Redesign The Circular Business Model for A Circular Innovation Ecosystem

An embedded single case study of the Dutch microelectronics ecosystem

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Abstract

Our research investigates Circular Business Models (CBM) from an innovation ecosystem perspective with an embedded case study of the Dutch microelectronics industry. By exploring CBMs throughout the value chain from manufacturers to recyclers, and drivers/barriers towards circularity, we proposed suggestions on circular ecosystemic collaboration for both industry and policymakers.

Keywords

Circular Economy, Innovation Ecosystem, Circular Business Model, Sustainability, Electronics

Introduction

From Circular Economy (CE) efforts such as The European Green Deal and the Paris Agreement (2015), it has become evident that industries should aim to extend product lifecycles, diminish resource usage, enhance material recycling, and reduce waste. Waste from Electrical and Electronic Equipment (WEEE) increased with time passing by, leading to a call for CE of electronics. Present studies on CE focus on the circularity of end-user products and consumer electronics recycling (Boons et al., 2013; Atalay et al., 2021). Fewer studies also address the circularity of microelectronics in the Business-to-Business (B2B) context. In addition, there is a need for insights into managerial challenges, best practices, and innovative strategies required for implementing circularity to allow stakeholders to effectively mitigate the environmental impacts associated with their (micro) electronic products (Bocken et al., 2014). This underscores the urgency of investigating the role of managerial decisions, supply chain practices, and business models in promoting sustainability and circularity within the microelectronics industry.

The Netherlands, with its advanced microelectronics development, supportive government policies, and a commitment to sustainability, serves as an ideal setting for circular economy research. Microelectronics are the essence of driving electronics' operations to function and maintain high value within devices, such as Printed Circuit Boards (PCBs) composed of more than 20 types of metals, which is critical to minimising hazardous environmental pollution, the shortage of rare metals and minerals, and providing an opportunity for a transition towards CE with reusing components and recycling metals. We intend to investigate the current existing Circular Business Models (CBMs) in practice in the microelectronics industry and discuss the dominant drivers and barriers for circularity. This research can also provide a basis to support the new CBM development.

In recent studies Konietzko et al. (2020), the circular innovation ecosystem serves as a platform that facilitates the coordination of intricate and dynamic coopetition processes, where cooperation and competition intertwine. The nature of building circular ecosystems emphasizes the importance of collaboration, experimentation, systemic thinking and incentivization in driving progress towards circularity and sustainability. Addressing these research gaps will contribute to a deeper understanding of how to effectively build and sustain circular ecosystems and foster CBM innovation (CBMI) from a circular ecosystem development. In this study, we focus on the following research questions:

What are the existing CBMs in the B2B electronics ecosystem and how to redesign the innovation ecosystem for CBMI?

Based on exploratory research using an embedded case study of the Dutch microelectronics ecosystem from 23 semi-structured interviews, we discuss different scenarios and strategies for decision-making for companies with different value chain roles. The research question will be answered by investigating the existing CBMs of the microelectronics industry that have been designed or practised. These CBMs include the profitable mechanism and how the microelectronics industry attempts to design, produce, and circularly manage microelectronics. The circularity of microelectronics is faced with multifaceted challenges and opportunities, so we would also investigate the factors influencing the adoption of circular microelectronics practices, as well as the obstacles that hinder progress. By identifying these patterns, our study aims to provide actionable insights and a tool for future CBMI development for industrial stakeholders, policymakers, institutions, consumers, and future research on new CBM generation.

Closed-Loop Microelectronics Value Chain

Among the microelectronics value chain, there are various stakeholders (Kortmann & Piller, 2016). In a linear economy, waste goes to landfills, contaminating soil, lives, and underground water. WEEE recyclers aim to separate and recycle precious materials to diminish using virgin resources and prevent further environmental pollution. Some metals that can be extracted from shredded e-waste will be transported to metal recyclers to produce recycled metals. Hence, raw material providers (including recycled metal providers), microchip manufacturers, component manufacturers, Original Equipment Manufacturers (OEMs), Repairing Service Providers (RSPs), waste collectors, and recyclers (WEEE recyclers & metal recyclers) are the essential stakeholders of the microelectronics value chain. Figure 1).

