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Exploration of decision-contexts for circular economy in automotive industry

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Abstract

Research emphasizes that existing approaches to identify drivers and barriers for implementing CE in organizations pay little attention to the roles of actors and their specific decision-contexts. Here, we identify research gaps in existing literature regarding the goals of actors, methods used and forms of collaboration in relation to CE. To address these gaps, we use the case of implementing CE for Electric Vehicle batteries at an automotive manufacturer in Germany to explore decision contexts for CE. Based on a number of internal stakeholder interviews, we identify four key decision contexts for CE, which we characterize in terms of goals, methods and forms of collaboration. Thereby, we provide novel insights into how implementing CE is linked to context-specific conditions in terms of transparency, plannability, integration in product development and entrepreneurial culture. Lastly, we discuss the findings in relation to existing literature and derive directions for future studies in the field of CE assessment and implementation.

Keywords: Circular Economy; Electric Vehicle Batteries; Circular Business Models; Decision-context; Circular Economy Asssessment;

1. Introduction

Circular Economy (CE) is defined as "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops" [1]. For companies seeking to implement these CE principles, this involves fundamentally rethinking their supply chains and ways of value delivery [2]. This is often associated with the notion of Circular Business Models (CBM) [3]. However, several knowledge gaps exist in scientific literature regarding the conditions for successfully implementing CE in organizations and the realization of CBM. Firstly, many analyzes of drivers and barriers of CBM are found to be "decidedly static, simply listing examples of barriers (see Tukker, 2015)", thus being unable to "capture the dynamic interactions between drivers and barriers in the development of CBMs" [4]. The authors thus call for a closer investigation of the *goals of actors* involved in the development of CBM and the alignment of their interests with so-called drivers and barriers.

Secondly, guiding principles for implementing CE in organizations [5] seldom consider how CE implementation can be integrated with methods to assess CE [6]. Relatively little attention is given to "company needs, operational-, mid-management-, or strategic must-haves and […] decision-making contexts […] that appear to be relevant to CE assessment" [7]. Although literature provides reviews of a wide range of CE indicators (CEI) to assess CE at micro, meso or macro level [8]–[11], relatively little is known about the conditions under which methods to assess CE fit within

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organizational contexts. Authors addressing this knowledge gap recommend interaction with key-users to explore the effects of specific CBMs on business processes of a company and support the selection of CEI [12].

Lastly, there is a knowledge gap regarding the way stakeholders work together in implementing CE. While some authors point towards forms of *collaboration*, e.g. to exchange information to assess CE [13], [14], others emphasize the need to study the effects of developing CBMs and the consequences this has for other actors [4]. This resonates with research on sustainability-related trade-offs, requiring methods to resolve target conflicts and goal prioritization for CE and sustainability in general [15].

Accordingly, the research question addressed in this paper is as follows: What are the conditions for successfully implementing CE in different decision-contexts of an organization? In relation to the abovementioned knowledge gaps regarding *i) goals and concerns of actors involved, ii) methods used,* and *iii) forms of collaboration among actors*, this study starts by investigating how internal stakeholders attend to these issues today. By investigating *who* carries out certain key tasks*, how* and *with whom*, we aim to understand critical characteristics of business processes and identify conditions for implementing CE in practice. The study focuses on the timely case of managing resource consumption for EV batteries in the automotive industry. This is a key issue within the CE action plan of the European Commission [16]. Several options for implementing CBM for EV batteries are presented in literature. These include battery remanufacturing and reuse in EVs [17], repurposing and further use in stationary battery energy storage systems [18]–[20], as well as closed loop recycling [21]. By using unique insights into the management practices for EV batteries in an organization, we propose an actor-focused perspective on what enables the implementation of CE. The goal is to advance scientific knowledge on what constitutes as drivers and barriers of certain CBMs in an organizational context.

