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Decision Engineering in the Context of Circular Economy: Practitioner Perspectives

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A B S T R A C T

This study investigates decision engineering in the context of the circular economy, aiming to explore practitioner perspectives on decision-making processes, tools and techniques, and challenges. The objective is to provide insights into how decision engineering can support the transition to a circular economy, enhancing sustainability and resource efficiency. Qualitative research methods were employed, utilizing semi-structured interviews with 22 practitioners involved in circular economy initiatives across various sectors. Purposive sampling ensured a diverse representation of perspectives. Data analysis was conducted using NVivo software to identify key themes and patterns in the practitioners' experiences and insights. The findings reveal several key themes. Decision-making processes include strategic planning, operational decisions, stakeholder engagement, feedback mechanisms, and resource allocation, all crucial for integrating circular economy principles into organizational strategies. Tools and techniques such as data analytics, modeling and simulation, lifecycle assessment, and decision support systems support informed decision-making. However, practitioners face significant challenges, including regulatory constraints, financial limitations, technological barriers, cultural resistance, information gaps, market dynamics, and resource limitations. Effective decision engineering is essential for navigating the complexities of the circular economy, facilitating sustainable practices, and achieving environmental goals. By understanding practitioner perspectives and addressing identified challenges, organizations can develop robust strategies to advance circular economy initiatives. This study underscores the importance of strategic planning, stakeholder engagement, and the use of advanced tools in fostering a circular economy that is resilient and resource-efficient.

Keywords: *Circular economy, decision engineering, sustainability, qualitative research, stakeholder engagement, challenges, tools and techniques.*

1. Introduction

The concept of a circular economy (CE) has garnered significant attention as a sustainable alternative to the traditional linear economy. In a circular economy, resources are kept in use for as long as possible, and waste is minimized through strategies such as reuse, remanufacturing, and recycling (Camacho-Otero, Boks, & Pettersen, 2018). This model presents an opportunity to achieve sustainable economic growth while reducing environmental impacts, aligning with global efforts to address climate change and resource scarcity (Ahmad et al., 2020; Gazzola et al., 2017; Li, 2023; Tran et al., 2023).

The shift towards a circular economy is underpinned by various theoretical frameworks that emphasize sustainability, resource efficiency, and systemic innovation (Abidin et al., 2023; Awan et al., 2021; Camacho-Otero et al., 2018; Ghaithan et al., 2023; Giudice et al., 2020; Guarnieri et al., 2020; Halari & Baric, 2023; Ţurcan, 2023; Velenturf et al., 2018). Central to this shift is the notion of closing the loop in product lifecycles, which involves rethinking product design, production processes, and consumption patterns (Giudice et al., 2020). By integrating principles of circularity into business models, companies can enhance their resilience and competitiveness while contributing to environmental sustainability (Awan et al., 2021).

Decision engineering plays a critical role in the successful implementation of circular economy principles. Decision engineering involves the use of structured methodologies and tools to improve decision-making processes, particularly in complex and dynamic environments. In the context of the circular economy, decision engineering helps organizations navigate the complexities of resource flows, stakeholder engagement, and regulatory compliance (Batista et al., 2018; Camacho-Otero et al., 2018). Effective decision-making frameworks are essential for optimizing resource use, reducing waste, and achieving sustainability goals (Parsakia et al., 2023).

Understanding the perspectives of practitioners is crucial for the practical application of circular economy principles. Practitioners bring valuable insights into the challenges and opportunities associated with transitioning to a circular economy. Their experiences can inform the development of more effective decision-making frameworks and tools, tailored to the specific needs of different sectors and industries (Halari & Baric, 2023).

The literature on the circular economy highlights several key areas of focus, including supply chain management, reverse logistics, and the role of digitalization. Effective supply chain management is critical for the circular economy, as it involves the coordination of various stakeholders and the optimization of resource flows. Giudice et al. (2020) emphasize the moderating effect of big data in enhancing supply chain efficiency and sustainability. By leveraging data analytics, companies can gain insights into resource use, identify inefficiencies, and make informed decisions to improve their supply chain operations (Giudice et al., 2020). Reverse logistics is another essential component of the circular economy, involving the processes of returning products and materials to the production cycle. Guarnieri, Streit, and Batista (2020) discuss the importance of reverse logistics in the packaging industry in Brazil, highlighting the need for sectoral agreements and collaborative efforts to facilitate the transition to a circular economy. Effective reverse logistics systems can reduce waste, recover valuable materials, and support sustainable production practices (Guarnieri et al., 2020).