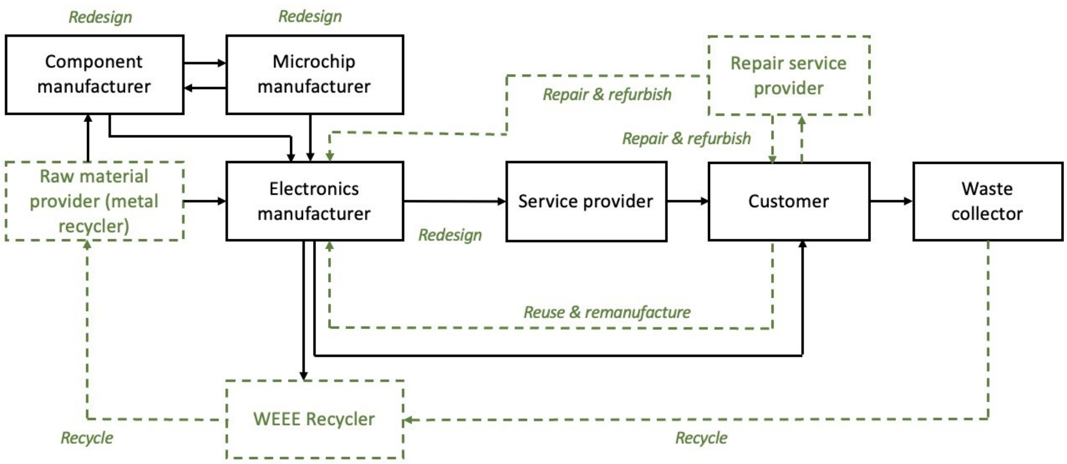

Figure 1 *Closed-loop value chain of microelectronics industry*

Circularity in the microelectronics industry

Several companies in the (micro)electronics industry focus on servitization, offering customized circular services and global service models (Agrawal et al., 2016). Redesign practices and sustainable product design are evident in the strategies of various companies. This involves creating products with a reduced environmental footprint, incorporating energy-saving features, and exploring design elements that facilitate reuse and recycling (Bocken et al., 2016). Reuse, repair, and refurbishment are integral components of circular strategies. Companies engage in the handling and resale of used products, providing repair support for specific components, and offering refurbishment services for EoL electronics (Guide & van Wassenhove, 2001). This approach extends the life cycle of products, reduces electronic waste, and contributes to a circular economy. Recycling initiatives involve the systematic processing and recovery of materials from EoL products (Corbett & DeCroix, 2002). Circular metals production, a specific focus for some companies, aims to meet the demand for recycled materials. This involves digitalization, technology integration, and comprehensive waste stream management, prioritizing the separation and refining of materials like aluminum, copper, and alloys. Collaboration with suppliers, leasing companies, and other stakeholders is emphasized in CBMs (Tukker & Tischner, 2006). Closed-loop relationships involve strategic partnerships, where materials are returned, recycled, and reused in a continuous cycle (Tasbirul & Nazmul, 2018). This collaborative approach enhances the overall sustainability of operations.

Companies in electronics showcase a rich variety of circular strategies, reflecting a commitment to environmental responsibility and circular practices (see Table 1). Whether through the provision of services, sustainable product design, or active engagement in recycling and refurbishment, these companies are contributing to the ongoing evolution of circular business models across diverse industries.

