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The CE-I4.0T Nexus Framework: A tool to accelerate the transition towards a Circular Business Model for Electronic products Manufacturing Companies

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Master thesis

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July, 2024

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By

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in partial fulfilment of the requirements for the degree of

Master of Science

in Management of Technology

at the Delft University of Technology,

to be defended publicly on 27-08-2024.

First Supervisor:	Dr. Khodaei
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This thesis is confidential and cannot be made public until December 31, 2025.

TU Delft

Acknowledgement

I'd want to offer my sincere appreciation to everyone who helped me writing this thesis. This task could not have been completed without their direction, encouragement and assistance.

First and foremost, I want to express my deepest gratitude to my supervisor, Dr. Hanieh Khodaei, whose experience, patience and insightful input were vital in shaping this thesis to what it has become now. Not only your ongoing encouragement and guidance as well as always honest opinion about my working progress, but also your ideas and your critical feedback helped me enormously to navigate this whole research process and considerably improved the quality of my work. I'm also really appreciative to Dr. Robert Verburg for all his further insights and assistance. Your expertise and dedication were important in refining my study focus and my final approach.

Furthermore I want to thank my colleagues and friends for their moral support and especially also for making this journey more enjoyable. Your openness to discuss ideas and provide feedback was in every situation throughout the last weeks and months extremely helpful.

Beyond that I am deeply grateful to my girlfriend and family for their consistent support and understanding, which allowed me to devote my time and attention to my thesis. Thank you for your love, patience and encouragement along this not always easy journey.

Finally, I would like to thank all of the participants and organizations that have contributed to this study. Your cooperation and contributions were unavoidable and incredibly critical to the success of this work. This thesis reflects the combined labour and support of all of these aforementioned individuals. I really appreciate your contributions and want to send my sincerest gratitude to each of you.

Thank you very, very much!

Jeffrey (J.H.M.) Chantrel

Executive summary

The circular economy (CE) is a potential solution for manufacturing companies to better utilize resources and balance economic growth and environmental protection. By implementing circular economy principles into business models, companies can shift from one-time product sales to continual profit generation through reused materials and products. Circular Business Models (CBMs) can help manufacturing companies mitigate critical raw material supply risk by reducing waste and landfill and reuse resources. By incorporating all CBM elements, businesses can create value by closing resource loops, reusing products and materials, and using renewable resources where possible. By reducing costs through reusing materials and enhancing environmental values, manufacturing companies can create new opportunities and reduce their dependence on raw materials.

CBMs are a promising approach for manufacturing companies to transition to a circular economy. However, widespread adoption and implementation of circular business models remain challenging due to various barriers. Digital Technologies, such as Industry 4.0 technologies (I4.0T), can enable the implementation of circular strategies and practices. IoT can improve transparency and optimize processes, while additive manufacturing and 3D printing can enable CBMs for remanufacturing. However, there is a lack of understanding of how circular strategies can structure elements of a circular business model and create value in a closed-loop manner.

This thesis aims to explore the use of the CE-I4.0T Nexus Framework (HCBMT-Framework) to facilitate the transition towards circular business models for Electronic products manufacturing companies. The research will focus on the influence of circular strategies on a company's value proposition, value creation, and value delivery, as well as how Industry 4.0 Technologies can accelerate the transition towards circular business models.

We researched three case companies to assess the applicability of the CE-I4.0T Nexus Framework in the electronic product manufacturing sector. The research focuses on circular strategies, practices, and utilization of Industry 4.0 Technologies (I4.0T) of the three European electronic manufacturing companies: Bosch Siemens Home Appliances (BSH), BlueMovement, and Miele. BSH is a multinational household appliances producer committed to sustainability and circularity, promoting energy-efficient technologies, durability, ease of maintenance, and recyclability in its products. BlueMovement is a division of Bosch that specializes in providing home appliances, offering rental services, maintenance, repair, refurbishment, and recycling services. Their circularity strategy is characterized by their business model, where consumers lease appliances while the company retains ownership and takes responsibility for maintenance, repair, collection, and processing. Once the contract period has ended, the appliances are refurbished and recycled. Miele is a premium manufacturer of high-quality household appliances known for their durability, performance, and timeless design. We collected data by analysing publicly available documents and information from the case companies and by interviewing case company representatives. The interviewed company representatives are well-informed about the business models, CE, circular strategies, and the usage of I4.0Ts. The findings present the results of data collection and development of frameworks for each case company. Empirical evidence for the CE-I4.0T Nexus Framework is gathered through observing implemented practices at the case companies which the framework also provides.

Case company 1 focuses on cycling, narrowing, and extending strategies, with practices from the intensifying strategy less mentioned. The CE-I4.0T Nexus Framework is used to identify circular strategies, practices, I4.0Ts, and business model elements. Case company 1 uses big data and predictive models to optimize product life cycles and promote the circular economy. To improve, the company can implement practices such as balancing supply and demand, utilizing Industry 4.0 technologies, optimizing resource consumption efficiency, and focusing on reselling channels.

Case company 2 focuses on the intensifying strategy in its business model by implementing practices related to sharing, leasing, and recycling. The CE-I4.0T Nexus Framework provides content for the current CBM of case company 2, which includes a greening strategy, focusing on delivering green products and reducing energy consumption through sustainable product delivery and eco-friendly packaging. Marketing channels should focus on creating awareness about their green offerings and using eco-friendly appliances.

Case company 3 implements cycling and extending strategies using IoT, big data, cloud computing, and analytics to monitor usage data and product performance. The framework also provides insights into practices that could be developed from the CE-I4.0T Nexus Framework, such as offering an app with energy insights, maintenance insights, and remote technical support for product maintenance or repair.

During the case company analysis we focused on three propositions and three rival arguments to minimize bias and verify the results. Proposition 1 suggests that Industry 4.0 technologies enhance the value proposition, value creation, and value delivery of electronic product manufacturing companies through the implementation of circular strategies. Proposition 2 asserts that Industry 4.0 technologies act as enablers or accelerators of circular business models by providing tools and capabilities that facilitate the adoption of circular strategies in electronic product manufacturing companies. Proposition 3 asserts that the CE-I4.0T Nexus business model tool provides clear insights that help manufacturing companies identify and leverage synergies between industry 4.0 technologies and circular strategies, facilitating an efficient transition towards a circular business model. However, rival arguments argue that implementation of Industry 4.0 technology may require significant financial investments, training, and adjustment, and that compatibility concerns with current systems and workflows could hinder its usefulness.

In this study we analysed the cases of three electronic household appliance companies, Case Companies 1, 2, and 3, to determine their implementation levels and improvement areas in their circular practices. The data showed that the companies either see the potential of Industry 4.0 technologies to enhance their business models or are already leveraging I4.0Ts to enhance their offerings. However, there were opposing arguments, such as the importance of customer approval for retrieving usage data and the focus on other factors like quality, hygiene, and price.

The CE-I4.0T Nexus Framework was empirically validated through analysing three electronic household appliance industry companies. It showed that it should be possible to derive circular practices enabled by I4.0Ts and implement them along the business model. 12 practices were found at the case companies which the CE-I4.0T Nexus Framework also provides.

However, there are limitations and recommendations to consider. Firstly, the framework in table format shows per circular strategy the I4.0T capabilities but doesn't include them in the practices shown in each business model element. Additionally, the case companies had practices in place that are not provided by the CE-I4.0T Nexus Framework but will give added value when implemented in the framework. A proposed improvement is to included practices that propose implement I4.0Ts in the products which enable circular practices. Further limitations are regarding the research itself. The case company analysis included only one interview from each case company, and more interviews with multiple representatives are recommended to get a full picture of all circular practices and industry 4.0 technology usage. Future research could focus on the enhancement of empirical evidence by conducting multiple interviews at each case company, improving the framework and testing its effectiveness.

List of Abbreviations

AI	Artificial Intelligence
AM	Additive Manufacturing
AR	Augmented Reality
BM	Business Model
BMI	Business Model Innovation
BSH	Bosch Siemens Household Appliances
CBM	Circular Business Model
CE	Circular Economy
CRM	Critical Raw Material
DT	Digital Technology
EoL	End-of-Life
HCBMT	Hybrid Circular Business Model Tech
HREC	Human Resources Ethical Committee
I4.0	Industry 4.0
I4.0T	Industry 4.0 Technology
IoT	Internet of Things
ML	Machine Learning
PaaS	Product-as-a-Service
PSS	Product-Service-System
SaaS	Software-as-a-Service
SBM	Sustainable Business Model

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1. Introduction

1.1 Background

Over the last few decades humans have been becoming increasingly aware of their impact on the environment. Regulatory bodies and companies are focussing more and more on sustainability, energy efficiency and a low carbon footprint. This awareness has incrementally increased the pressure on manufacturing companies. Ever since the industrial revolution, emissions, waste generation and landfill have increased in order to meet the demand of society (Lieder & Rashid, 2016). Producing increasing numbers of products has a big impact on earth's natural resources. Furthermore, numerous industries essential to achieving the Paris Climate Agreement's climate change goals rely on more and more complex resources. These raw materials are used in electric vehicles, wind turbines, photovoltaic panels, lithium batteries, fuel cells and computer processors. Nonetheless, the EU significantly depends on other nations and continents for the supply of these materials. However, due to Europe's dependence on other continents for the supply of raw materials, we waste a substantial amount of these raw materials during manufacturing processes and when products become obsolete. This increases the pressure on the natural environment even further. The earth's resources are limited and therefore the requirements of exponential economic and population growth cannot be met (Meadows et al., 1972). Fortunately, the Circular Economy (CE) has emerged as a potential solution to make better use of resources (Velenturf & Purnell, 2021) and harmonizing ambitions for economic growth and environmental protection (Lieder & Rashid, 2016).

