire embedded in the maturity model is divided into 5 sections. The first section collects company demographic data. It refers to the company's industry, number of employees, annual turnover and type of business relationships. The second section relates to the introduction of the circular economy in the company. It covers corporate strategy, knowledge transfer, the use of circular business models and cooperation with suppliers. This is followed by a section with specific questions on the 9R framework and the use of various R principles in the company. In the fourth section, questions are asked about material and energy consumption as well as waste generated. The model concludes with questions on environmental management, product design and innovation. To ensure the comparability of responses, quantitative questions were prioritised. For questions not directly quantifiable by companies, ordinal variables in the form of Likert Scales (Joshi et al., 2015) were employed to characterise progress towards the circular economy incrementally (Baker & Baker, 1991). Conversely, ratio variables were utilised for indicators quantifiable with specific figures to optimise data precision, statistical validity and analysis of correlations (Hill & Lewicki, 2006)

The literature emphasises that pre-testing a data collection instrument is crucial to ensure reliability and to ensure that no constructs have been overlooked. This pre-testing allows the vocabulary and structure of the questions to be adjusted and at the same time helps to eliminate possible measurement errors (Moosbrugger & Kelava, 2020). The review of the questionnaire was conducted by four researchers and a company representative with experience and expertise in the field of sustainability and circular economy and in conducting survey-based research. Two of the reviewers had extensive experience in managing and participating in projects in the machinery and vehicle manufacturing industry and in the circular economy. Potential problems could thus be recognised and corrected (E.Clow & E.James, 2014).

3.3 Target Audience and Respondents

The study is aimed exclusively at companies from the mechanical and vehicle engineering sector with production sites in Austria. These were specified based on their allocation in the "Statistical Classification of Economic Activities in the European Community" - NACE codes for short. Within code C (Manufacturing), the focus is on 28 - Manufacture of machinery and equipment n.e.c., 29 - Manufacture of motor vehicles, trailers and semi-trailers and 30 - Manufacture of other transport equipment (European Commission, 2006). In Austria these sectors comprise 1,854 firms, 1,437 of which have more than one employee. Collectively, these companies account for 22% of the manufacturing industry's (European Commission, 2006) gross value added, 23% of its turnover, and employ 21% of the workforce in the industry (Statistik Austria, 2021).The target group for participation in the survey is predominantly people in management positions. If the company already has sustainability officers, they were asked to participate; in the case of small companies, the management was asked to participate. A database was subsequently compiled through an extensive research process, capturing as many companies and associated contact details as possible within these sectors. The Austrian Chamber of Commerce supported this effort by providing a list of companies from all federal provinces in Austria. As a result, a contact list consisting of 2,125 individuals from the specified sectors was established. Of these contacts, emails were successfully sent to 1,973 unique companies, as determined by distinct email addresses. In the study, the observed discrepancy between the number of companies contacted and the total population within the sector can be attributed to multiple factors.

- The data from Statistics Austria relies on self-reported assessments from companies, serving as an approximate rather than an exact representation of the sector's complexities (Information from Statistik Austria).
- The categorisation of the Austrian Federal Economic Chamber follows its own sectoral breakdown, which meant that a uniform assessment according to NACE Rev. 2 (European Commission, 2006) was only possible in 6/8 provinces (WKO, 2022).
- The presence of companies with production facilities in Austria but with headquarters located outside the country also contributed to the variance in the data, as such entities were nonetheless included in the survey.