CE Strategy	Company	CBM	Description	B2B/B2C
Servitization	Electronics manufacturer	Customized Circular Services	Monthly subscription-based managed services with a focus on functionality and a closed-loop system.	B2B
		Global Service Model	Implements a global service model for worldwide operations, emphasizing servitization with services beyond product sales.	B2B
Non-Ownership	Service provider	Cloud Services	Offers cloud services without physically providing the product, emphasizing efficiency and reducing hardware footprint.	B2B/B2C (Primarily B2B)
	Electronics manufacturer	Leasing	Adopts a leasing model where products are offered for use rather than ownership, promoting resource sharing and return/refurbishment.	B2B
Redesign	Electronics manufacturer	Sustainable Product Design	Emphasizes sustainable product design, incorporating features to reduce energy consumption.	B2B
		Design for Reuse and Repair	Adopts a design strategy for maximizing material reuse and incorporates features for easy repairment.	B2B
	Component manufacturer	Design for CE	Actively works on guidelines for design for circularity, including redesign practices for reuse and recyclability.	B2B
Reuse	WEEE recycler	Handling Small Appliances and White Goods	Deals with small appliances and white goods, assessing quality and functionality, and selling functional parts for reuse.	B2B and Trading Market
		Second-hand Market Engagement	Participates in the second-hand market by selling functional components to computer hardware companies, repair companies, and businesses.	B2B and Trading Market
	Component manufacturer	Refurbishment for Customers	Receives and refurbishes used products from customers, some of which are sold as new.	B2B
Repair	WEEE recycler	Repair Support for Specific Components	Provides repair support for specific components, such as hard drives.	B2B
	Electronics manufacturer	Repairing Services	Offers repairing services as part of its circular business model, extending the lifespan of products.	B2B
Refurbishment	WEEE recycler	End-of-Life Services for Electronics	Offers services for end-of-life electronics, including wiping, testing, and potential refurbishment for reuse.	B2B
	Component manufacturer	Refurbishment for Customers	Involves receiving used and refurbished products, some of which are reassembled into new cabinets for resale.	B2B
Remanufacturing	Component manufacturer	Remanufacturing for Customers	Involves receiving used and refurbished products, some of which are reassembled into new cabinets for resale.	B2B
Recycling	WEEE recycler	Recycling and Reuse of IT Equipment	Focuses on recycling and reusing IT equipment components, including memory chips, CPUs, graphic cards, screens, and PCBs.	B2B
	Metal recycler	Comprehensive Waste Stream Management	Prioritizes waste streams and plans to build a complete refining line for recycling.	B2B
		Increasing Material Recovery Scope	Aims to chemically recover a broader range of materials to increase the scope of recyclable materials.	B2B
	Microchips manufacturer	Design for Recycling	Focuses on designing chips for recyclability, tracking them through a monitoring system.	B2B

Table 1 *Existing CBMs in the electronics industry*

Data and Methodology

To answer our research questions, we have opted for an embedded single-case study (Yin, 2018), focusing on the Dutch microelectronics industry. This sector faces challenges in global competitiveness while transitioning to a circular product-service ecosystem. Data collection unfolds in two phases, utilizing multiple data units such as company visits, reports, discussions, interviews, and project meetings. This approach enables us to triangulate our findings and provide a holistic view of the ecosystem simultaneously.

The first phase encompassed 13 company visits, which included multiple project meetings, eight unstructured interviews with experts from various companies, an examination of sustainability reports and documentation provided by the companies, and observations. These observations were partly documented through field pictures capturing factories, assembly lines, and products. Insights gleaned from observations, documentation, and interview data in the first phase prompted the formulation of more specific research questions. This, in turn, led to the development of an interview protocol and coding schemes for the second phase of our study on Circular Business Models (CBMs). For a graphical representation of the research design, refer to Figure 2.