Businesses have the largest power to influence the resource availability in Europe (Hool et al., 2022). The key is to transform the economic system, which is today defined by a take-make-dispose model, also known as a linear model. This concept has serious implications for the natural environment and resources availability. The circular economy approach, on the other hand, might alleviate major raw material availability risks with the use of closed material cycles. Moreover, the circular economy can generate new business opportunities, reputational advantages, limit material costs and price volatility (N. M. P. Bocken et al., 2016; Kalmykova et al., 2018; Schulte, 2013), besides the CE can reduce the dependency on raw material imports and increase resource security (Mathews & Tan, 2016; Stahel, 2016). In order to benefit from CE practices businesses must significantly alter their business practices to achieve a circular economy.

Unfortunately companies have difficulties in implementing these CE practices due to financial feasibility, logistical difficulties, complex physical properties of the raw materials and low recycling rates (Karali & Shah, 2022). A promising approach is to implement circular economy principles into the business models (BMs), because it allows companies for a systemic shift in the core logic of business (Geissdoerfer et al., 2020). Implementing circular economy principles into business models (BMs) let firms rethink the way they do business and firms can leverage on the new possible opportunities.

Firms can innovate their current business models with circular components in a hybrid form or could implement Circular Business Models (CBMs). Circular Business Models are eco-conscious models that shift from one-time product sales to continual profit generation through reused materials and products, preserving embedded value (Bocken et al., 2016; Guldmann & Huulgaard, 2020; Stahel, 2010). They extend product utility and recycle materials to slow resource flow and close resource loops. Integrating these strategies adds a value recreation and redelivery component and a value recapture component to traditional BMs, offering a more comprehensive value proposition (Guldmann & Huulgaard, 2020). This approach aligns with circular principles, with the best results achieved by incorporating all CBM elements (Geissdoerfer et al., 2020). Using CBMs, new ways of value creation and capture can be found in relation to closing resource loops by reusing products and materials. CBMs thus can enable economically viable ways to continually reuse products and materials, using renewable resources where possible (N. M. P. Bocken et al., 2016). In this way manufacturing companies can mitigate critical raw material (CRM) supply risk, because they no longer only rely on primary resource supplies and thus waste and landfill will be minimized.

Material cycles can be closed in different ways. The 4R framework of the EU waste Framework Directive introduced four strategies for achieving this (1) reduce (refuse, redesign, rethink, reduce and prevent

resource use) (2) reuse (reuse (excluding waste), close the loop, repair, and refurbish) (3) recycle (remanufacture, recycle, close the loop and reuse of waste) and (4) recover (recover energy by incinerating materials) (European Commission, 2008). BMs in the circular economy can create value along these four dimensions, for instance by developing new activities that eliminate life cycle waste or by organising new partnerships in which waste is transferred to other firms (Bocken et al., 2014). On the one hand economic value is captured by reducing costs through reusing materials and on the other hand environmental values are enhanced by reducing the environmental footprint and the use of virgin materials (Bocken et al., 2014).

However, so far, widespread adoption and implementation of CBMs has not happened. This has been attributed to various barriers that firms encounter and perceive when developing and implementing CBMs (Linder & Williander, 2017; Ormazabal et al., 2018). Innovating the BM of a firm is a challenging type of innovation and differs from more familiar types of innovation like product and process innovation (Amit & Zott, 2010). Companies often lack the tools and business processes to deal with business model innovation (BMI). Breaking with the company's old value creation logic, locked-in management structure and distribution of resources can severely block the innovation process (Guldmann & Huulgaard, 2020). Moreover, businesses might need large capital reserves for business model innovation and shareholder approval may be hard to obtain (Lahti et al., 2018). Established firms frequently face organizational inertia and resistance towards radical transformation, which makes CBM implementation difficult. For the managers however, it is hard to imagine what doing business in the circular economy will look like because of limited value in relying on historical data and examples of other companies (Lahti et al., 2018).

A promising approach to enable CBM implementation are Digital Technologies. For manufacturing companies, Industry 4.0 technologies (I4.0T) could be used as enablers for CBM implementation. According to Neligan (2023), Digital Technologies (DT) can overcome barriers to CBMs and facilitate the operationalisation of circular material, components and product flows. DTs can be seen as a 'glue' between value chain partners and other stakeholders by enabling data sharing and improving transparency along the value chain. Optimizing processes and product designs to become more sustainable and circular would be made much more efficient using DTs. Internet of Things (IoT) for example improves the tracking and record keeping of in-use and post-use products allowed condition monitoring and predictive maintenance as well as the estimation of the remaining lifetime of products (Ingemarsdotter et al., 2020). Additive manufacturing and 3D printing are Industry 4.0 technologies that could enable CBMs for re-distributed manufacturing according to Turner et al. (2019). Unfortunately, literature is scarce on the connection between digitalisation and DTs to the circular economy and CBMs as an enabler (Neligan et al., 2023).

The availability of data, automation and digital networking raises expectations in terms of more resource-efficient and circular production methods and business models (Kristoffersen et al., 2019). However, the specific role of DTs for the CE and CBMs has been under investigated (Bressanelli et al., 2018). There is clarity that I4.0T can play a significant role in increasing the speed of the transition to a circular economy, but how these technologies exactly can be leveraged remains undiscovered (Hennemann Hilario Da Silva & Sehnem, 2022). To date, firstly, there is a lack of understanding of how circular strategies can structure the elements of a CBM and create value in a closed-loop manner. Secondly, an understanding of how I4.0T can enable the aimed value is seen as a missing dimension from circular approaches. Third, knowledge is missing on which circular strategies can be applied along a firm's value chain to change it from a linear to a circular perspective. And lastly, there is a tool needed that could assist manufacturing companies in ideating on how they could implement CBMs and I4.0T in order to enhance their value proposition, value creation, delivery and value capture landscape (Tripodis, 2023). Resulting from an extensive literature review, Tripodis (2023) build a conceptual framework to connect three important topics for the circular economy. 1). Circular strategies, 2) Circular business model components, 3) I4.0T as enablers. The Hybrid-Circular-Business-Model-Technology-Framework (HCBMT-Framework) (Tripodis, 2023) serves as a tool for manufacturing companies to easily understand the different parts of the respective three topics and shows how the strategies and technologies can be used to transition to a CBM. The HCBMT-Framework is the first practical tool for firms that shows all the knowledge about CE and how it can be implemented using I4.0T into their BMs.

All in all, resource availability in Europe is under pressure. The demand for raw materials is rising because of new technologies and the way society consumes products. In order to prevent resource availability problems and economic decline, society has to rethink the economic environment. Redefining the economic system from a linear system to a circular system is the most promising approach. With the aim of successfully transforming the economic system, companies should change the way they do business. The European Commission has defined four strategies to slow down and close resource loops, the so called 4R Framework. This framework consists of the following four; Reduce, Reuse, Recycle and Recover. Based on these strategies, businesses can leverage to build in these strategies into their BMs. However, widespread implementation stays behind. Industry 4.0 technologies could serve as enablers to accelerate the transition to a CBM, but there is a lack of a tool which help manufacturing companies to understand how circular strategies and I4.0T can be used to transition to a CBM. The HCBMT-Framework is the first tool that could assist manufacturing companies in this process.

1.2 Problem Statement

According to García-Sánchez et al. (2021) only 26% of the companies have implemented a CBM initiative. Even though the circularity of the global economy is declining. In the last circularity gap report it is stated that only 7.2% of the economy is circular while in 2018 the circularity index was at 9.1% (Circle Economy, 2023). Pressure on the European economy is increasing, due to increasing demand and new technologies where more and more complex materials are needed for. Still the most promising approach is to transform the economic system from a linear system to a circular system.

There are various reasons for the lack in implementing CBMs for companies. Guldmann & Huulgaard (2020) researched the barriers firms encounter in implementing CBMs applying a cross-case analysis. The most significant barriers are "Market demand unclear", "Takes time to build new partnerships and mutual trust", "Lack of resources, knowledge or competencies in-house" and "Prevailing linear business model structure and thinking". Vermunt et al. (2019) conducted a similar study. They did, however, attempt to determine whether CBM implementation barriers differ between different CBMs. Vermunt et al. observed that firms with different CBMs face different barriers. For faster adoption of CBMs Vermunt et al. propose that firms and policy makers should focus on bespoke solutions and strategies for different types of CBMs. An additional barrier blocking the implementation of CE within a business setting is related to a lack of knowledge and incentives. This knowledge dissemination among firms is necessary for building CBMs, designing new offerings for the customers and achieving faster the sustainability goals (Salvioni et al., 2021). I4.0Ts can enable faster transition to a CBM for manufacturing firms. However, an understanding about how to leverage these technologies is missing within the manufacturing industry (Hennemann Hilario Da Silva & Sehnem, 2022).

Resource supply risks are rising in the current European economy, and dependency on foreign continents and countries is substantial. In order to change this, firms must rethink their business models and close resource loops. However, due to many barriers, few businesses have been able to successfully implement circular economy principles. Researchers tried to made an effort to identify the barriers firms face while implementing CBMs or CBM components in order to help them in their journey to a CBM. Still there is a lack of understanding how circular strategies can structure the elements of a circular business model and create value in a closed-loop manner (Tripodis, 2023). Scholars concerned themselves to design different CBMs and frameworks, but because implementation stays behind empirical evidence is hard to obtain. The HCBMT-Framework could help manufacturing companies to better understand how circular strategies can structure BM elements, how to profit from circular strategies and how I4.0T could be used to ease implementation of CBMs or circular strategies. Unfortunately, up to date empirical evidence that verifies the value of the framework doesn't exist yet. In further research the HCBMT-Framework should be validated in practise. The first step would be to perform case studies in order to find out the effectiveness of the HCBMT-Framework and if necessary to further adapt the it from the lessons learned in real BM transformation processes of companies.