Despite these limitations, the profile of the companies contacted and those that participated, as elaborated in subsequent sections, aligns with the fundamental structure of the target sectors. Consequently, the data gathered is deemed to possess a level of representativeness that allows for generalization within these sectors. The maturity model was embedded in LimeSurvey, a free online survey tool (www.limesurvey.org). The study utilized an online survey methodology, recognized for its cost-efficiency, ease of data entry, format control, and high participant acceptance (Granello & Wheaton, 2004). However, challenges include suboptimal response rates (Granello & Wheaton, 2004) and reliance on a convenience sample (E.Clow & E.James, 2014), which restricts the generalizability of findings and underscores the research's exploratory character. The survey was sent to 2,125 respondents, with 834 opening and at least partially answering the maturity model and 216 participating fully in the study. The Dillmann formula was used to check the number of participants for representativeness and generalisation of the results (Dillman, 2007). This allows a generalisation of the results with a confidence level of 95% and a margin of error of 6.12%, which confirms a satisfactory generalisability of the study despite the limitations. The response rate is therefore around 10%. The high amount of time required to use the maturity level model (approx. 60 minutes) must be considered here.

3.4 Sample Characterization

In the first part of the maturity model, basic information on the companies such as sector, business relationship, number of employees and annual turnover was obtained. As can be seen in Table 1, it was primarily large companies that took part, and in line with the sector, the majority of these were companies with B2B business relationships. In addition, the industry distribution is like the actual distribution of the total number of companies in Austria in these industries. Overall, most companies surveyed were mechanical engineering companies, followed by manufacturers of motor vehicles and other vehicle manufacturers.

Table 1. Demographics of participants

Company Size Employees	*Number*	*Percentage*
≤ 250 Employees	*80*	*37%*
< 50 Employees	*64*	*29,6%*
< 10 Employees	*63*	*29,2%*
n.a.	*9*	*4,2%*
Company Size Turnover	*Number*	*Percentage*
≤ € 50 m	*44*	*20,4%*
≤ € 10 m	*23*	*10,6%*
≤ € 2 m	*29*	*13,4%*
n.a.	*120*	*55,6%*
Business relationship	*Number*	*Percentage*
B2B	*202*	*93,5%*
B2C	*20*	*9,3%*
B2PA	*11*	*5,1%*
n.a.	*4*	*1,8%*
Business Sector	*Number*	*Percentage*
C28	*137*	*63,4%*
C29	*53*	*24,5%*
C30	*30*	*13,8%*
n.a.	*24*	*11,1%*

3.5 Data Analysis and integration

Data analysis and integration begins with the export of data from LimeSurvey, followed by import into SPSS for further processing. After thorough data cleaning, including the removal of incomplete questionnaires and duplicates, a precise sample was determined. The inductive analysis of the data was based on Tukey's exploratory data analysis (Tukey, 1977). This method aims to discover new things, generate hypotheses, recognise special features and present facts. The overarching goal is to assess the current state of the manufacturing industry in Austria in the context of the circular economy. This comprehensive analysis should provide insights that contribute to the evaluation and possible improvement of the existing circular economy model.

4. RESULTS AND DISCUSSION

This chapter presents the results of this study, organized into two sections: Section 4.1 evaluates the maturity of these practices in the mechanical and vehicle engineering sectors., while Section 4.2 discusses the implementation of circular economy practices.

4.1 Circular Economy Maturity Levels in Companies

The study assesses strategic maturity prerequisites for circular economy adoption in Austria's mechanical and vehicle engineering sectors, focusing on strategy integration, knowledge base, training, communication, external collaborations, logistics, and environmental management.

4.1.1 Knowledge on circular economy

The analysis assessed internal key stakeholders' familiarity with the Circular Economy (CE) concept, as detailed Figure 3. Findings show that top management and experts generally have a basic understanding of CE. Notably, both the proportion of companies lacking CE knowledge and those with extensive company-wide CE expertise are minimal. Additionally, this trend is consistent across large enterprises and small to medium-sized enterprises (SMEs), with no significant differences observed.