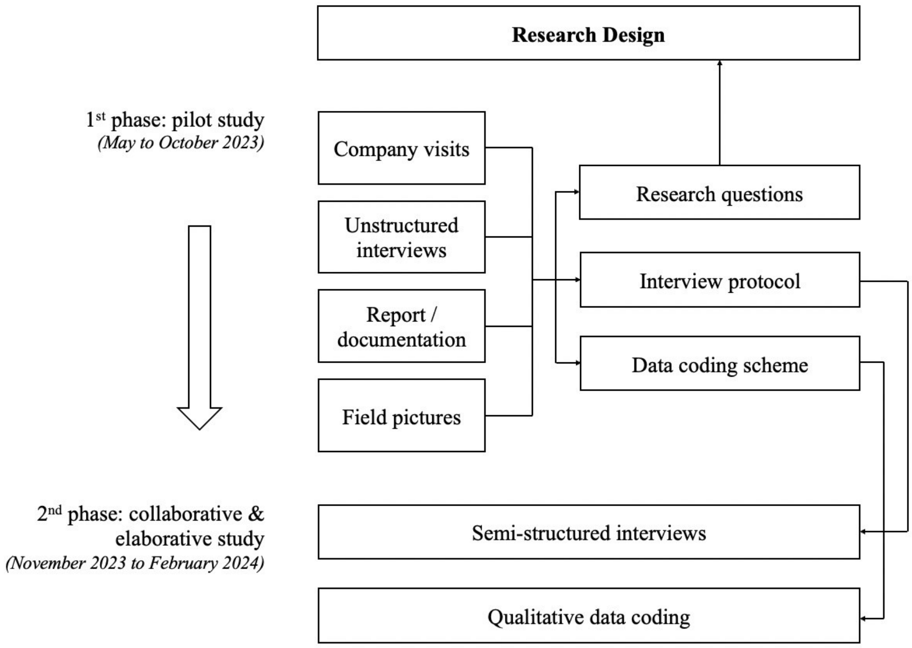

Figure 2 *Research design*

The study's second phase consists of semi-structured interviews with 23 experts from 18 companies conducted from November 2023 to March 2024. The interviewees had technical, commercial, and supply chain backgrounds in the company to reduce biases caused by different professions, thereby increasing validity (Miles & Huberman, 1984). The case companies represented diverse roles in the microelectronics ecosystem and were selected through purposive theoretical sampling to enhance external validity and reduce biases (Yin, 2018). The case companies are involved in the microelectronics industry and are either planning to implement some circular strategies or have already done so. We selected multiple companies playing different roles in the whole value chain of microelectronics production, including raw materials providers, microelectronics manufacturers, component manufacturers, electronics manufacturers, waste collectors, RSPs, recyclers, and metal recyclers. To identify suitable companies, we used publicly available data on companies' websites and their sustainability reports to assess their current circular progress.

Preliminary results

CBMs in the Dutch microelectronics ecosystem

RSPs are innovative circular start-ups. Their operational model revolves around providing services to OEMs before forwarding all received products to WEEE recyclers. The core of their business model lies in inspecting and assessing electronics products received from OEMs' clients. This initial step serves as the foundation upon which subsequent actions are based, as RSPs meticulously evaluate each product to determine its condition and potential for reuse, repair, or remanufacture. They undertake repairs for products that are deemed repairable, subsequently returning them to clients.

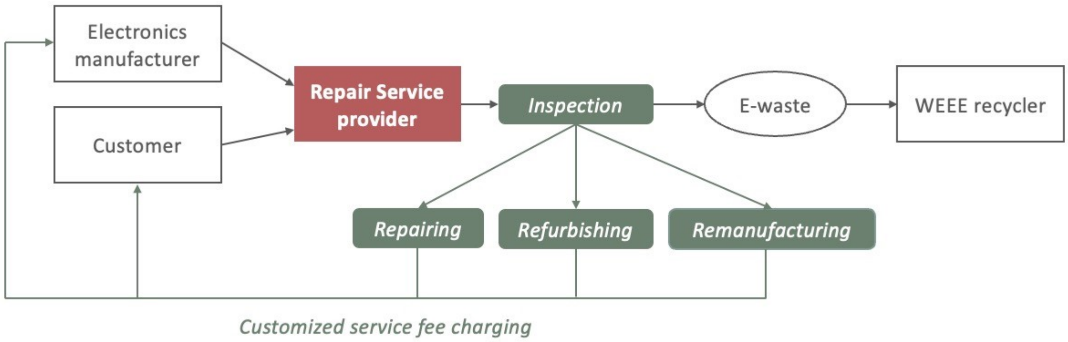

Figure 3 *CBM of RSPs*

WEEE recyclers are increasingly diversifying their service offerings by embracing CBMs. These innovative models expand beyond traditional recycling practices, incorporating elements of repair, refurbishment, and customization into their repertoire of services. This transition enables recyclers to cater to the evolving needs of clients who seek to prolong the lifespan of their electronic devices or require tailored solutions to meet specific requirements, which mirror the functions of RSPs. By integrating CBMs into their operations, recyclers effectively position themselves as holistic service providers capable of delivering end-to-end solutions for WEEE management. However, this blending of roles has led to a convergence of business models, resulting in increased competition in the market. Sometimes, the implementation of CBMs may not uniformly benefit all stakeholders across the value chain. For example, the value generated by RSPs may now be absorbed by WEEE recyclers as they participate in the new value delivery process. While this may stimulate individual innovation, it runs the risk of undermining collaboration and synergy within the broader innovation ecosystem.