1.3 Identification of knowledge gap

The current field of the circular economy is maturing, although it is still a quite new field of research. Several scholars have worked hard to define CBMs, frameworks and identify CBM implementation barriers. Changing the linear economy to a circular economy includes that companies need to implement circular strategies. Transition to a circular business model would have the best results because companies can leverage on the opportunities the circular economy provides. However, the industry is currently battling with how to implement CBMs and capitalize on new opportunities in the circular economy. One way to help accelerate the transition for companies to a CBM is by using I4.0T. Manufacturing companies can benefit from I4.0T to optimizing their operations and meanwhile using these technologies to accelerate the transition to CBMs, as these technologies enable leveraging on circular strategies. Researchers have identified the value I4.0T can provide for manufacturers looking to transition to a CBM. However, it is unknown how I4.0T could accelerate the transition, which BM elements they can positively affect and how to incorporate circular strategies into their BMs to benefit from the circular economy. Up to date, (Tripodis, 2023) was able to develop a framework that clearly connects circular strategies, I4.0T and CBM elements. Hopefully, as a result, manufacturing businesses will be able to identify how circular strategies and I4.0T may support and accelerate their BMs elements' transition to a more circular state while benefiting from the new business model. However, the question of whether this framework provides more clarity remains unresolved. It would strengthen the framework if it were tested in practice and empirically validated.

1.4 Research objective

The objective of this research is to build upon the work of Tripodis (2023), empirically validate the HCBMT-Frameworks usability and if necessary give recommendations for improvement of the framework. The HCBMT-Framework provides a conceptual theory of how to transition to a CBM implementing circular practices enabled by I4.0Ts. A business model we define as a CE-I4.0T Nexus business model. This name contains both the CE concepts as the I4.0T concept in a business model. To align Tripodis' framework we will mentioned the framework after the CE-I4.0T Nexus Framework in this thesis. A first step to validation would be to find empirical evidence for the practices and relationships between the concepts in business settings. If representatives of European manufacturing companies see value in the CE-I4.0T Nexus Framework and confirm that it clarifies how I4.0T could be used to accelerate the implementation of circular strategies in the BMs, additional research can be conducted to determine its effectiveness in CBM implementations for manufacturing companies. Following that, an effective tool would emerge, helping to accelerate the transition to a circular economy. Furthermore, widespread adoption of CBM components by companies would help to ensure critical raw material availability in Europe. Transitioning the European economy to a circular economic system will lessen dependency on other nations for CRM supplies, resulting in a more competitive position for European enterprises on the global market.

1.5 Research questions

The main research question for this thesis is:

"How can the CE-I4.0T Nexus Framework assist in the transition towards circular business models for Electronic products manufacturing companies?"

The following sub-questions are designed to help to answer the main research question:

SQ1: How can circular strategies influence the value proposition, value creation and value delivery of a company?
The answer to this sub-question will provide an understanding of the advantages circular strategies can have on the business model elements of a company. This information will show how circular strategies can be leveraged.

SQ2: How can Industry 4.0 Technologies accelerate the transition towards circular business models?
The answer to this sub-question will provide an understanding about how I4.0T practically can assist in the transition towards a CBM.

SQ3: What clarity does the CE-I4.0T Nexus Business Model – tool provide to manufacturing companies in the Circular business model transition process?
The answer to this research question will give an understanding about the usability of the tool for CBM implementation.

SQ4: How does the CE-I4.0T Nexus Business Model- Tool gives a clear overview of the synergies between industry 4.0 technologies, circular strategies and circular business models?
The answer to this research question will give important requirements for an effective tool for CBM implementation utilizing I4.0Ts.

1.6 Scientific and practical relevance

This study adds to our understanding of how to implement circular business models, as well as to the literature on the circular economy. This research improves the understanding of how to faster adopt circular business models. Whereas, other scholars have concentrated on implementation barriers, this research focusses to enlarge the knowledge about transition to a CBM using I4.0T as accelerator. In practice, this research contributes to a more efficient way of implementing CBMs. The knowledge provided by this thesis will be beneficial to businesses and managers. The research will show the practical relevance of the HCBMT-Framework on how I4.0T can be used as accelerator for CBM implementation. We hope that our findings will assist to show the importance of shifting to a circular economy. This is essential for Europe since we are now reliant on other countries, putting European businesses at a competitive disadvantage.

1.7 Scope of research

The scope of this thesis is based on a business perspective. Where governments and public organizations can make a significant contribution to shifting the economic system from a linear system to a circular system, eventually businesses will contribute the most. In order to transition to a circular economic system companies must widely implement circular business models. Within this thesis the focus lays on manufacturing companies, because these companies are confronted simultaneously with the pressure of environmental regulations, challenges of resource price volatility and resource supply risks, in addition to their daily business (Lieder & Rashid, 2016). Manufacturing companies will benefit to most of a transition to a CBM. Meanwhile, manufacturing companies are the biggest consumer of virgin raw materials, if they are able to reduce their demand for virgin raw materials by replacing it for recycled resources as input to their processes the whole economic system will benefits from this. Furthermore, manufacturing companies benefit from using I4.0T even without using these technologies to accelerate their implementations of CBMs. Whereas, other scholars have chosen a national research context, this research is focused on the continent of Europe. We chose this context in order to have a bigger selection pool for potential case studies. Meanwhile, because Europe has free trade agreements, the supply for resources should be allocated equally over the companies in Europe.

2. Research Methodology

2.1 Research design

This thesis is a follow-up thesis from the thesis of Tripodis (2023), we build upon his extensive literature review and his conceptual HCBMT-Framework. Manufacturing companies are struggling with implementing circular strategies or transition towards circular business models. In theory, I4.0T could be used to assist manufacturing companies in implementing circular strategies into their BMs (Hennemann Hilario Da Silva & Sehnem, 2022). However, researchers have reported that it is unclear for manufacturing companies how I4.0T can help assist implementing circular strategies and how this could influence their BMs (Hennemann Hilario Da Silva & Sehnem, 2022; Tripodis, 2023). The HCBMT-Framework was specifically designed to give manufacturing companies a clear overview of I4.0T as enablers for implementing circular strategies and how both can influence their BMs (Tripodis, 2023). Although, the HCBMT-Framework is not yet verified in practice. Up to date, the HCBMT-Framework is a conceptual framework and is missing empirical evidence. In order for the HCBMT-Framework to be an effective tool, empirical evidence of its usability and effectiveness in practice should be verified. Therefore, the objective

of this research is to contribute to the verification of the HCBMT-Framework in practice through gathering empirical evidence for its usability and effectiveness and if necessary to further develop this framework. Eventually, the goal would be to contribute to a proven framework which helps manufacturing companies accelerate the transition to a circular business model, while profiting from the benefits.

2.1.1 Research Approach

This verification starts with researching case companies. We take a qualitative research approach, because secondary data does not exist. We need to gather primary data ourselves. We want field specialists to test the HCBMT-Framework's effectiveness and usability. A case company analysis approach is the most appropriate research approach for gathering data on the effectiveness of the HCBMT-Framework. A case analysis approach is well-suited to evaluating a conceptual theory in company settings while maintaining a holistic viewpoint (Stufflebeam, z.d.; Yin, 2018). We strive to discover answers to the question of how the HCBMT-Framework could enable manufacturing organizations transition to CBMs using I4.0T. The research will be constructed around a theory based on the HCBMT-Framework and existing literature on circular strategy and CBM implementation by manufacturers. To evaluate the usability and effectiveness of the HCBMT-Framework, several real-life cases have to be analysed to draw a conclusion and if needed to build further on the framework. For this reason a multiple-case company approach will be applied. However, generalizability would be an issue knowing that due to time and resource restrictions only three cases can be analysed. This is why an extensive research protocol will be established which will make further research and replication possible. Based on the literature, theoretical propositions will be defined and tested using the method of semi-structured interviews with representatives of the case companies.

2.2 Unit of analysis

The objective of this research is verifying the HCBMT-Framework for manufacturing companies to better understand the synergies between I4.0T, circular strategies and BMs. The unit of analysis are European manufacturing companies. However, this unit of analysis needs to be narrowed down, because of resource reasons. The first selection of industries is based on the report of the European commission (2020) addressing resource demanding and growing industries. These industries are key industries for the European economy and are expected to grow substantially, because of economic growth and the transition towards a zero-carbon society. To further narrow the scope a publication analysis is performed. A summary of the search queries and number of articles found, are shown in Table 1. The complete table is shown in Appendix A Table 13.