2. Materials and method

The study is based on case within the automotive industry as this enables us to explore on-going issues associated with implementing CE, i.e. identify key actors, methods and forms of collaboration. This then serves to formulate a hypothesis on the conditions affecting successful execution of CBM in certain decision-contexts [22]. The study is conducted at a large automotive manufacturer in Germany that is currently undergoing a technological shift towards e-mobility. Despite the early stage of EV markets and the relative novelty of EV battery technology, the company has established several CBM such as EV battery remanufacturing, repurposing and recycling [23]. Additionally, decoupling resource consumption from economic growth has been announced as a strategic goal as part of the sustainable business strategy of the company, thereby indicating a commitment towards CE [24].

The study is based on 22 semi-structured interviews, conducted with company-internal stakeholders in 2020. All interviewees work with EV batteries in different functions within the organization. Interviewees were selected based on suggestions from members of the research and sustainability department, who chose employees previously involved in company-internal dialogues and working groups on managing resource consumption of EV batteries.

To guide the analysis, the interviewees were classified using the five business processes [25]: product development (8 interviewees), supply chain (3), production (3), business model (BM) (4), and end of life (EoL) (4). The interviews were structured based on the three key aspects identified in literature (see Figure 1). The first part addresses the stakeholders' responsibilities, goals and typical concerns. The second part explores their work practices in terms of methods, units of assessment and data sources used. The third part describes the relationship among stakeholders, forms of collaboration and methods to resolve target conflicts.

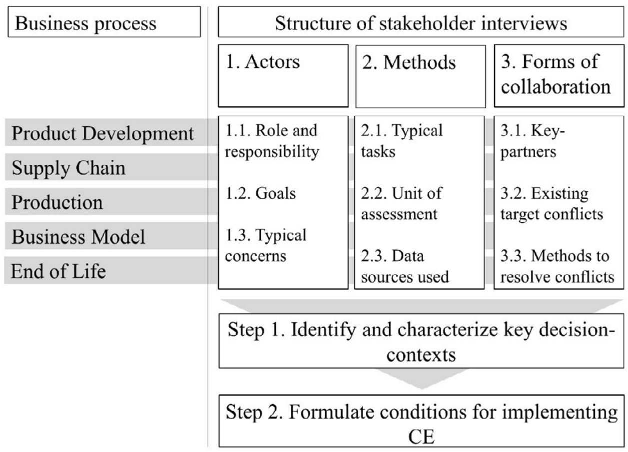

Figure 1. Research framework

The analysis is carried out in 2 steps: firstly, we focus on reoccurring themes, unique statements or cross-relationship across business processes. In this way, we identify key decision contexts, which are characterized by goals, methods and forms of collaboration. Lastly, these characteristics are translated into conditions for implementing CE.

3. Results

3.1. Step 1 – Identified key decision-contexts

Generally, the study reveals that the company has a great number of activities aimed at further developing management practices for EV batteries. This is primarily due to the relative importance of batteries for the performance, cost and sustainability profile of EVs as a whole. Thus, numerous company-internal working groups are mentioned during the interviews, e.g. groups dealing with advances in cell technology development, raw material availability and implications of EV market uptake. The analysis of the interview data reveals four key-decision contexts, which deal with crucial aspects of designing and managing EV battery life cycles (see Table 1). Based on the data collected, each of these decision-contexts can be characterized in terms of goals of actors, methods used and forms of collaboration. In the following, we briefly outline the key findings for each decision-context.

Table 1. Key decision-contexts identified in interview data

Business Process	Decision context 1	Decision context 2	Decision context 3	Decision context 4
Product development	X	-	X	-
Supply Chain	X	X	-	-
Production	-	-	X	-
Business Model	-	-	-	X
End of Life	-	X	X	X