The role of digitalization in the circular economy is increasingly recognized as a key enabler of sustainable business models. Digital technologies such as the Internet of Things (IoT), blockchain, and artificial intelligence (AI) can enhance transparency, traceability, and efficiency in resource management (Ţurcan, 2023). Awan, Sroufe, and Shahbaz (2021) review the intersection of Industry 4.0 and the circular economy, recommending future research to explore the potential of digital technologies in driving circularity (Awan et al., 2021). Consumption patterns also play a significant role in the circular economy. Camacho-Otero, Boks, and Pettersen (2018) review the literature on consumption in the circular economy, highlighting the need for behavioral change and the adoption of sustainable consumption practices. Engaging consumers and promoting circular products and services are essential for creating demand and driving the transition to a circular economy (Camacho-Otero et al., 2018).

The transition to a circular economy represents a paradigm shift in how we manage resources, design products, and engage with stakeholders. Decision engineering is critical for navigating this transition, providing structured methodologies and tools to enhance decision-making processes. By exploring the perspectives of practitioners, this study aims to provide valuable insights into the practical application of circular economy principles, contributing to the development of more effective and

sustainable business models. The integration of decision engineering and circular economy principles can drive significant environmental, economic, and social benefits. As the global community continues to address the challenges of climate change and resource scarcity, the adoption of circular economy practices, supported by robust decision-making frameworks, will be essential for achieving a sustainable future. By drawing on the rich insights from practitioners and the existing body of literature, this study aims to advance our understanding of decision engineering in the context of the circular economy, providing a foundation for future research and practice.

2. Methods and Materials

2.1. Study Design and Participants

This study adopts a qualitative research design to explore decision engineering in the context of the circular economy from the perspectives of practitioners. Qualitative methods are particularly suited for this inquiry as they allow for a deep understanding of complex phenomena through rich, detailed data collection and analysis.

Participants were selected using purposive sampling to ensure a diverse representation of practitioners involved in circular economy initiatives across various sectors. This approach allows for the inclusion of individuals with relevant expertise and experience, thereby enriching the data. Recruitment was facilitated through professional networks, industry conferences, and online platforms dedicated to sustainability and circular economy practices.

2.2. Measures

2.2.1. Semi-Structured Interview

The primary method of data collection employed in this research is semi-structured interviews. Semi-structured interviews provide a balance between structured and unstructured interviews, allowing for flexibility in probing deeper into respondents' insights while maintaining consistency across interviews. The interviews were designed to capture practitioners' experiences, challenges, and strategies related to decision engineering within the circular economy.

An interview protocol was developed to guide the conversations. The protocol included open-ended questions aimed at understanding:

- Participants' professional backgrounds and roles.
- Their involvement in circular economy initiatives.
- Decision-making processes and tools used.
- Challenges and barriers encountered in implementing circular economy principles.
- Perceived benefits and outcomes of adopting circular economy practices.
- Suggestions for improving decision-making frameworks within this context.

2.3. Data Analysis

The concept of theoretical saturation guided the sample size determination. Interviews continued until no new themes or insights emerged, indicating that theoretical saturation had been reached. This approach ensures that the collected data is comprehensive and robust, capturing the full spectrum of practitioners' perspectives.

Data analysis was conducted using NVivo software, a powerful tool for qualitative data analysis. The process involved several stages:

Transcription: All interviews were transcribed verbatim to ensure accuracy and facilitate detailed analysis.

Coding: The transcriptions were imported into NVivo, where a coding framework was developed. Initial codes were generated based on the interview questions and emergent themes from the data.

Thematic Analysis: Codes were systematically organized into themes and sub-themes. This process involved identifying patterns, relationships, and overarching themes that capture the essence of practitioners' perspectives on decision engineering in the circular economy.

Validation: To enhance the credibility and validity of the findings, member checking was employed. Participants were invited to review and validate the preliminary themes and interpretations, ensuring that their perspectives were accurately represented.

3. Findings and Results

The study included a total of 22 participants, all of whom are practitioners involved in circular economy initiatives across various sectors. The participants represented a diverse range of professional backgrounds and roles, ensuring a comprehensive perspective on decision engineering practices. Among the participants, 10 (45%) were from manufacturing industries, 6 (27%) were from the service sector, and 6 (27%) were from government or regulatory bodies. The gender distribution included 14 males (64%) and 8 females (36%), reflecting the broader industry demographics. The age range of participants varied from 30

to 55 years, with a mean age of 42 years. The participants' professional experience in the circular economy ranged from 5 to 20 years, with an average of 12 years, indicating a high level of expertise and familiarity with the subject matter.