Table 1: Summary Number of articles found industries

Source	**Search Query**	**Automotive**			**Electronic products**			**Battery Manufacturing**			**Wind turbines**			**PV panels**		
		S	W	G	S	W	G	S	W	G	S	W	G	S	W	G
Scopus (S) Wiley Online (W) Google Scholar (G)	CE AND I4.0T + Industry	13	1	3	5	0	0	4	0	0	1	0	0	0	0	0
	CE AND DT + Industry	5	0	0	5	0	0	2	0	0	0	0	0	2	0	0
	CE + Industry	233	15	85	309	38	10	437	54	76	10	1	6	4	5	4
	CBM + Industry	26	0	0	33	1	0	36	0	6	4	0	0	5	0	0

The results show that for the automotive industry the highest number of articles are found which mention the circular economy, I4.0T and the automotive industry in the publication. However, the most articles found in total are form the battery manufacturing industry. The electronic products industry has one more article mentioning CE, I4.0T and the electronic products industry. Moreover, only three articles less are

found in comparison to the battery manufacturing industry. Solely making a decision on the number of articles will result in researching the battery manufacturing industry, but from a sustainability perspective most electronic products have a much shorter lifespan then batteries. Additionally, WEEE-waste is one of the major drivers for a circular economy (Forti et al., 2020). WEEE constitutes the largest and fastest growing fraction of municipal waste (Işıldar et al., 2019). Batteries are just sub-group of the electronic products industry. We think that focusing on the electronic products industry could have the most impact, also because this industry includes products of low value which because of their low value a low recycling rate is expected.

All in all, the unit of analysis are European manufacturing companies in the electronic products industry. We will analyse three companies. At the case companies' representatives will be interviewed. Important for this thesis is that the representatives have roles in strategic positions and are involved in the implementation of circular strategies.

2.3 Data collection

Secondary data is not available for this research. Data will be collected through a literature review, semi-structured interviews with representatives of the case companies and publicly available documents from the case companies. The literature review will provide data to understand the foundation of the HCBMT-Framework. Furthermore, the literature review will help establishing a prediction about the patterns to find in the case studies later in the research. At the case analysis stage of this research we will be looking for data to better understand the usability of the HCBMT-Framework and how a practical tool can help them understanding how I4.0T can be used as enablers to implement circular strategies into their BM. In this chapter is explained what data will be gathered, in what way and with what purpose.

Literature Review

The objective of the literature review is to build a theory about how the HCBMT-Framework could provide manufacturing companies with a clear overview of how industry I4.0T can be used to help implementing circular strategies into their business model. Additionally, we want to retrieve knowledge about how I4.0T could be used as accelerator for circular strategy implementation from the literature. Moreover, we use the literature to understand basic concepts important for this research and the conceptual HCBMT-Framework. The literature review will be the foundation to build our theory, set propositions and make predictions of the outcome of this research. The theory building is described in the fourth chapter.

This thesis is a follow-up research for the thesis of Tripodis (2023). Due to his extensive literature review we can build upon his work. We will use a similar approach in finding relevant literature based on the principles of the structured literature review of Bougie and Sekaran (2020). Although, we include new literature, focussing more on recent case studies of manufacturing companies, specific manufacturing companies in the electronic products industry. Furthermore, we use the backwards snowballing effect as described by Wohlin (2014) to find further relevant literature. The selection of the articles and books is based on the number of citations and the relevance of the research perspective by assessing the title and abstract. After selecting the literature, relevant information and knowledge will be outlined in the third chapter of this report and used to build a theoretical framework, research protocol, set propositions and expectations for the case studies.

Table 2: Overview of literature review data collection queries (Tripodis, 2023) adjusted with own interpretation

Sources	Themes	Keywords
ScienceDirect TU Delft-Library Scopus Whiley Online-Library	Business model frameworks	Business model definition, business model innovation, sustainable business models
	Business model elements	Value proposition, value creation, value delivery, value capture, business model canvas
	Circular economy	Circular strategies, circular practices, resources minimization, CE barriers and enablers

Google Scholar	Circular economy and business models	Circular business model (CBM) definition, archetypes, CBM components, CBM frameworks, CBM in manufacturing sector
	Industry 4.0 technologies and capabilities	Data technologies, additive manufacturing, industry 4.0 and innovative technologies, enabling industrial technologies, capabilities and characteristics.
	Industry 4.0 and circular business models	Resources tracking, technologies and circularity, technological enabling factors and circular economy, Digital Technologies and CBM in manufacturing, I4.0-CE business models
	Electronic products manufacturing and circular business models	Electronic products manufacturing and circular business models, industry 4.0 technologies and electronic products manufacturing

Interviews

According to Sekaran & Bougie (2020), interviews are a common research strategy since they allow researchers to gather a wide range of varied information about the topic. Especially in exploratory research, interviews provide the opportunity to collect primary data when secondary data is unavailable, as in the situation of this study. After conducting a literature review and defining the theoretical framework we will analysis three case companies to evaluate the usability and effectiveness of the HCBMT-Framework in practice. Conducting interviews gives the opportunity to gather information from representatives of the companies which will be analysed as part of the cases.

We will follow a semi-structured interview approach. A set of predetermined questions will be asked, but there will be space to dive into secondary topics as the interviewee purposed other directions or new knowledge and this information can be of added value to the research. In the interview we want to get an understanding of the current situation at the case companies. We will focus on their current situation regarding circular strategy implementation, their current business model and the usage of I4.0T in the business processes. We will use the HCBMT-Framework to collect and organize the data gathered from the interviews and document analysis. Although, the information gathered during the interview will be used to later on fill in the HCBMT-Framework table. After the data analysis and applying the framework, the findings will be shared with the case company representatives with the request to give feedback. For later data analysis purposes, the interview will be recorded and transcribed. Following the research protocol, beforehand the interviewees will be asked if they agree with the interview being recorded.

Case companies will be found through circular economy networks like; The circulars, The Circle Economy Foundation, The European Commission, The Ellen MacArthur Foundation and the Circular Economy Initiative Deutschland. Representatives of the case companies will be searched and approached through LinkedIn.

2.4 Research process

This research will follow five research phases. In the first phase through a literature review an understanding of the basic concepts will be formed and the research protocol will be compiled. In the second phase qualitative data will be gathered through semi-structured interviews with representatives of the case companies and this data will be analysed using Atlas.ti following the data analysis protocol defined in the research protocol. In the third phase, with the lessons learned from the second phase, the framework will be shared with the case company representatives for evaluation. In the fourth phase, the first findings will be shared with the case company representatives. Additionally, in the feedback round the framework will be evaluated by the field experts. In the fifth and last phase, the gathered data from the feedback round will be analysed, using pattern matching logic and explanation building (Yin, 2018) we draw a conclusion and an answer to the research question. In Table 3 the research strategy for each research question is set out.

Table 3: Overview research strategies for research questions

Research question	Research strategy
SQ1: How can circular strategies influence the value proposition, value creation and value delivery of a company?	Literature review
SQ2: How can Industry 4.0 Technologies accelerate the transition towards circular business models?	Literature review
SQ3: What clarity does the CE-I4.0T Nexus Business Model – tool provide to manufacturing companies in the Circular business model transition process?	Interviews
SQ4: How does a CE-I4.0T Nexus Business Model- Tool give a clear overview of the synergies between industry 4.0 technologies, circular strategies and circular business models?	Interviews

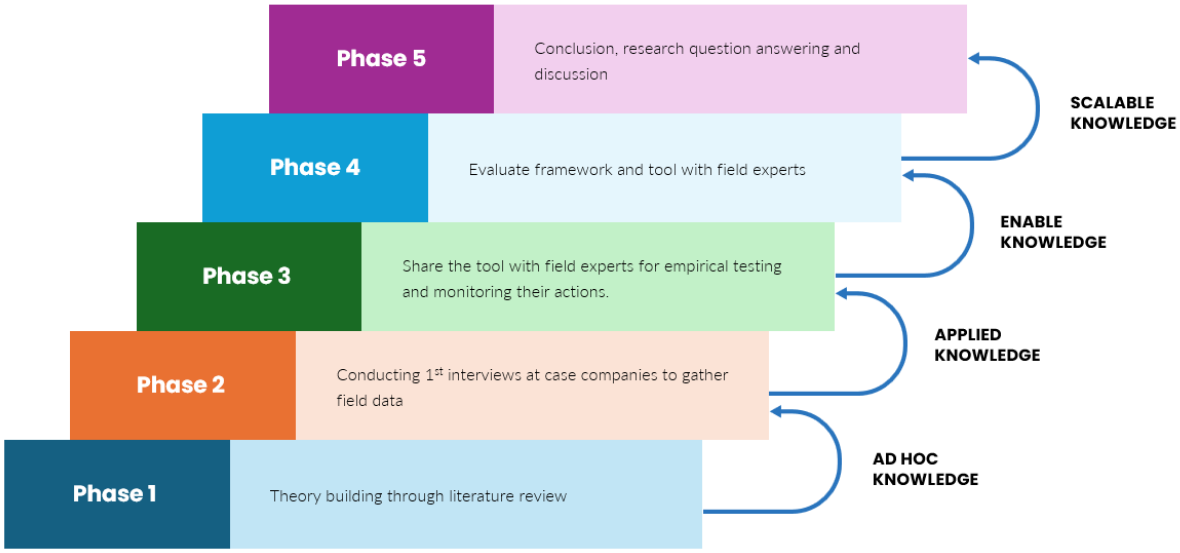


Figure 1: Research process

2.5 Structure of the report

In chapter three the findings from the literature are set out. The concepts business model, circular business model, circular strategies, and industry 4.0 technologies are explained. Furthermore, findings on how industry 4.0 technologies can assist companies in implementing circular strategies and how both can influence business models is highlighted. Also in Chapter three, the theoretical framework and the research protocol is described. In the fourth chapter the case companies are given. In Chapter five the results of the case findings are outlined. In chapter six, the research is discussed. Lastly, in chapter seven conclusions are drawn, the research question will be answered and a discussion of the research will be given.