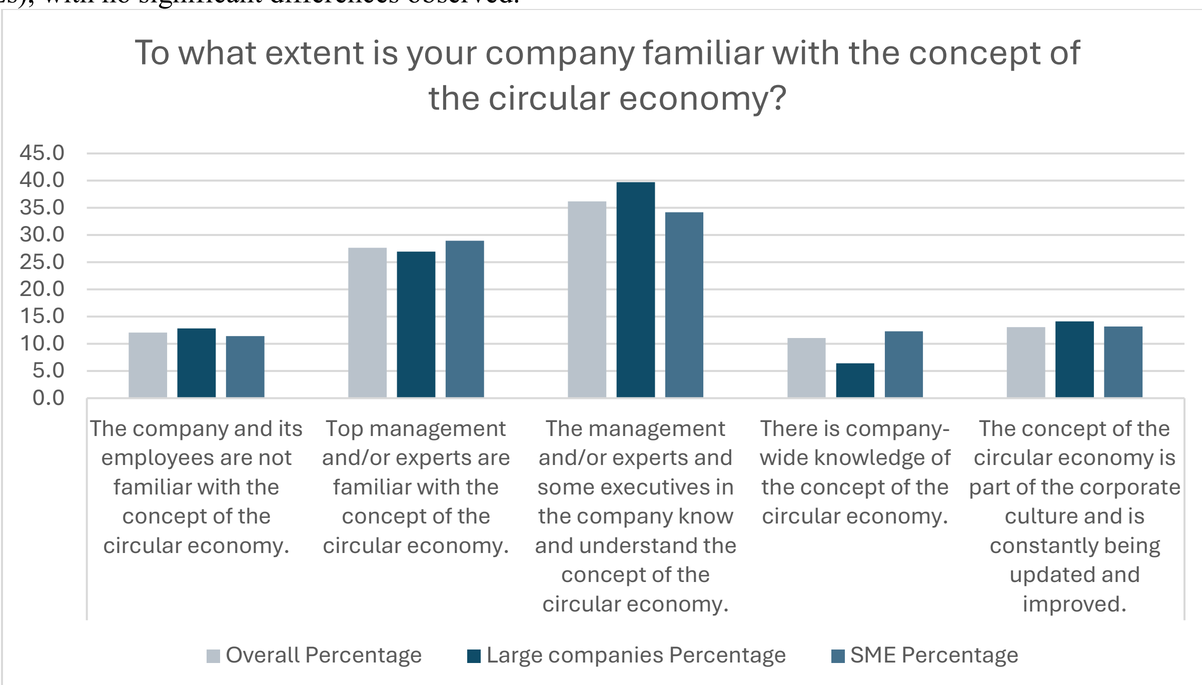

Figure 3. Knowledge on Circular Economy

The study also investigated the modes of knowledge dissemination within companies regarding this topic. Results revealed that over 50% of companies transfer knowledge as needed. A small segment (3.8%) does not share knowledge on this topic, while 18.3% engage in informal knowledge sharing and 31.7% disseminate knowledge on an as-required basis. Approximately one quarter actively practice and encourage knowledge sharing, and just under 20% have integrated it into their corporate culture. The study further explored how companies expand knowledge through training related to this topic. It was found that almost 70% of companies do not offer any training on this subject. Additionally, 13% indicated that training is only occasional and almost negligible. Another 7.5% are in the early stages of implementing such training programs, not yet company-wide, while 7% have formalized training that is also not implemented company-wide. Distinctly, just over 1% offer company-wide training, and a separate 1% have training ingrained in their corporate strategy for continuous improvement.

4.1.2 Strategic integration of the circular economy

The study also evaluated the extent of circular economy integration within companies' corporate strategies. As illustrated in Figure 4, the strategic integration of the circular economy is found to be quite uniform across the spectrum. Approximately two-thirds of all respondents reported that the circular economy has influenced several of their projects. Notably, the disparity between large companies and SMEs is most pronounced at the minimal integration level, with over a quarter of SMEs indicating no inclusion of circular economy in their strategies, compared to less than 15% for large companies.