Table 1

The Results of Thematic Analysis

Category	Subcategory	Concepts
Decision-Making Processes	Strategic Planning	Long-term goals, Policy alignment, Sustainability objectives
	Operational Decisions	Process optimization, Cost reduction, Efficiency improvements
	Stakeholder Engagement	Stakeholder identification, Communication strategies, Collaboration platforms
	Feedback Mechanisms	Performance metrics, Continuous improvement, Corrective actions
	Resource Allocation	Budgeting, Prioritization, Resource distribution
Tools and Techniques	Data Analytics	Big data, Predictive analytics, Data visualization
	Modeling and Simulation	Simulation models, Risk assessment, System dynamics
	Lifecycle Assessment	Environmental impact, Carbon footprint, End-of-life management
	Decision Support Systems	Expert systems, Decision trees, Optimization algorithms
	Benchmarking	Industry standards, Best practices, Competitor analysis
	Scenario Planning	Alternative futures, Risk scenarios, Contingency planning
Challenges and Barriers	Regulatory Constraints	Compliance, Legal requirements, Policy changes
	Financial Constraints	Funding availability, Investment priorities, Cost-benefit analysis
	Technological Barriers	Innovation gaps, Technology adoption, Infrastructure needs
	Cultural Resistance	Change management, Organizational behavior, Employee training
	Information Gaps	Knowledge management, Data sharing, Research and development
	Market Dynamics	Market trends, Consumer behavior, Competitive pressure
	Resource Limitations	Material scarcity, Supply chain issues, Resource depletion

3.1. Decision-Making Processes

Strategic Planning: Practitioners emphasized the importance of strategic planning in aligning long-term goals with sustainability objectives. One interviewee noted, "Strategic planning is crucial for integrating circular economy principles into our long-term vision and policy alignment." This alignment ensures that sustainability objectives are embedded within organizational strategies, facilitating a more structured approach to circular economy initiatives.

Operational Decisions: Decision-making at the operational level focuses on process optimization, cost reduction, and efficiency improvements. As one participant shared, "Operational decisions are driven by the need to enhance efficiency and reduce costs while maintaining our commitment to sustainability." This approach ensures that day-to-day operations align with broader circular economy goals.

Stakeholder Engagement: Engaging stakeholders is critical for successful circular economy initiatives. This involves identifying key stakeholders, developing effective communication strategies, and leveraging collaboration platforms. One practitioner explained, "Effective stakeholder engagement allows us to build partnerships and collaborate on circular projects, ensuring that all voices are heard and integrated into the decision-making process."

Feedback Mechanisms: Establishing robust feedback mechanisms helps organizations measure performance, drive continuous improvement, and implement corrective actions. An interviewee highlighted, "Feedback loops are essential for monitoring progress and making necessary adjustments to our circular economy practices." This continuous feedback fosters a culture of improvement and adaptability.

Resource Allocation: Efficient resource allocation is vital for prioritizing and distributing resources effectively. This includes budgeting and prioritization to ensure that critical areas receive the necessary support. A participant mentioned, "Resource allocation decisions are fundamental to our ability to prioritize initiatives that have the most significant impact on our sustainability goals."

3.2. Tools and Techniques

Data Analytics: The use of big data, predictive analytics, and data visualization tools plays a significant role in decision-making. As one practitioner stated, "Data analytics provides us with the insights needed to make informed decisions and predict future trends in our circular economy efforts."

Modeling and Simulation: Simulation models, risk assessments, and system dynamics are used to anticipate and mitigate potential risks. One interviewee noted, "Modeling and simulation help us understand the complexities of circular systems and evaluate potential outcomes before implementation."

Lifecycle Assessment: Assessing environmental impacts, carbon footprints, and end-of-life management are crucial for understanding the full lifecycle of products and processes. A participant shared, "Lifecycle assessment allows us to identify areas for improvement and reduce our environmental impact throughout the product's lifecycle."

Decision Support Systems: These systems, including expert systems, decision trees, and optimization algorithms, assist in making complex decisions. One practitioner explained, "Decision support systems provide the structure and tools needed to analyze multiple scenarios and select the best course of action."

Benchmarking: Benchmarking against industry standards, best practices, and competitor analysis helps organizations gauge their performance. An interviewee mentioned, "Benchmarking enables us to learn from industry leaders and adopt best practices that enhance our circular economy initiatives."

Scenario Planning: Scenario planning involves exploring alternative futures, risk scenarios, and contingency planning. As one participant highlighted, "Scenario planning helps us prepare for various possibilities and develop strategies that are resilient and adaptable."