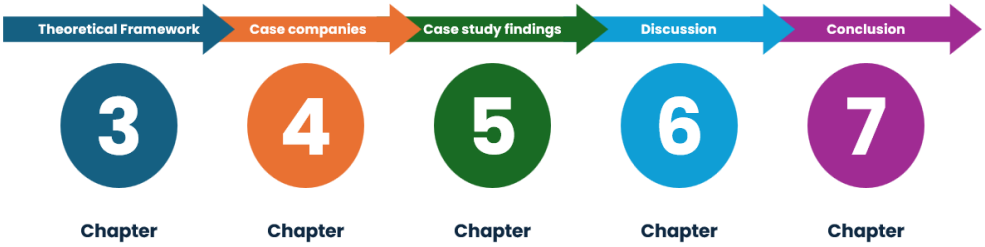


Figure 2: Structure of the report

3. Theoretical Framework

Here, we will explore the theoretical framework of the study. This section will present the literature review, theoretical propositions, research framework, rivalry theory, and research protocol. This chapter establishes the groundwork for the research, which will be utilized later to analyse the case findings, compare them with the anticipated outcomes, and address any limitations and potential enhancements.

3.1 Literature review

This sub-chapter provides the explanation of the CE-I4.0T Nexus Framework from Tripodis (2023) and shows the alignments presented by different scholars in the literature. The CE-I4.0T Nexus Framework is based upon the concepts CBMs, I4.0T capabilities, circular strategies and circular practices. The aim of this thesis is to empirically validate the CE-I4.0T Nexus Framework, we first start to validate the framework to existing literature.

3.1.1 HCBMT-Framework

A former Delft university of technology student has performed an extensive literature review of which parts also have been mentioned in this thesis. From the gathered and analysed literature a framework has been developed, the Hybrid Circular Business Model Technology Framework (HCBMT-Framework) (Tripodis, 2023). The goal of this framework is to clearly show the relationships between circular strategies, circular practices, business model elements and the capabilities of industry 4.0 technologies as enablers for incorporating circular practices and strategies in a company's business model.

3.1.1.1 Circular strategies

Firstly, five circular strategies have been identified in the literature. These strategies when incorporated contribute to the circular economy. Through circular practices circular strategies are being incorporated. In the first step Tripodis (2023) clustered the different circular practices along the five derived circular strategies.

Figure 3: Clustering circular practices in circular strategies (Tripodis, 2023)

These strategies can also be retrieved from the literature. Bocken et al. (2016) defined three strategies which help companies modify the material and energy loops and change the way of creating, delivering and capturing value in the business model. These strategies are; closing strategy, product life extension strategy and the narrowing strategy. Moreover, product life extension can also be achieved through upgradability as discussed by Khan et al. (2018). Organizations can enhance recyclability and repairability by using circular product design as a circular strategy (Moreno et al., 2016). Furthermore, Geissdoerfer et al. (2020) adds the intensifying strategy to this list. The intensifying strategy focussed on incorporating practices to increase the

usage of products and resources. The greening strategy is described by Konietzko et al. (2020) who defines this strategy as the regenerate strategy which includes practices to convince consumers to share products and to minimize energy consumption in the whole product life cycle. An overview of the circular strategies implemented in the HCBMT-Framework with their literature foundation is shown in Figure 4.

Figure 4: Circular strategies

3.1.1.2 Business models

Secondly, the strategies with related practices where mapped along the value chain. In this thesis we focus on the CBM, circular strategies, circular practices and industry 4.0 technologies. The value chain part we have excluded from the research.

The circular business model is a business model that is based on the principles of the circular economy. The circular economy is a production and consumption model that promotes the reuse, repair, recycling and reconditioning of materials and products in order the extend their life cycle as much as possible, helping to minimize waste (Bigliardi & Filippelli, 2021). A CBM is a type of sustainable business model that integrates environmental and economic value creation by shifting the business logic from generating profits from one-time sales of goods, to generating profits from continual flow of reused materials and products over time by capitalizing on the value embedded in used products (N. M. P. Bocken et al., 2016; Guldmann & Huulgaard, 2020). As we follow the framework developed by Tripodis (2023) we will be using the same definition of a CBM. In this thesis we will follow the definition as set out by Geissdoerfer et al. (2020).

"A CBM is a BM which considers cycling, extending, dematerializing and intensifying of resources loops (energy and material) as a mean to reduce input and output losses to and from and organizational system."

CBMs are similar to SBMs, however they include additional characteristics which are mainly concerned with slowing, intensifying, and narrowing resource loops as stated by Nosratabadi et al. (2019). The SBM aims at creating long-term and sustaining monetary and non-monetary value (Shakeel et al., 2020). A SBM consists of the classical business model elements of value proposition, creation, delivery and capture, but aligned with the concept of sustainability which goes beyond financial benefits and aims at a wider range of value acquisition through various stakeholders (N. M. P. Bocken et al., 2016). However, many companies find it difficult to meet their sustainability targets. Therefore, innovation on the business model level is required to align incentives and revenue mechanisms to leverage sustainable solutions (Rashid et al., 2013). BMI enables

companies to incorporate these changes in the core of their business by changing the business model. SBMs are the result of companies who innovate their business model with a focus on generating economic, environmental and social value (Geissdoerfer et al., 2018; Joyce & Paquin, 2016). Unlike traditional business models, which prioritize short-term financial gains, SBMs seek to balance economic prosperity with sustainability, and social equity (N. M. P. Bocken et al., 2016).

BMI involves the fundamental redesign of how organizations create, deliver, and capture value. This includes reconfiguring various components of the business model, such as the value proposition, value creation processes, revenue streams and cost structures, as addressed by Spieth et al. (2014). BMI is and goes beyond incremental improvements to existing business models and seeks transformative changes that disrupt industry norms and create new opportunities for value creation (Geissdoerfer et al., 2017).

CBMs are a subset from SBMs which are the result of BMI. The foundation of these concepts lay in the literature of BMs. According to Teece (2010) the business model of a company describes the logic of the value proposition for the customer and a viable structure of revenues, and costs for the business delivering that value. Shafer et al. (2005) includes the value network into the definition. They define a business model as a representation of a firm's underlying core logic and strategic choices for creating and capturing value within a value network. A commonly known tool used by practitioners is the business model canvas as presented by Osterwalder & Pigneur (2010). This framework uses the same elements are described by Richardson (2008), but they divided the three key elements into nine total elements. The business model canvas as developed by Osterwalder & Pigneur is shown in Figure 5.