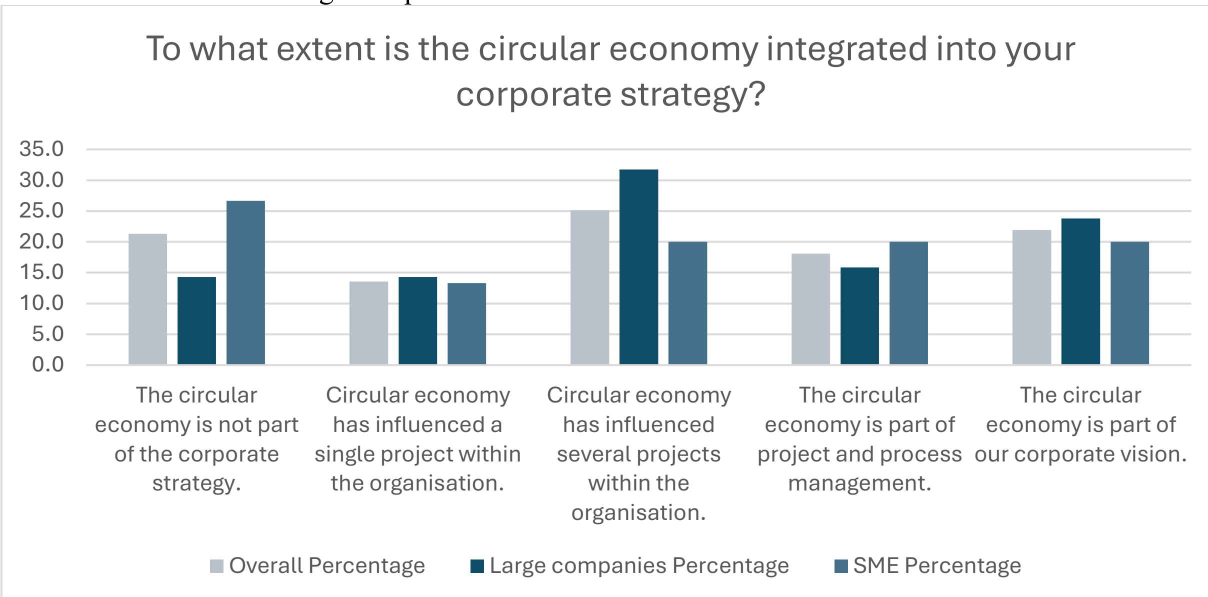

Figure 4. Strategic Integration of Circular Economy

A comparison with existing and comparable studies shows that this study confirms existing results in terms of knowledge about CE and strategic anchoring. In a series of interviews from 2021, 64% stated that CE plays a role in the strategic agenda, at least in individual company divisions or projects (Schöggl et al., 2021). In addition to examining the integration of the circular economy in corporate strategies, the study also focused on the optimization of production processes with respect to waste and reject reduction. The findings revealed that nearly a quarter of the respondents have never engaged in waste reduction projects. Distinctly, 14% are in the design phase and another 14% are in the pilot phase of such initiatives. 35% of respondents have integrated waste reduction into their process management. Notably, 8% are actively enhancing their methods for reducing waste and rejects. Additionally, 1.7% of the respondents indicated that they do not generate relevant waste in their production processes. Regarding both knowledge in companies and strategic integration, it is noticeable that the discrepancy between large companies and SMEs is not as significant as the existing literature would suggest. Here, additional barriers and limited opportunities are often described for small and medium-sized enterprises compared to large companies (Hina et al., 2022; Korne et al., 2022; Mura et al., 2020).