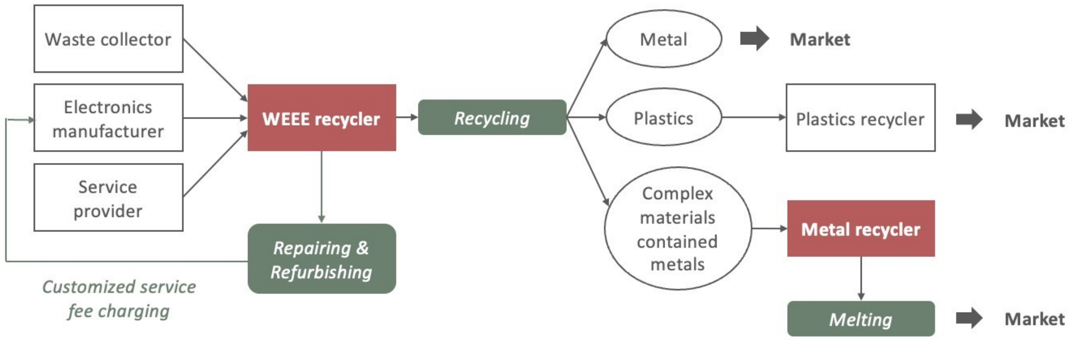

Figure 4 *CBM of Recyclers*

Manufactures are developing more CBMI for their B2B customers. They are trying to transform from a linear to a circular business model. There are already some successful cases in B2B products, which provides the evidence for B2B electronics companies to develop CBMs. Several companies focus on servitization, offering customized circular services and global service models. These models often involve monthly subscription-based managed services, emphasizing functionality and a closed-loop system. Additionally, non-ownership models, such as cloud services and leasing, are adopted to promote resource sharing, reduce hardware footprints, and extend product lifespans (Agrawal et al., 2016). Customers are provided with a range of options for product ownership and service models, reflecting a shift towards circular business practices. They can choose to retain full ownership of the product, assuming responsibility for maintenance and disposal, or accept service offered by OEMs, where ongoing maintenance, repairs, and upgrades are provided as part of a subscription or pay-per-use arrangement. Alternatively, customers may prefer to lease the product for a specified duration, paying a monthly fee without the burden of ownership, with options to renew, return, or upgrade at the end of leasing.

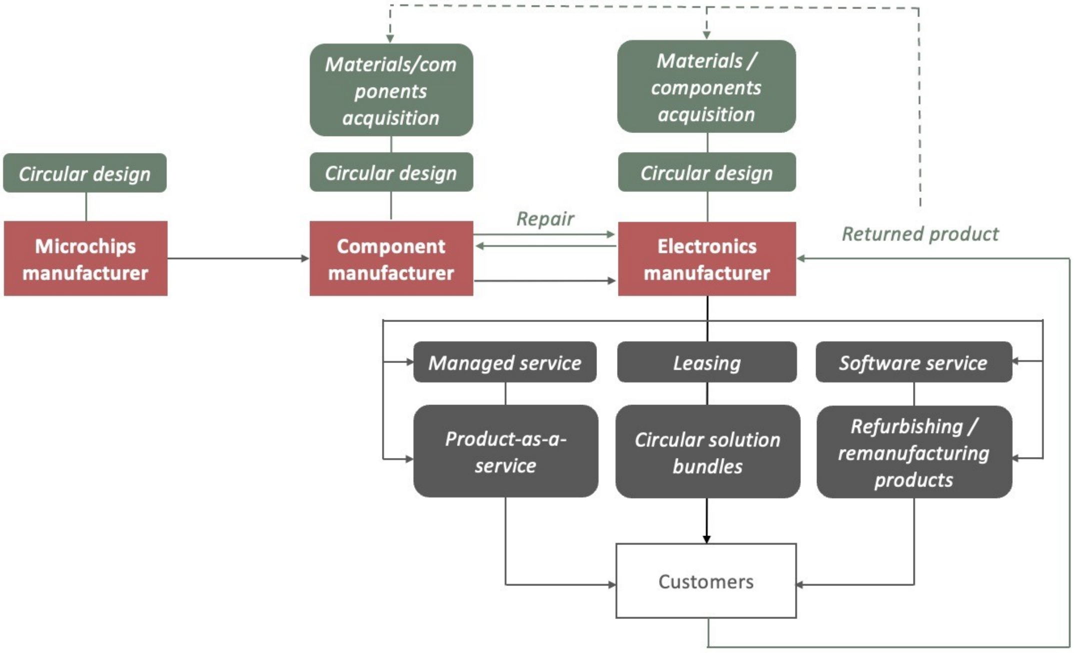

Figure 5 *CBMs of OEMs*

Drivers and Barriers towards circularity

In the dynamic landscape of contemporary business practices, the transition towards circularity has become a critical focal point. Understanding the pivotal drivers that shape organizational behavior in embracing circularity is foundational to this transformative journey. Based on the interviews, we found various drivers and barriers for circularity (see Table 2 and 3) and some strategic challenges, which we will discuss below.