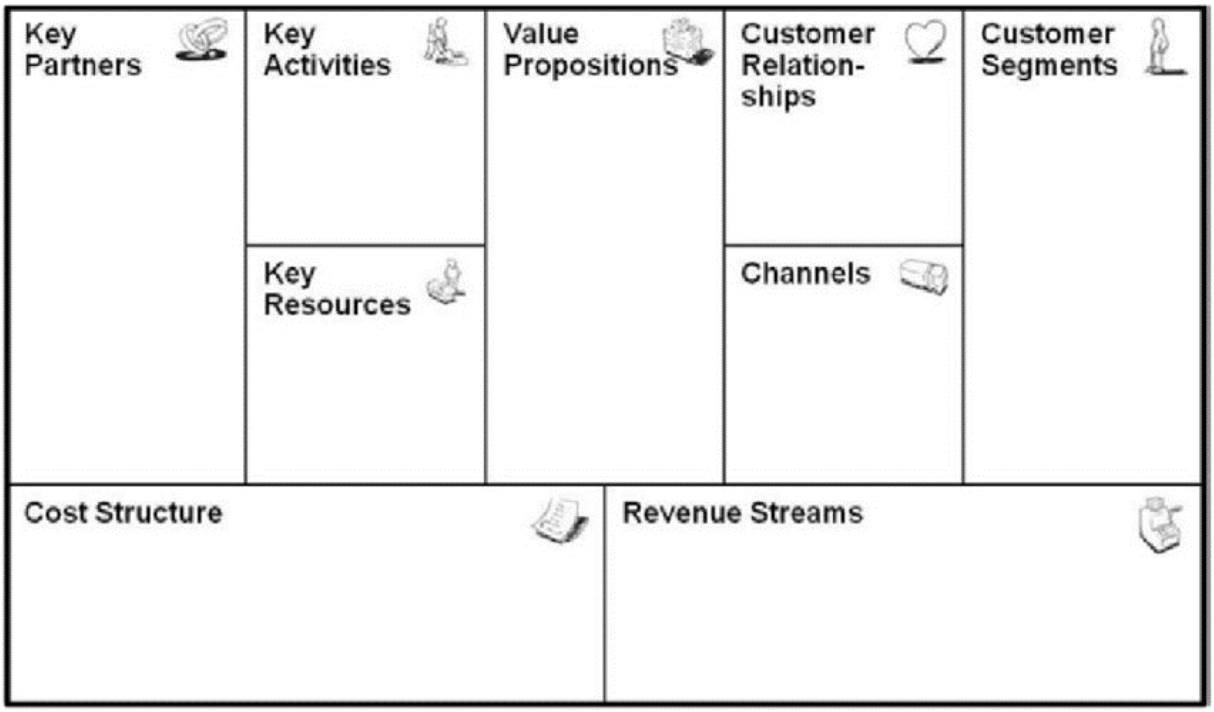


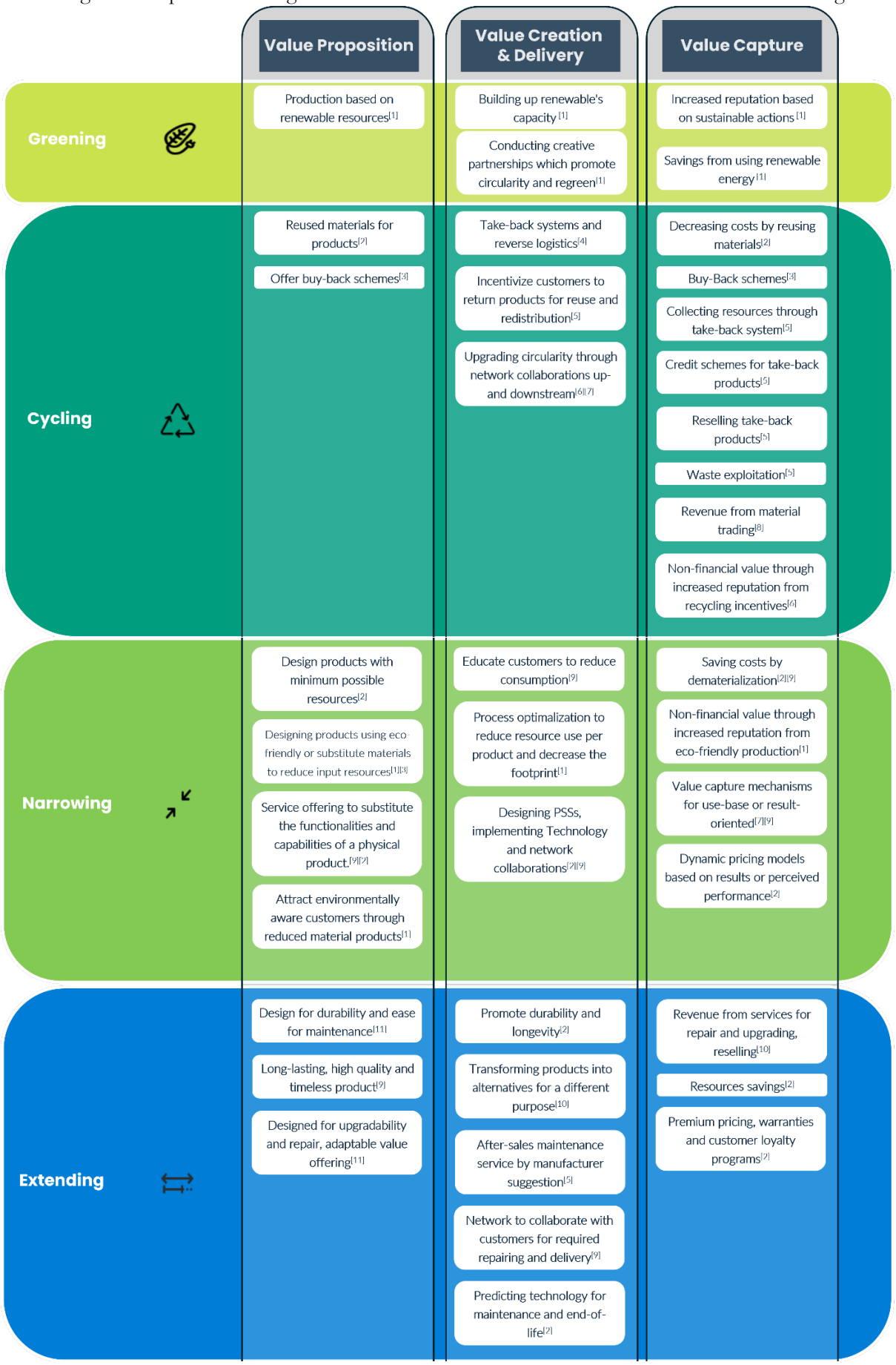
Figure 5: business model canvas (Osterwalder & Pigneur, 2010)

The CE-I4.0T Nexus Framework is based on the business model canvas as described by Osterwalder & Pigneur (2010) and the theory about CBMs as a subset of SBMs resulted from BMI by incorporating circular practices and circular strategies into the business model canvas.

3.1.1.3 Circular strategies and practices along the business model canvas

In the third step the circular strategies are connected to the business model elements. The business model canvas with nine elements as set out by Osterwalder & Pigneur (2010) and the circular strategies and practices as defined earlier in this report has been connected by Tripodis (2023). Appendix A Figure 10 contain the practices connected to the CBM elements for each strategy. We found similar approaches of

connecting circular practices along the business model in the literature and combined this in Figure 6.



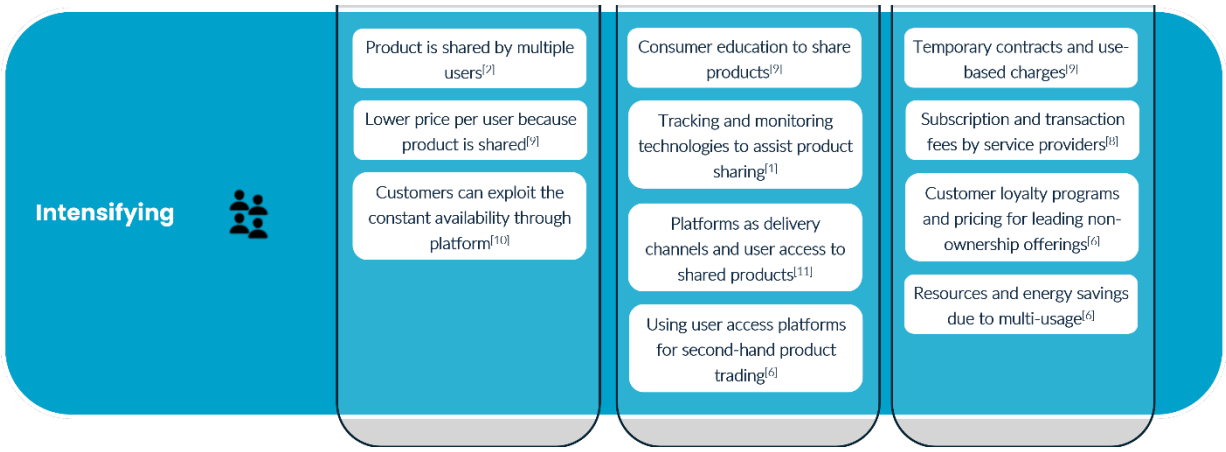


Figure 6: Circular strategies and practices along the business model

[1] (Konietzko et al., 2020)
[2] (N. M. P. Bocken et al., 2016)
[3] (Nußholz, 2017)
[4] (Lewandowski, 2016)
[5] (Lüdeke-Freund et al., 2019)
[6] (N. Bocken & Ritala, 2022)
[7] (Urbinati et al., 2017)
[8] (Whalen, 2019)
[9] (Geissdoerfer et al., 2020)
[10] (Planing, 2018)
[11] (M. A. Khan et al., 2018)

3.1.1.4 Industry 4.0 technology capabilities and circular strategies.

In the fourth step Tripodis included the I4.0 technology capabilities. The I4.0T capabilities act as enablers to integrate circularity in the business models of companies. Industry 4.0 is a concept in which manufacturing systems are driven by information technologies (Lasi et al., 2014). Industry 4.0 aims to provide real time information on production, machines, and flow of components. This information subsequently helps managers to make decisions, monitor performance and track parts and product or automate decision processes (Lu, 2017). The technologies that are considered part of Industry 4.0 enables real-time monitoring and controlling of important production parameters such as production status, energy consumption, flow of materials, customer's orders, and suppliers' data. Additionally, these technologies facilitate connectivity between customers and products and manufacturers and products (Shrouf et al., 2014). Tripodis has indicated how these technologies support the implementation of the five circular strategies, Appendix A Table 16. From the literature we can derive similar capabilities from the different I4.0Ts which enable circular practices. The technologies and literature references found are shown in Table 14 in Appendix A.

Lastly, the circular strategies, circular practices, CBM elements and the industry 4.0 technology capabilities are combined in one framework visualized in one table. The complete HCBMT-Framework is show in Appendix A Table 17. The circular strategies are shown on the left side of the table on the y-axis. The general circular practices per circular strategy are shown as well as the I4.0T capabilities per circular strategy. On the top on the x-axis the CBM elements are shown. The table is completed with the practices per strategy per CBM element. The purpose of the framework is to show the relationships between circular strategies, circular practices and I4.0T capabilities along the CBM elements in order to help companies ideating new CBMs or assist in implementing circular practices in their business model with I4.0T as enablers for these practices to achieve more circularity.

3.2 Theoretical propositions

Using the information gathered from the literature review and the research questions, we will formulate predictions regarding the results we will find at the case companies. Theoretical propositions serve an evaluative purpose in two distinct manners. One method is inherent to this research. The theoretical propositions will be utilized to examine the findings of the cases and determine if they align with the theoretical predictions of the research or if the empirical evidence from the case companies indicates a

different outcome. The second purpose of the evaluative function is to facilitate the replication of this research by other researchers (Yin, 2018). In this context, the theoretical propositions serve the purpose of elucidating the interpretation of the literature by the researchers and assessing any biases that may exist before undertaking the research.

Proposition 1: "The adoption of industry 4.0 technologies enhances the value proposition, value creation and value delivery of electronic product manufacturing companies through the implementation of circular strategies."

According to Hennemann Hilario Da Silva & Sehnem (2022), the implementation of Industry 4.0 technologies such as Internet of Things (IoT), Artificial Intelligence (AI), and Big Data Analytics can enable organizations to provide additional services such as extending the lifespan of products, conducting predictive maintenance, and adopting Platform as a Service (PaaS) models. Empirical evidence is anticipated to support the notion that advanced manufacturing technologies, such as cyber-physical systems, additive manufacturing, simulation software, and AI, have the ability to enhance resource utilization, minimize waste, enhance product quality and durability, and simplify maintenance and remanufacturing processes. Improved logistics, including tracking, predictive models, and energy simulation, can facilitate reverse logistics and promote more environmentally friendly and localized supply chains.