3.3. Challenges and Barriers

Regulatory Constraints: Compliance with legal requirements and policy changes can pose significant challenges. One practitioner noted, "Navigating regulatory constraints is often challenging, but it is essential for ensuring our initiatives are compliant and sustainable."

Financial Constraints: Funding availability, investment priorities, and cost-benefit analyses are critical financial considerations. A participant explained, "Securing funding for circular economy projects is a major challenge, but it's necessary for driving innovation and achieving our sustainability goals."

Technological Barriers: Innovation gaps, technology adoption, and infrastructure needs can hinder progress. One interviewee stated, "Technological barriers can slow down our efforts, but overcoming these challenges is key to advancing our circular economy practices."

Cultural Resistance: Change management, organizational behavior, and employee training are necessary to address cultural resistance. As one practitioner shared, "Cultural resistance is one of the toughest barriers to overcome, but with effective change management and training, we can foster a culture that supports circular economy principles."

Information Gaps: Knowledge management, data sharing, and research and development are essential for bridging information gaps. A participant mentioned, "Addressing information gaps through better knowledge management and data sharing can significantly enhance our decision-making processes."

Market Dynamics: Understanding market trends, consumer behavior, and competitive pressure is vital for adapting to market dynamics. One interviewee noted, "Staying attuned to market dynamics helps us anticipate changes and adapt our strategies accordingly."

Resource Limitations: Material scarcity, supply chain issues, and resource depletion are significant concerns. As one practitioner highlighted, "Resource limitations are a constant challenge, but finding innovative solutions to these issues is essential for sustainable circular economy practices."

4. Discussion and Conclusion

The findings from this study reveal several key insights into decision engineering in the context of the circular economy, drawn from the perspectives of practitioners. The results highlight three main themes: decision-making processes, tools and techniques, and challenges and barriers.

Practitioners emphasized the importance of strategic planning, operational decisions, stakeholder engagement, feedback mechanisms, and resource allocation in the decision-making processes. Strategic planning was noted as crucial for aligning long-term goals with sustainability objectives. Operational decisions focused on process optimization and cost reduction, while stakeholder engagement was critical for collaboration and communication. Feedback mechanisms and resource allocation ensured continuous improvement and effective prioritization of resources.

Various tools and techniques were identified as essential for supporting decision-making in the circular economy. These included data analytics, modeling and simulation, lifecycle assessment, decision support systems, benchmarking, and scenario planning. Data analytics and modeling were particularly highlighted for their role in

providing insights and predicting future trends, while lifecycle assessment helped in understanding the environmental impact of products and processes.

The study also identified several challenges and barriers that practitioners face in implementing circular economy initiatives. Regulatory constraints, financial constraints, technological barriers, cultural resistance, information gaps, market dynamics, and resource limitations were all significant hurdles. These challenges underscore the complexity of transitioning to a circular economy and the need for robust strategies to address them.

The results align with existing literature on the circular economy and decision engineering. For instance, Awan, Sroufe, and Shahbaz (2021) highlighted the importance of integrating circular economy principles into strategic planning and operational decisions. Their findings support the emphasis on aligning long-term goals with sustainability objectives and optimizing processes to reduce costs and enhance efficiency. This alignment is crucial for achieving the systemic changes required for a circular economy (Awan et al., 2021).

Stakeholder engagement is another critical aspect supported by the literature. Camacho-Otero, Boks, and Pettersen (2018) emphasized the need for effective communication and collaboration among stakeholders to drive circular economy initiatives. The findings from this study confirm that identifying and engaging stakeholders are essential for building partnerships and ensuring that all voices are heard in the decision-making process (Camacho-Otero et al., 2018).

The use of tools and techniques such as data analytics, modeling and simulation, and lifecycle assessment is well-documented in the literature. Giudice et al. (2020) highlighted the role of big data in enhancing supply chain efficiency and sustainability (Giudice et al., 2020). Similarly, Batista et al. (2018) discussed the importance of lifecycle assessment in understanding the environmental impacts of packaging recovery ecosystems (Batista et al., 2018). These tools provide critical insights that help practitioners make informed decisions and optimize resource use.

Challenges and barriers identified in this study are consistent with previous research. Guarnieri, Streit, and Batista (2020) highlighted the regulatory and financial constraints faced by the packaging industry in Brazil (Guarnieri et al., 2020). Technological barriers, such as innovation gaps and infrastructure needs, were also noted by Ţurcan (2023) as significant hurdles in the adoption of circular economy practices. Addressing these challenges requires a multifaceted approach that includes policy support, investment in technology, and cultural change within organizations (Ţurcan, 2023).