4.1.3 Communication and Cooperation in the context of Circular Economy

This study also assessed corporate communication regarding circular economy information. It found that most companies (82.8%) do not disseminate any information on the circular economy. Among those that do, over half share minimal information (23.1%) or are in a testing phase (30.8%). The remainder predominantly share extensive information (11.5%), tailor communications to audience preferences (23.1%), or personalize marketing activities in real time (11.5%). In the context of circular economy implementation, one of the major barriers identified by companies is the dual challenge of perceiving remanufactured products as less valuable and showing reluctance to pay higher prices for circular products (Bhandari et al., 2019; Hermann & Vetter, 2021). Addressing these challenges could be facilitated through improved communication with consumers. The analysis extended to collaboration with external partners, revealing that slightly more than half (53.3%) do not engage in any such cooperation. About 22.8% of companies indicated independent stakeholder work without close collaboration. Approximately 12% engage in regular exchanges, including tacit information sharing. A smaller proportion have established common goals (5.4%), ongoing cooperative projects (5.4%), or a structured joint venture (1.4%). Customer collaboration exhibits a similar pattern. Just over half of the participants (51.7%) reported no collaboration in this area. About 14.2% noted minimal agreement and communication with customers. Meanwhile, 8.5% have committed to a structured communication channel, 10.8% engage in strategic communication with continuous evolution of customer collaboration and communication, and 3.4% have a high level of integration with their customers. Lastly, 11.4% continuously adapt to customer needs based on collaborative feedback. The low rate of collaboration with partners and customers is surprising in that companies have indicated in previous studies that internal reluctance to collaborate with other companies is seen as a negligible barrier (Holly et al., 2023a).

4.1.4 Logistics in the circular supply chain

In the study, further insights were gathered regarding the logistics practices of the surveyed companies. Notably, 47.1% of respondents have implemented strategies to optimize transport routes. Regarding supplier selection, a significant portion (56.1%) reported not using specific CE criteria in their purchasing processes. Additionally, 21.4% do not possess a formal evaluation process for CE in supplier selection, while 13.9% assess suppliers on an ad hoc basis using CE criteria. A smaller fraction of respondents systematically evaluates suppliers based on CE principles (5.2%), and only 3.5% consistently apply CE criteria in supplier assessments. These findings underscore the significant challenges faced by companies in transitioning towards a circular economy, particularly due to the complexity and limited availability of supply chain partners aligned with Circular Economy principles (Kumar et al., 2019; Masi et al., 2018).

4.2 Circular Economy Implementation

4.2.1 R-Strategies

This study examined the application of product life extension concepts in Austrian mechanical and vehicle engineering sectors. It focused on different R-strategies, ranked by increasing effort and energy consumption, namely Reuse, Repair, Refurbish, Remanufacture, and Repurpose (Potting et al., 2017). The findings reveal that implementing product take-back systems offers substantial benefits to manufacturers: approximately 40% of surveyed companies have established such systems, with an average product take-back rate of 20%. Furthermore, 90% of these companies intend to continue utilizing the reclaimed products. This is in line with existing literature, which sees structured reverse logistics as one of the biggest enablers and a key capability for the introduction of the circular economy (Seles et al., 2022).

The distribution of R-strategies among surveyed companies indicates a significant adoption of these approaches for product life extension. Reuse, followed by repair, refurbishment, and remanufacturing, are the most prevalent strategies. However, there is still untapped potential in strategies like repurposing.