Proposition 2: "Industry 4.0 technologies act as enablers and/or accelerators of circular business models by providing tools and capabilities that facilitate the adoption of circular strategies in electronic product manufacturing companies."

The justification for proposition 2 lies in the potential offered by accelerating technologies such as digital twins, IoT, AI, and big data analytics. These technologies enable real-time monitoring, predictions, and feedback, facilitating companies in optimizing processes and minimizing resource use (Shrouf et al., 2014). These technologies are essential for effectively monitoring, forecasting, and enhancing processes. Simulation software and additive manufacturing can facilitate the redesign of items to enhance their ease of repair, remanufacture, and recycling efficiency . Blockchain technology can enhance transparency and traceability, which are essential for monitoring the life cycle of products, as well as for product recovery and recycling (I. S. Khan et al., 2021).

Proposition 3: "The CE-I4.0T Nexus business model tool provides clear and actionable insights that help manufacturing companies identify and leverage the synergies between industry 4.0 technologies and circular strategies, thereby facilitating an efficient transition towards a circular business model."

Proposition 3 emphasizes the anticipated applicability of the CE-I4.0T Nexus business model tool. Based on the research, it is evident that manufacturing organizations require a better understanding of the connections between circular strategies, practices, the aspects of their business model, and industry 4.0 technology. The CE-I4.0T Nexus business model tool is anticipated to provide the necessary clarity and facilitate the generation of new circular business models or methods for implementing circular strategies within the elements of the business model.

3.3 Rivalry Theory

Alternative interpretations of the literature are also possible. Due to the scarcity of statistical evidence in this particular research, the outcome may be influenced by other explanations that are not included in the theoretical propositions. Rivalry arguments are employed to shed light on the thinking process of the researcher in this thesis, in order to counter the theoretical propositions.

Rival argument 1: "Implementing Industry 4.0 technology sometimes requires significant financial investments, training, and a period of adjustment. Internal personnel and maybe

partners within the company's current value chain often exhibit opposition against the incorporation of new technology (Vermunt et al., 2019). In addition, there is a possibility of encountering compatibility concerns with current systems and workflows, which could potentially hinder the usefulness of industry 4.0 technology. The market's lack of readiness for circular products may lead to a lack of return on investment in industry 4.0 technology (Geissdoerfer et al., 2020)."

Rival argument 2: "The adoption of industry 4.0 technology may have a contradictory outcome. Introducing new hardware to the items may result in a reduction in recyclability compared to the current level of recyclability. Devices consume more electricity rather than consuming less power. The logistical procedures may encounter increased complexity, leading to inefficiencies (Kumar, 2020; Piscicelli, 2023)."

Rival argument 3: "The efficacy of the CE-I4.0T Nexus business model tool in offering clear insights regarding the utilization of industry 4.0 technology for incorporating circular strategies into the business model is uncertain. The tool inadequately considers organizational culture and stakeholder interaction, resulting in overly general recommendations that lack specificity for individual organizations. Consequently, the tool's use falls short (Guldmann & Huulgaard, 2020)."

Through these rivalry arguments, we emphasize possible constraints and alternative points of view that question the initial proposals. Formulating a theory of rivalry contributes to the attainment of internal validity. During the case company analysis, the search will not only focus on finding evidence to support the theoretical propositions, but also on identifying any alternative arguments and other factors. rival theories facilitate maintaining an unbiased perspective and discourage the accumulation of data that supports the initial theoretical assumptions (Yin, 2018).

3.4 Framework

Geissdoerfer et al. (2020) showed how CBMs can be established by incorporating circular practices along the value components of a business model. As show in Figure 6 the circular practices have been derived from a wide range of scholars. The scholars Bag et al. (2021), Bag & Pretorius (2020), Hennemann Hilario Da Silva & Sehnem (2022), Khan et al. (2021), Lieder et al (2020), Jabbour et al. (2018), Moreno & Charnley (2016), Nascimento et al. (2019), Pagoropoulos et al. (2017), Rajput & Singh (2020), Rosa et al. (2019), Tavera Romero et al. (2021), and Toth-Peter et al. (2023) all have argued how I4.0T capabilities can assist or enable the implementation of circular practices at companies. Based on this literature Tripodis (2023) has developed a framework. This framework in combination with the reviewed literature forms the theoretical framework for this thesis in which we try to find empirical evidence for the statements in the literature and the established CE-I4.0T Nexus Framework which is based on this literature. When applying this framework to the Electronic products manufacturing industry, it is important to consider certain theoretical consequences. This is because the framework was not originally built for this specific industry, but rather constructed from a general market perspective.

1. Electronic manufacturing organizations are likely to have recycle practices or disposal practices in place due to the promotion of these practices by the WEEE legislation and low return numbers of used products.
2. Electronic companies lean more into the leasing, product-life-extension and PaaS circular business models to increase used product return and decrease improper disposal.

In addition, the CE-I4.0T Nexus Framework offers a robust theoretical foundation. The purpose of this research is to empirically establish evidence for the usability of this framework. Consequently, other theoretical frameworks have been rejected.

3.5 Interview protocol

This section will provide a detailed description and outline of the case company analysis process. Referring to the research design, we will be doing a holistic multiple-case research. We will choose companies from the electronic product manufacturing sector as our case studies and aim to collect empirical data to assess the applicability of the CE-I4.0T Nexus Framework. A concise explanation of the procedure that will be implemented, with the objective of achieving replication, will be provided. Furthermore, this report will provide an explanation for the procedure, the specific questions addressed, the anticipated data analysis, and the research validity.

3.5.1 Case company search

The research design for this Master Thesis involves selecting organizations from the electronic product manufacturing industry to participate in the research. A list of 100 potential case companies has been created. These case companies are identified through the use of network organizations and competitors analysis. The websites of the following network organizations are referred to: The circulars, The Circle Economy Foundation, The European Commission, The Ellen MacArthur Foundation, and the Circular Economy Initiative Deutschland. The criteria for selecting potential case firms are as follows:

1. Electronic products manufacturer
2. European Origin

Each company will receive a generic email and its representatives will be sought out on LinkedIn using the search terms "Sustainability manager (specific company)", "CEO (specific company)", or "Founder (specific company)". Afterwards, the representatives will be emailed an invitation to participate via LinkedIn InMail. The invitation will include a research description, the objective of the study, and the process of participation. Upon obtaining a favourable response, a one-hour MS Teams meeting will be scheduled at the agreed-upon date and time.

3.5.2 Case research procedures

Ethical considerations

Given the nature of our research and the level of analysis, we may potentially handle data that is of a sensitive nature. By creating a data management plan, we aim to identify and address the risks associated with data leakage or unauthorized data sharing. The subsequent approach has been followed.

1. HREC checklist by the Delft University of Technology Human Resource Ethics Committee.
2. Risk Assessment and Mitigation Plan
3. Compiling Data Management Plan (DMP)
4. Compiling Informed Consent Form (ICP)

Seven risks have been identified and are summarized in Table 4. The risks that have been identified and the corresponding steps to mitigate them are displayed.

Table 4: HREC risks and mitigation actions

Identified Risk	**Mitigation actions**
Possibility of re-identification for research participant duo to small number of expert participants.	The companies and representatives can be anonymized in the thesis. The name, job position and company of the representatives will be stored in a data protected environment of TU Delft. In the published thesis the representatives and companies can be anonymized.
Participants will be recruited through my own professional channels like LinkedIn	The participants will be asked for consensus through the ICF.

The research will possibly involve disclosing commercially or professionally sensitive, or confidential information.	The representatives and company will be anonymized in the published thesis.
The research will involve collecting, processing and storing directly identifiable (PII) information.	The TU Delft SharePoint will be used to save this data. No copy including PII will be stored anywhere else.
The research will involve collecting, processing and storing indirectly identifiable (PIRD) information.	The TU Delft SharePoint will be used to save this data. No copy including PIRD will be stored anywhere else. After successful transcribing the audio-recordings will be destroyed.
The research will involve collecting data from social media which have been originally contributed by human participants.	The interviewees will be asked for consensus that they could be find through my LinkedIn network. If they disagree the LinkedIn connection will be deleted.
The research will be published in the public master thesis repository of TU Delft.	PII and PIRD will be anonymized in the publication.

The mitigation actions are incorporated into the Data Management Plan and Informed Consent Form, both of which will undergo assessment by the Human Research Ethics Committee of Delft University of Technology. Prior to conducting interviews, the representatives will be provided with the ICF (Informed Consent Form) and asked to sign the document before returning it to the researcher. Prior to the beginning of the interviews, it will be ensured that the interviewees are informed about the recording and transcription of the interview. They will then be requested to give their consent once again for the recording, as well as for the proposed data processing and storage.

Interview procedure

The case company representatives will undergo a 1-hour semi-structured interview. Prior to the interview, the interviewer will give the interviewee the ICF (Informed Consent Form) by email and ask them to return a signed copy. During the initial stage of the interview, the researcher inquires whether the interviewee comprehended the information presented in the ICF and requests consent once more for recording the interview. Once the respondent has given consent for the interview to be recorded, the researcher will provide a brief introduction about oneself, the research project, and its objectives. Subsequently, there is the chance to introduce the interviewee. Following that, the researcher begin the process of posing the pre-established questions. The purpose of the preset questions is to provide a framework for gathering data. The goal is to gather empirical data to support or contradict the usability of the CE-I4.0T Nexus Framework. The pre-established questions aid in obtaining a comprehensive understanding of the circular strategies and practices used by this case company, their alignment with the elements of the business model, and the extent to which industry 4.0 technologies are utilized.