3.1.1. Product development and supply chain

Regarding decision-context 1, interviewees assigned to product development repeatedly mentioned the task to translate customer requirements for EVs into requirement specifications for EV batteries. A key task thus lies in balancing different design criteria such as battery performance, lifetime and cost. Interviewees often referred to the issue of measuring effects of inter-dependent parameters, e.g. how increasing battery lifetime affects cost, performance or environmental footprint. Another example mentioned was that increasing the share of recycled content in battery materials reduces the environmental footprint, but requires a different supply chain of raw materials at supplier level, thereby, potentially affecting the cost of battery cells. This challenge is also mentioned by the supply chain department, whose goal is to ensure the realization of specified requirements and achieve the "best product at best prize and lowest impact".
To address this task, employees working in both product development and supply chain jointly use scenario analysis as a key method to assess and compare different technically feasible design options. Here, interviewees emphasized the importance of two specific actors, being product cost engineering (PCE) and technology research. Both these actors carry out market research on technology roadmaps, price development and production processes, using different data sources such as scientific literature, supplier data, simulation and experiments. By providing reliable and transparent knowledge and data on e.g. potential cost per kWh of battery capacity or kg cathode material, both actors support the process of defining ambitious and yet credible and realistic targets and balancing battery design criteria. Interestingly, although not being directly involved in design or procurement, PCE and technology research thereby fundamentally contribute to structuring and focusing the collaboration between the two business processes product development and supply chain.
Based on our interviews, this decision context is characterized by:

- Battery requirements need to be specified in a understandable and transparent way in order to be communicated transparently towards suppliers;
- Reproducible methods are needed to compare scenarios of different battery design decisions on product-, component-, process- or raw material-level;
- Independent and informed actors support the definition of ambitious yet realistic targets for specific battery requirements and thereby maintain credibility in collaboration with suppliers and in public communication.

3.1.2. Supply chain and EoL

In decision-context 2, interviewees involved in EoL operations described their function as to ensure legal compliance of battery recycling and disposal and to identify potential purposes for EoL batteries. A key goal is the systematic reduction of service and maintenance costs. To achieve this, a key concern lies in planning and establishing standardized processes. This is a challenge due to regulatory differences in local markets. Therefore, the availability of empirical and future material flow data is emphasized, e.g. in order to make investment decisions on logistic networks, increasing accuracy of EoL battery diagnosis or for process capacity planning.
At the same time, interviewees working with battery supply chains explained that their role includes the assessment of battery raw material supply. They emphasized the issue of managing fluctuating battery material prices as well as ongoing changes in battery cell technology. A key concern mentioned was the availability of knowledge on future material characteristics and markets. Methods to manage these goals therefore include the development of technology roadmaps as well as regular market forecasts in order to enable strategic planning. Key data sources are suppliers, public reports and internal reviews from product cost engineering. In terms of collaboration, interviewees mentioned the potential to reduce supply risks by increasing the use of secondary raw materials from recycled batteries. Therefore, a key finding was the need to establish a supplier relationship with EoL processes for EV batteries, in which the market stock of EV batteries is considered a "virtual mine" of raw materials. The underlying goal mentioned was to build EoL supply chains, which satisfy the same standards applied in strategic supplier management respectively, e.g. in terms of supply risk assessments and plannability of available volumes.
In summary, the decision-context 2 has the following characteristics:

- Standardization of EoL processes is needed to ensure plannability and to systematically reduce service costs;
- Management of EoL battery material flows requires integration with case-specific legal and technical requirements in local markets;
- In order to reduce supply risks for EV batteries by using secondary raw materials, EoL operations need to be assessed using the same standards applied in strategic supplier management.

3.1.3. Product development, production and EoL

In decision-context 3, stakeholders in battery production described their role as to translate product characteristics into process design. With the goal of minimizing costs, a key concern was to avoid product design changes after start of production. Costs can be minimized by engaging with product development in early battery design stage. Similarly, interviewees from EoL processes also mentioned reducing costs by improving battery design for serviceability in the early development phase. In terms of methods, both production and EoL processes focus on process parameters such as process capacity and efficiency, whereas product developers require information on how these measures affect the cost of a battery, i.e. on a product level. Therefore, a key task within this context lies in assessing and translating process improvements based on empirical data into potential benefits at product level. Besides cost, it was indicated during the interviews that a similar need exists for methods to assess potentials for reducing environmental impacts. Furthermore, in terms of collaboration, interviewees mentioned that both in production and EoL processes, certain actors take the role of an aggregator, who collects information, derives proposals for design improvements and communicates them towards product developers at early stage. Based on these findings, the decision context is characterized by:

- Integration of production and EoL requirements in early design stage is needed to avoid cost and impacts of late design changes;
- Methods needed to assess and communicate process-based improvement potentials into product-based benefits per battery
- Actors needed who take the role of collecting, aggregating and communicating information towards product development.