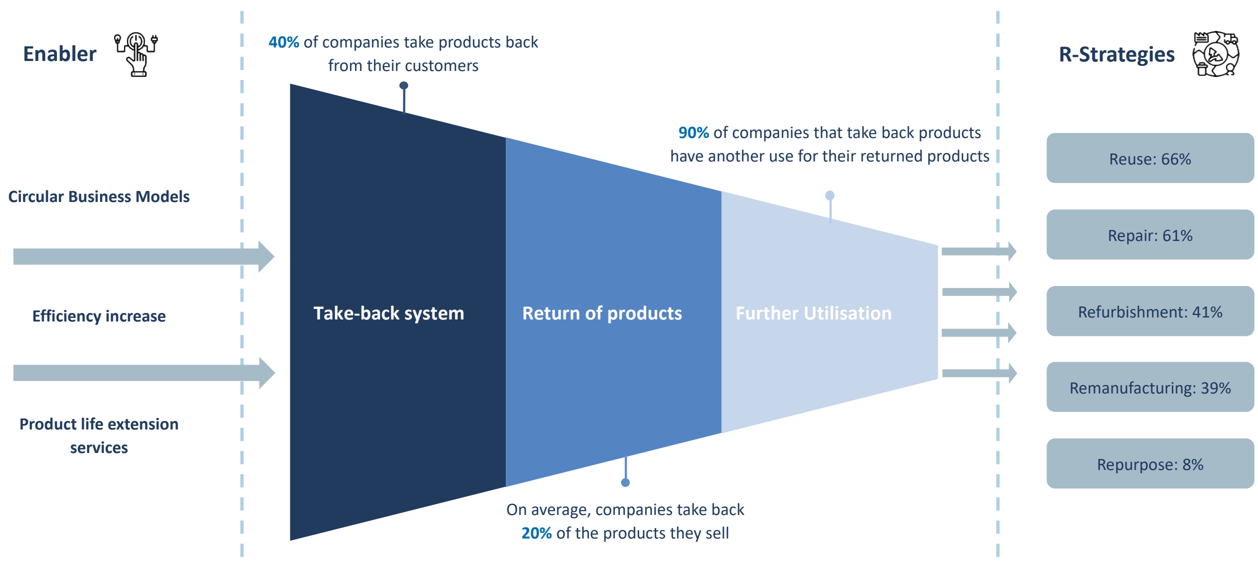

Figure 5. Summary of take-back systems and R-Strategy implementation (own figure)

Utilizing reused or remanufactured products presents multiple benefits for companies. These products typically retain high market value while contributing to reduced waste generation, enhanced productivity, and diminished resource utilization (Galvão et al., 2020; Kumar et al., 2019). It is crucial to distinguish between direct reuse and the processes of refurbishment or remanufacturing. While both approaches necessitate thoughtful product design, remanufacturing specifically demands robust technical execution to ensure the delivery of high-quality products (Kirchherr et al., 2018). This distinction may be reflected in the hierarchy of the R-strategies employed in this study.

4.2.2 Circular Business Models.

The survey part on circular business models (CBMs) in various companies reveals a spectrum of implementations. Key highlights include:

- Circular Inputs: A significant proportion (43%) of companies have integrated eco or circular design, with over half of these (55%) utilizing reusable materials. Circular product design is often a prerequisite for the realisation or optimal use of circular business models (Bocken et al., 2016). Renewable energy is adopted by 59% of companies, and a majority (90%) use non-hazardous materials. In Austria, the mechanical engineering and vehicle construction sectors demonstrate a distinct energy usage profile. In Austria, renewable energy sources are responsible for generating 74.4% of the country's electricity, while contributing to 33.8% of its total energy consumption (Eurostat, 2023). This indicates that sectors with a higher electricity demand, such as mechanical and vehicle engineering (Petrick et al., 2011), are more aligned with the national trend of utilizing renewable energy for electricity generation.
- Product as a Service (PaaS): Nearly a third (29%) of companies offer products as services, contributing substantially (37%) to their turnover. Leasing models are less common, used by 23% of companies but representing a smaller fraction (11%) of turnover. In the case of PaaS systems, it is also important to ensure that they also contribute to the circular economy. This is only the case if added value is created for the customer and economic growth is achieved, both of which are decoupled from additional resource consumption (P. P. Pieroni et al., 2019). Ultimately, this requires increased operational efficiency, a longer product life, an intensification of product utilisation or a switch to an entirely more efficient system (Kjaer et al., 2019).
- Product Use Extension: Almost half (46%) of the companies are involved in selling used or reconditioned products, accounting for 9% of their turnover. A notable majority (72%) offer maintenance and support services, impacting 18% of their turnover. Strategies for extending service life in the focus industry are relevant due to typical product characteristics, including high value, complexity, and essential core components, complemented by the common sale of used products attributable to their generally long service life (Fontana et al., 2021; Pieroni et al., 2021). Both facts are also reflected in this study.
- Sharing Platforms and Industrial Clusters: A small segment (4%) operates sharing platforms, yet these contribute significantly (21%) to their turnover. Engagement in industrial clusters is observed in 14% of companies, with a prevalence of large enterprises. The low prevalence of sharing platform operations can be attributed to challenges like high startup costs and complexities in developing a strong user community, leading to constrained market entry. This factor potentially explains the small proportion of companies engaged in sharing platforms, despite their significant impact on turnover for those who operate them successfully (Ritter & Schanz, 2019).
- Resource Recovery: Over half (52%) of the companies engage in selling industrial waste, which constitutes 14% of their turnover. The breakdown of waste utilization reveals 18% reuse, 58% recycling, and 17% thermal recovery. These outcomes are consistent with studies on substance and material flows. They underscore Austria's leadership in recycling, with 58% of waste currently recycled. In the context of the analyzed sector, this is notably significant for steel, a critical raw material, of which 76% is recycled (Jacobi et al., 2018).