Despite the comprehensive insights provided by this study, there are several limitations that should be acknowledged. First, the sample size of 22 participants, while diverse, may not fully capture the breadth of experiences and perspectives across all sectors and regions. Future studies could benefit from a larger and more geographically diverse sample to enhance the generalizability of the findings. Second, the study relies on self-reported data from practitioners, which may be subject to bias. Triangulating these findings with quantitative data or case studies could provide a more robust understanding of the issues.

Another limitation is the focus on qualitative data collected through semi-structured interviews. While this method provides rich, detailed insights, it may not capture the full complexity of decision-making processes and challenges in the circular economy. Incorporating mixed methods approaches, including quantitative surveys and observational studies, could provide a more comprehensive view. Additionally, the study was conducted in a specific timeframe, and the rapidly evolving nature of the circular economy and related technologies means that some findings may quickly become outdated.

Based on the findings and limitations of this study, several areas for future research are suggested. First, there is a need for longitudinal studies that track the evolution of decision-making processes and the impact of circular economy initiatives over time. Such studies could provide valuable insights into the long-term benefits and challenges of transitioning to a circular economy.

Second, future research could explore the role of emerging technologies, such as blockchain and artificial intelligence, in enhancing decision-making and transparency in circular economy practices. Researchers highlighted the potential of Industry 4.0 technologies to drive circularity, and further investigation into specific applications and impacts could provide valuable guidance for practitioners (Awan et al., 2021; Bayanati, 2024; Ghaithan et al., 2023; Haleem et al., 2023; Zhou et al., 2023).

Third, comparative studies across different sectors and regions could help identify best practices and common challenges in implementing circular economy initiatives. For example, Batista et al. (2018) conducted a comparative study of packaging recovery ecosystems in China and Brazil,

providing insights into the unique challenges and opportunities in different contexts. Expanding this approach to other sectors and regions could enhance our understanding of the global applicability of circular economy principles (Batista et al., 2018).

Lastly, research could focus on the behavioral aspects of decision-making in the circular economy. Understanding how individual and organizational behaviors influence the adoption of circular practices could inform the development of more effective strategies for change management and cultural transformation. Camacho-Otero, Boks, and Pettersen (2018) emphasized the importance of consumer behavior in driving circular economy initiatives, and further research in this area could provide valuable insights for policymakers and practitioners (Camacho-Otero et al., 2018).

The findings from this study provide several practical recommendations for organizations looking to implement circular economy principles. First, organizations should prioritize strategic planning and align their long-term goals with sustainability objectives. This alignment ensures that circular economy principles are embedded in the organizational culture and decision-making processes.

Second, effective stakeholder engagement is critical for the success of circular economy initiatives. Organizations should develop strategies for identifying and engaging stakeholders, fostering collaboration, and ensuring that all voices are heard in the decision-making process. This approach can help build partnerships and drive collective action towards sustainability goals.

Third, organizations should invest in data analytics, modeling and simulation, and lifecycle assessment tools to support decision-making. These tools provide valuable insights into resource use, environmental impacts, and potential risks, enabling organizations to make informed decisions and optimize their operations. Giudice et al. (2020) and Batista et al. (2018) highlighted the importance of these tools in enhancing supply chain efficiency and sustainability (Batista et al., 2018; Giudice et al., 2020).

Additionally, addressing the challenges and barriers identified in this study requires a multifaceted approach. Organizations should work closely with policymakers to navigate regulatory constraints and seek financial support for circular economy initiatives. Investing in technology and infrastructure is also crucial for overcoming technological barriers and enhancing innovation. Țurcan (2023) emphasized the role of digitalization in driving circular economy practices, and organizations should explore the potential of emerging technologies to enhance their operations (Țurcan, 2023).

Finally, organizations should focus on change management and cultural transformation to address cultural resistance and information gaps. Developing training programs and promoting knowledge sharing can help build a culture that supports circular economy principles and fosters continuous improvement. Camacho-Otero, Boks, and Pettersen (2018) highlighted the importance of engaging consumers and promoting sustainable consumption practices, and organizations should incorporate these strategies into their overall approach (Camacho-Otero et al., 2018).

In conclusion, this study provides valuable insights into decision engineering in the context of the circular economy, highlighting the importance of strategic planning, stakeholder engagement, and the use of advanced tools and techniques. By addressing the challenges and barriers identified, organizations can enhance their decision-making processes and drive the transition to a more sustainable and circular economy. The practical recommendations provided can guide practitioners in implementing circular economy principles, contributing to a more sustainable future for all.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were considered.

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