3.1.4. Business Model and EoL

For decision-context 4, interviewees working with business models for EV batteries repeatedly stated their responsibility as "giving batteries a second chance". This means developing products and services based on EoL batteries, which create value for customers. As an example, interviewees working with EV battery repurposing mentioned the need to understand energy market developments in detail in order to offer competitive and sustainable battery storage solutions. Another interviewee mentioned similar issues with regard to battery recycling, given the changing regulatory landscape for EV battery EoL. In light of these case-based benefits, they had a general concern regarding the flexibility needed to define value creation of business models for EV batteries for the company. Consequently, as the interviewees put it, they have to pursue a "culture of circularity and entrepreneurship." By that, they refer to a mind-set of finding value of materials, products or services at any life cycle stage, and the notions that this value is determined by specific market- and customer needs in different sectors. This is exemplified by interviewees efforts to implement pilot projects, e.g. for EV battery repurposing to showcase the value of energy flexibility in future electricity grids.

In terms of methods, interviewees emphasized the need to enable a case-by-case comparison of alternative business models for EoL batteries, i.e. remanufacturing, repurposing and recycling. For that, they mentioned the need for systematic data exchange. This is in keeping with the pursuit of standardized processes and methods, which is mentioned as key to assess material flows of EoL batteries. Lastly, interviewees consistently stated that currently collaboration focuses mostly on technical cascading systems, i.e. select business models based on the technical condition of a battery. In the future, this should be developed further by defining joint, strategic targets at a company level. The characteristics of decision-context 4 are thus as follows:

- Flexibility is needed to capture the different forms of value creation through business models for EV batteries in relation to company goals;
- EoL battery material flows need to be integrated with systematic methods to assess EoL batteries;
- Collaboration between business models for EV batteries needs to be based on joint targets on a company level.

3.2. Step 2 - Formulating conditions for implementing CE

To formulate a hypothesis on conditions for implementing CE, we define key themes for implementing CE in the organization based on the decision contexts identified. These are then specified by conditions regarding actors, methods and forms of collaboration, which are CBM-specific and derived from the characteristics of each decision-context. An overview of the results is presented in Table 2.

For *decision-context 1*, the results lead to the conclusion that ensuring transparency regarding the relationship between CBM and key product parameters is a condition for actors in product development and supply chain. This is linked to the ability to assess CBM scenarios based on reproducible methods and data. Additionally, the need for transparency can be supported by engaging with independent actors, who conduct market research on CBM for EV batteries and support the definition of realistic targets. Within *decision-context 2*, plannability is identified as an overall condition for implementing CE between EoL and supply chain. Detailed needs in this respect include the pursuit of standardization of processes, integrated methods to assess EoL battery flows as well as a robust assessment of CBM based on existing supplier management practices. Although closed-loop recycling was particularly mentioned as an example during the interviews, similar conditions could apply for other CBM as well. *Decision-context 3* is characterized by a general need for early integration of process-based data in optimizing battery design. This requires both suitable methods and dedicated functions. Lastly, results on *decision-context 4* reveal the need for a culture of circularity and entrepreneurship, which could be supported by flexible definition of value creation for the company, systematic methods to make case-based decisions for EoL batteries, as well as joint targets across business models towards benefits on a company level.

4. Discussion

In terms of the contributions to existing literature, some results of the present study are in keeping with- or expand findings from previous studies, whereas other results contradict existing findings.

Firstly, our finding on the importance of "credibility" for stakeholders involved in decision-context 1, particularly in communication with external parties, resonates well with the point made in [4] regarding the importance of the alignment of interests; without credibility it is difficult to align interests. Our study confirms the relevance of this point, indicating that a lack of credible and realistic data can inhibit the definition of CE targets, and thus potentially prevent the development of CBM. While other authors have addressed the general issue of cross-company collaboration for CE [14], our study has brought further insights to the issue.