Table 1. Summary of the implementation of circular business models

CBM	*Implementation*	*Result*
Circular Inputs	*Eco / Circular-Design*	*43% are concerned with eco / circular design* *Of which 55 % use reusable materials*
	Renewable Energy	*59% renewable energy is used*
	Non-Hazardous Material	*90% of the material consumption is non-hazardous*
Product as a Service	*Product as a Service*	*29% offer Product as a Service* *Of those: 37% of turnover* *In total: 10% turnover*
	Leasing	*23% offer leasing* *Of those: 11% of turnover* *In total: 2% turnover*
Product Use Extension	*Sale of used/remanufactured products*	*46% sell used/remanufactured products* *Of those: 9% turnover* *In total: 4%*
	Maintenance, repair, upgrading and product support	*72% offer Maintenance, repair, upgrading or product support* *Of those: 18% turnover* *In total: 13% turnover*
Sharing Platforms	*Sharing*	*4% operate sharing or sharing platforms* *Of those: 21% turnover* *In total: 1% turnover*
	Industrial clusters	*14% are involved in an industrial cluster* *Of which:* *50% are large companies*
Resource Recovery	*Sale of industrial waste*	*52% Sell industrial waste* *Of those: 14% turnover* *In total: 7%*
	Internal and external utilisation of industrial waste	*Utilisation of solid waste:* *18% is reused* *58% is recycled* *17% is thermally utilisied*

4.2.3 Product lifetime extension services

In the analysis of circular business models, emphasis was placed on strategies enhancing product longevity, with average revenue contributions identified as follows:

- upgrade and modernisation (5.7%),
- repair of products (5.5%),
- product maintenance (4.8%),
- monitoring the condition and performance of the product (2.7%),
- inspection and cleaning of products (2.1%),
- and warranty extension (1.6%).

In conclusion, the analysis delineates the revenue contributions of various strategies, highlighting their effectiveness in extending product service life and reducing the need for end-of-life interventions in circular business models. Consumer willingness to invest in product life extension remains generally low, as most prefer purchasing new items over repairing old ones (Güsser-Fachbach et al., 2023). However, this inclination shifts positively with the product's cost and lifespan (Fachbach et al., 2022). Consequently, the mechanical engineering and vehicle construction sectors, characterized by higher-value and longer-lifespan products, are more likely to benefit from increased sales in repair and maintenance services (Fontana et al., 2021).

5 CONCLUSION

With 140,000 employees and an annual turnover of 52 billion Euros, the machinery and vehicle manufacturing sector in Austria ranks among the largest industries. Transforming this sector into an economically successful circular economy represents a significant contribution to the overall societal shift towards circularity. However, little was known about the progress in this context within this industry. Hence, this study focuses on assessing the circularity and maturity levels regarding circular economy practices in the Austrian machinery and vehicle manufacturing sector and aims to answer the following research questions:

- RQ1: How circular and mature is the Austrian machinery and vehicle industry?
- RQ2: What strategic prerequisites for the circular economy have already been implemented in the Austrian mechanical and vehicle engineering industry?
- RQ3: Which strategies, services and business models are currently dominant in the implementation of the circular economy?