Stakeholder	**Microchips Manufacturer**		**Component Manufacturer**	**Electronics Manufacturer**						**Telecommunication Service Provider**	**RSP**		**Waste Collector**	**WEEE Recycler**		**Metal Recycler**	
Customer Segment	B2B	B2B	B2B	B2B	B2B	B2B	B2B & B2C	B2C	B2C	B2B & B2C	B2B	B2B	B2B	B2B	B2B	B2B	B2B
Size	Large	Medium	Medium	Large	Large	Small	Large	Large	Large	Large	Small	Small	N/A	Large	Small	Large	Medium
Established Year	2006	2017	1969	1929	1984	1936	2016	1984	1987	1989	2015	2006	2007	2007	2003	1989	1917
Case Company	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**
Governance Drivers																	
Legislation and Regulations				×						×				×			
Extended Producer Responsibility			×				×			×							
Digital material passport																×	
Market and Consumer Drivers																	
Market Sustainable Demand												×		×			×
Consumer Sustainable Behavior and Preference		×	×	×		×	×	×						×			
Brand Image	×				×						×						
Product innovation	×															×	
Technological Drivers																	
Technology Development				×						×				×			
Improved Recycling Efficiency					×									×			
Organizational and Cultural Drivers																	
Company Engagement and Motivation				×													
Personal Drive and Culture										×							
Stakeholder Collaboration				×	×	×		×			×			×		×	
Economic Drivers																	
Financial Incentives								×			×			×		×	
Service Model Transformation					×					×							×

Table 2 *Drivers for circularity of the microelectronics industry*

Stakeholder	Microchips Manufacturer		Component Manufacturer	Electronics Manufacturer						Telecommunication Service Provider	RSP		Waste Collector	WEEE Recycler		Metal Recycler	
Customer Segment	B2B	B2B	B2B	B2B	B2B	B2B	B2B & B2C	B2C	B2C	B2B & B2C	B2B	B2B	B2B	B2B	B2B	B2B	B2B
Size	Large	Medium	Medium	Large	Large	Small	Large	Large	Large	Large	Small	Small	N/A	Large	Small	Large	Medium
Established Year	2006	2017	1969	1929	1984	1936	2016	1984	1987	1989	2015	2006	2007	2007	2003	1989	1917
Case Company	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**
Governance Barriers																	
Regulatory and Certification Challenges			×		×		×					×					
Information Transparency		×				×		×						×			
Consumer-related Barriers																	
Consumer Economical Behavior and Preferences			×		×			×			×			×	×	×	×
Supply Chain and Logistics Barriers									×			×	×				
Complexity Supply Chain Network	×		×			×				×						×	
Return Logistics Challenges	×		×			×		×					×				
Material Shortages	×		×			×					×		×			×	
Organizational and Collaboration Barriers																	
Supplier Collaboration		×													×		
Recycling Efficiency for Complex Components		×		×				×									
Economic Barriers																	
Cost Challenges			×		×	×		×	×	×	×			×			
Long-Term Goals and Incentives			×				×					×	×				
Complex Operation Management		×															

Table 3 *Barriers for circularity of the microelectronics industry*

We summarized dominant drivers and barriers towards circular ecosystems as Figure 6. A critical aspect of the transition towards circularity lies in the identification of dominant drivers shaping organizational behavior. Legislation and regulations play a significant role in driving circularity, with emerging European laws promoting transparency and circular practices. The shift towards a service model meets the market demand for circularity, driven by factors such as customer interest in circular products and consumer preferences that prioritize sustainability (Gülserliler et al., 2022). This transition is further reinforced by companies recognizing the positive environmental impact and aiming for circularity to align with consumer values, thus maintaining a positive brand image. Additionally, advancements in recycling technologies, especially for metals, and continuous technological improvements are crucial drivers, as they promote recyclability and enhance recycling efficiency (Richter et al., 2023).