Secondly, the interviews highlight the importance of establishing common CE targets at company level when jointly pursuing different CBM for EV batteries. We find that actors require flexible methods, allowing for a comparison of CBMs

Table 2. Conditions for implementing CE in relation to goals/ concerns of actors, methods used and dominant forms of collaboration

Key decision-context	Conditions for implementing CE	Goals/ Concerns	Methods	Collaboration
1. Product development, supply chain	Ensure transparency by…	… describing how enabling a CBM affects battery design parameters (e.g. cost/ performance).	… providing reproducible methods to assess scenarios of enhancing a CBM in battery design.	… engaging with specialized and informed actors to define credible targets for a specific CBM.
2. Supply chain, EoL,	Ensure plannability by…	… establishing standardized processes for a CBM (e.g. to support investment decisions in equipment and infrastructure).	… integrating EoL material flow models with case-specific data on assessment criteria for a battery CBM.	… establishing a supplier relationship between battery EoL and supply chain.
3. Product development, production, EoL	Ensure early integration in product development by…	… using different CBM to increase battery design maturity.	… establishing methods to collect and communicate process-based data for battery CBM into early design stage.	… establishing actors who aggregate and communicate requirements for a CBM towards product development.
4. Business Model, EoL	Ensure a culture of circularity and entrepreneurship by…	… describing the different forms of value created by CBM in relation to company goals.	… establishing systematic processes to assess EoL batteries in terms of potential benefits of CBM options.	… establishing joint targets to collaborate towards benefits for the company as a whole.

and their different forms of value creation, thus enabling a full company view. These findings add to the existing CEI literature, which focuses mostly on circularity at product level (see [8]–[11]). Although requiring validation, our proposed hypothesis on conditions for implementing CE instead underlines the results presented in [7], concluding that the scale of assessment for CE depends on the characteristics of end users and their context (see also [12]). Our results thus suggest- and offer guidance to expand the product-centred view applied in most case studies on CEI (see e.g. [13]) and introduce context-specific needs of actors at company-level. In this respect, no case studies exist to our knowledge, which compare product-level and company-level CEI for the same case to study the interactions between business processes for CE in organizations. Here, using existing research on business models for EV batteries, e.g. for the case of EV battery repurposing [18], seems a promising path for future research on testing CEI.

Thirdly, the findings regarding the need to transparently balance inter-related design parameters for CBM of EV batteries matches the theme of sustainability trade-offs stated in [15]. While existing research focuses on eco-design tools and the criteria applied for making trade-off decisions, the present study introduces an actor-focused perspective, which reveals the importance of certain independent actors, who provide data and knowledge needed to resolve target conflicts. In terms of limitations, one weakness of the study is that conditions for implementing CE are derived from current practices, thereby not considering implications of fundamental changes in work practices in the future. However, we believe that at the current stage, targeted attempts at integrating CE with current practices still offers the possibility of disclosing and overcoming limits of methods used today. Furthermore, the selection of interviewees, based on their participation in existing project groups in relation to sustainability or CE, introduces a bias as they are likely to be familiar with principles of reducing resource consumption or sustainability in general. Another sample, based on a broader selection of interviewees, may yield different results.

5. Conclusion

This study addresses some of the knowledge gaps regarding the implementation of CE in organizations by taking an (internal) stakeholder based approach on goals and concerns, methods and forms of collaborations used today. For the case of management practices for EV batteries in automotive industry, the study identifies and characterizes key decision-contexts, which involve different business processes within the case company. The study yields novel insights into the conditions for implementing CE in EV production. This includes the identification of independent roles undertaken by actors to ensure transparency and credibility of defined targets for CBM in supply chain processes. Furthermore, we find methods needed to ensure plannability of EoL operations towards closed loop recycling. Furthermore, the finding that assessing CE must combine product-, process- or material-focused views of different business processes can stir discussions on which methods best suited to describe circularity performance. This is underlined by the study's results indicating that CBM such as EV battery repurposing seem to require new, flexible frameworks for measuring value creation at a company level. Although our results on the conditions presented and the effects on the implementation of CE require further validation, they show the potential of emphasizing the role of employees and analyzing work practices. Particularly the research field of CEI, in which no standards for assessing CE performance have been established, could potentially benefit from the results of the present study. We therefore propose to study other cases of implementing CE and go beyond barriers rooted in technology or market development. Instead, understanding even better the individual goals of actors engaged in CBM could open new pathways in the adoption of CE in industry.

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