To address these research questions, a survey of companies was conducted. To account for both international and national circular economy strategies, regulations, and networks, a model specifically developed for the Austrian economic area was employed to assess circularity and maturity levels. This model categorizes manufacturing companies into 10 business areas and examines them using 66 different questions. The survey was conducted online using the LimeSurvey tool.

The study provides a comprehensive analysis of the maturity and implementation of circular economy practices in the machinery and vehicle manufacturing sectors in Austria. It highlights various aspects such as knowledge of circular economy, strategic integration, communication and cooperation, logistics in the circular supply chain, and the implementation of circular economy models. Particularly noteworthy is the degree of strategic anchoring of the circular economy in companies and its impact on business models, product lifecycle strategies, and innovation management.

5.1 Theoretical and Practical Implications

Knowledge and Strategic Integration: The study indicates that a basic understanding of the circular economy is prevalent in most companies, yet there is considerable variation in the dissemination of this knowledge and its strategic integration. A moderate correlation is observed between the depth of strategic embedding of the circular economy and the level of knowledge. Business Models and Practices: The implementation of various R-strategies and the application of circular economy business models such as Product-as-a-Service (PaaS), product life extension, and resource recovery exhibit differing rates of success and pose unique challenges. Innovation Management and Research & Development (R&D): The findings suggest that a higher orientation towards innovation and research in companies does not necessarily lead to deeper integration of the circular economy. No significant correlation was found between the strategic anchoring of the circular economy and innovation management or R&D expenditures. Environmental and Sustainability Management: Advances in environmental and sustainability management demonstrate that legislative measures and initiatives promoting or demanding ecologically sustainable business practices are increasingly yielding positive results. Similar positive outcomes are also anticipated from circular economy initiatives.

5.2 Limitations and Future Studies

This study represents the first in-depth investigation in Austria into the current state of the machinery and vehicle manufacturing sectors during their transition to a circular economy. It predominantly provides a descriptive account of the status quo in the industry. Consequently, the study's focus on specific sectors and regions limits the generalizability of its findings. The survey model is designed for efficient execution, offering value to participants and encouraging their extensive involvement. However, due to the specific nature of the questions aimed at assessing circularity and maturity levels, the ability to establish correlations is somewhat limited. Furthermore, the survey does not inquire about the business reasons behind the adoption of circular concepts such as circular business models and R-strategies. Building upon the insights from this study, future research should conduct more in-depth qualitative investigations into the motivations and barriers driving the transformation and integration of the circular economy within the industry. Special attention should be given to the role of innovation and R&D in understanding the link between circular economy and corporate innovation. The study's findings also reveal a limited number of companies with comprehensive CE expertise and a lack of knowledge dissemination within organizations. Future research could focus on how companies can effectively spread knowledge about the circular economy and integrate it into their corporate culture, thereby enhancing the implementation and strategic integration of the circular economy. With minor adaptations to the maturity model, it can also be utilized for assessing the current state of circular economy practices in other manufacturing industry sectors. The chosen methodology for this survey can be replicated in other regions or countries, allowing for comparability across different subsectors and regions.

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AUTHOR CONTRIBUTIONS

Fabian Holly: is a PhD-candidate 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 at the Institute of Management Sciences and provided support for the scientific work.
Sebastian Schlund: is head of research area Industrial Engineering and provided scientific support for the work.

DECLARATIONS

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Data availability: The datasets analyzed during the current study are available from the corresponding author on reasonable request.
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 no competing interests.

APPENDIX

For full the full-size images please click here or copy the following on your url bar: http://circulareconomyjournal.org/wp-content/uploads/2024/12/Appendix_Holly_et_al_Survey-of-circular-economy-maturity-and-circularity-in-Austrian-mechanical-and-vehicle-engineering.pdf

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