However, significant barriers exist, including cost challenges such as the preference for one-time purchases, capital-intensive circular practices, and higher costs of raw materials. The complexity of the supply chain network for circular practices, encompassing reverse logistics, redesign, and collaboration, adds another layer of difficulty, making return logistics difficult for manufacturers to reuse materials and components (Govindan et al., 2015). Long-term goals face obstacles such as thin profit margins, the need for continuous evaluation, and the necessity to balance economic viability with circular objectives. Regulatory and certification challenges, marked by a lack of transparency, certification requirements, and unclear legislation, create hurdles for circular efforts. Finally, consumer behaviour and preferences, influenced by emotional attachments, privacy concerns, and the delicate balance between customer demand for sustainability and cost considerations, present challenges in CBMs.

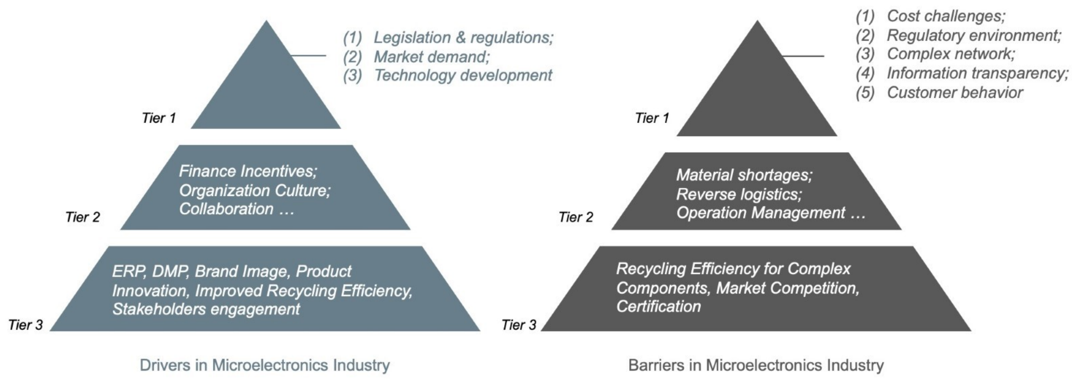

Figure 6 *Dominant drivers and barriers towards circularity*

The findings from our research converge into cross-cutting themes that helps to identify strategy directions for the different value chain roles in the Dutch microelectronics industry. The universal importance of circularity across all perspectives underscores its essential role in sustainable development. Collaboration, both within organizations and across the supply chain, emerges as a recurring theme, emphasizing its critical role in advancing circular initiatives. Information transparency and the availability of reliable data are identified as fundamental prerequisites for making informed and sustainable decisions. Some innovations like digital material passports might help industry. The absence of industry-wide standards for PCB classification and material reuse further hinders alignment in circular stages. After the sale, ownership of microelectronic products is transferred, impeding manufacturers from accessing WEEE for material reuse. Manufacturers must incentivize consumers to return products, hindering direct retrieval. This ownership transfer may impede effective closed-loop practices and self-sufficiency.

The global distribution of microelectronics in the reverse supply chain results in time-consuming transportation and increased greenhouse gas emissions. Challenges in establishing local contract manufacturing and recyclers, coupled with legislative limitations, hinder global efforts. Circularity implementation may not always increase profits. Cost dynamics, where producing new microchips is economically favorable compared to remanufacturing or recycling, presents a dilemma.

Conclusions

Our study reveals that companies employ diverse strategies to align with market demand, regulatory compliance, and technological advancements and face challenges due to cost constraints, and supply chain complexities. This delicate balance between environmental sustainability and economic viability underscores the complexity of circular practices. Unique factors, such as extended producer responsibility and financial incentives, play roles in driving circularity. Collaborative efforts, information transparency, and balancing the triad of demand, supply, and production emerge as critical themes shaping the circular economy landscape. Overall, these companies navigate complexities, demonstrating a commitment to circular practices and sustainable development.

While this study has provided valuable insights into CBM innovation within the microelectronics industry, it also opens avenues for future research in the broader electronics sector. Several key areas warrant further investigation to advance our understanding of CBM and its applicability. Furthermore, future research can explore the development of new CBMs to optimise the economic, social, and environmental benefits of the electronics circular economy, contributing to both theoretical knowledge and practical application.

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