The predetermined interview questions are displayed in Table 18 in Appendix A. The interview questions are based on the CE-I4.0T Nexus Framework. The order and template are derived from the business model canvas, with specific questions for each business model element on the integration of circular strategies, practices, and Industry 4.0 Technologies. This template offers a well-defined framework for conducting interviews and facilitates the gathering of necessary data for future analysis and addressing the research questions.

The interview will follow a semi-structured approach, allowing the interviewee to explore relevant topics or related subjects that contribute to the collection of evidence for evaluating the CE-I4.0T Nexus Framework. If there are specific questions in the question overview that are more suitable for the interview but not in the intended order, we will take advantage of that opportunity. Once the interview questions have been addressed, we conclude the conversation by providing an explanation of what's coming next and requesting that they explore the tool and framework to which they will be given access.

Data collection

The data will be gathered from three sources in the research. The sources of information include the interview transcripts, publicly available data from the case companies, and feedback received on the utilization of the designed tool. During the data collection, our main objective is to acquire information specifically about the present circular strategies, practices, and utilization of Industry 4.0 Technologies (I4.0T) by the case companies. We also aim to understand how these strategies and practices are integrated into the companies' business models. The interviews will be recorded and transcribed using the recording and transcribing features of MS Teams. Information from the case companies is collected from their publicly accessible websites. Furthermore, the interviewers are being asked to provide comments on the CE-I4.0T Nexus tool. The tool is an Excel-based tool that includes of four separate feedback columns. Case company representatives can provide their comments in the tool and submit the Excel file to us. The data will be stored in a designated MS OneDrive folder provided by Delft University of Technology, with exclusive access granted to the researchers. The recordings will be erased upon successful transcribing. The transcripts will undergo anonymization to remove any personal identifiable information (PII) and personally identifiable research data (PIRD). Additionally, measures will be taken to ensure that interviewees cannot be re-identified. Prior to data analysis, the transcripts will be sent to the interviewee for their authorization to use the data. Additionally, the interviewee will be given the opportunity to withdraw any specific remarks or information from the analysis.

Data analysis

The research entails an in-depth examination of the transcripts of the semi-structured interviews, analysis of publicly available documents, and consideration of feedback from the interviewees. The main goal is to evaluate the practical applicability of the CE-I4.0T Nexus Framework. The software program ATLAS.ti will be utilized for the analysis of transcripts and documents. In order to provide a concise summary of the gathered data from the case company, our objective is to complete the CE-I4.0T Nexus Framework table, as depicted in Appendix A Table 17. By formatting the data in a specific manner, it becomes feasible to fill in the vacant CE-I4.0T Nexus Framework table. By comparing the completed framework tables with the default framework, one can identify discrepancies and similarities. By combining this information with interview quotations and feedback from the tool, it becomes possible to assess the usability of the framework.

The data preparation to apply the framework will involve qualitative deductive coding using ATLAS.ti. Codes and code groups are predetermined and constructed according to the notions derived from the framework. A three step coding approach as mentioned by Gioia (Gioia et al., 2013) is applied. The first step will be coding to an aggregate dimension. The second step the data will be coded to the 2nd order themes and the last step will be coding the data according to the 1st order concepts. The codes and code groups are displayed in Appendix A Table 19. The interview transcripts and public documents will undergo coding in order to address the questions and analyse the concepts outlined in the framework. The method of structural coding will be utilized. The research findings will incorporate the researcher's interpretation together with actual quotations from the interview transcripts or public materials. Network analysis will be utilized in Atlas.ti to examine the connections between circular strategies, practices, I4.0T usage, and business model elements. As an illustration, a section of the interview transcript or company report has been coded using the following codes: "Simulation" "Narrowing strategy," and "Product/Offering,". A network analysis will provide a comprehensive visual representation of this coding. Using this network of codes and the given quotation, we can determine the appropriate location to store this information within the vacant CE-I4.0T Nexus Framework table. Moreover, we will assess the extent to which these strategies, practices, and technologies are utilized within the organization's existing framework. We will also explore how these currently established technologies and strategies might be further optimized inside the business model.

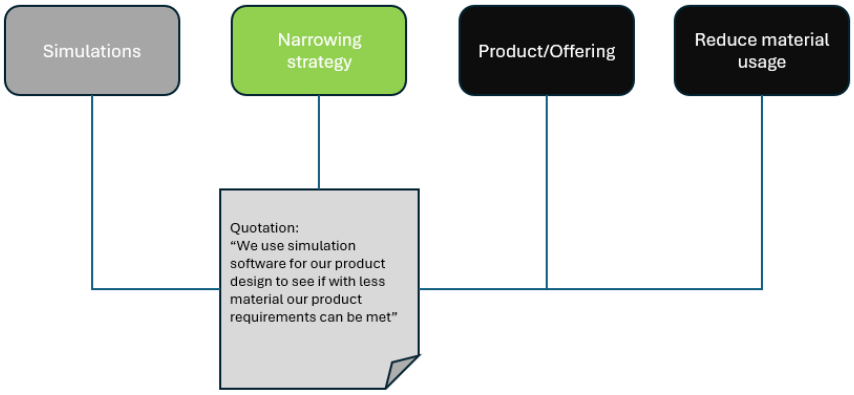


Figure 7: Example network analysis from data codes

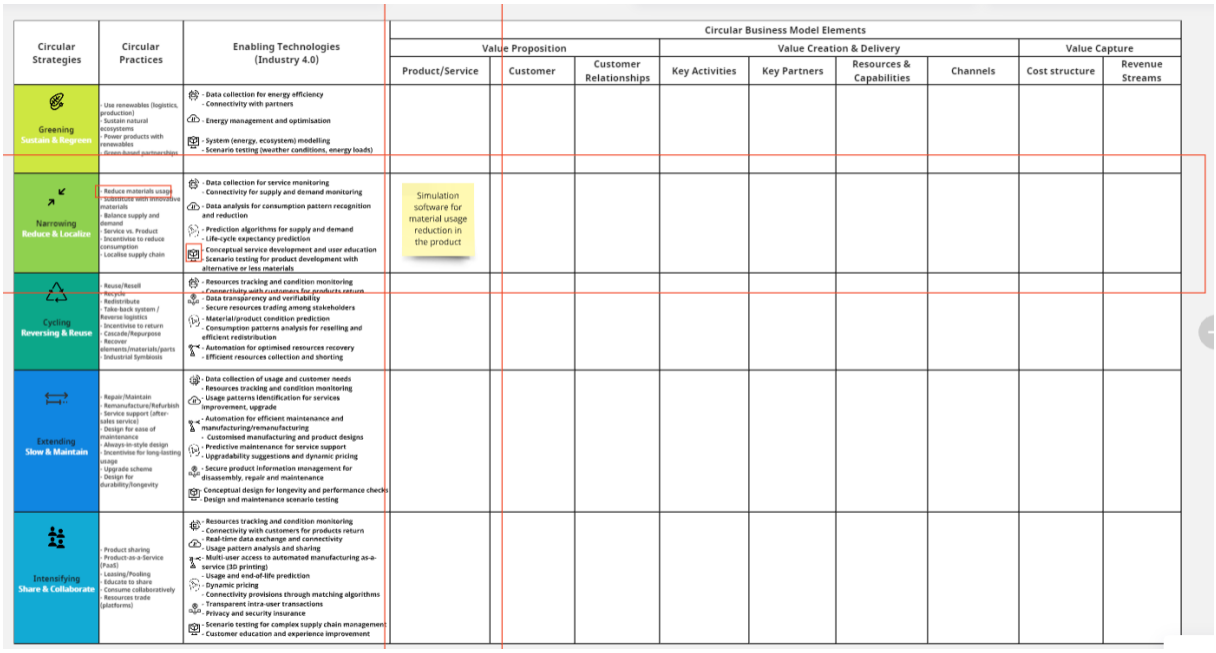


Figure 8: Example CE-I4.0T Nexus Framework application to case company

In Figure 7 is show how the data from the interview transcripts and the company reports are coded and subsequently used in a network analysis. A quotation is coded according to the predetermined codes and the network analysis shows which combination of codes are used for labelling the quotation. The combination of the codes for the quotation are used to fill in the CE-I4.0T Nexus Framework for each case company. An example is shown in Figure 8.

Validity

In his work, Yin (2018) presents a comprehensive examination of methods and tactics aimed at enhancing the validity of research. This summary presents the techniques that have been utilized in the research part of this thesis. In order to achieve construct validity, Yin recommends utilizing many sources of evidence. We have implemented this strategy to conduct a multi-case research methodology. In each instance, we collected evidence by conducting interviews and analysing publicly accessible company data. In order to achieve internal validity, we employ pattern matching by conducting a predicted network analysis of the coding and comparing it to the actual network analysis of the collected data. Using this comparison, we generate explanations by analysing quotations from the data, interpreting them based on existing literature, and comparing the results to the expected outcomes from the theoretical framework. We also consider alternative explanations in the process. External validity will be achieved through the application of replication logic, which involves comparing the outcomes obtained from multiple case firms. Reliability is

established by employing a comprehensive research process and gathering a chain of evidence from many sources.

Tests	Case Study Tactic	Phase of Case Study Research in Which Tactic Is Addressed
Construct validity	• use multiple sources of evidence • have key informants review draft case study report	data collection (see Chap. 4) composition (see Chap. 6)
Internal validity	• do pattern matching • do explanation building • address rival explanations • use logic models	data analysis (see Chap. 5) data analysis (see Chap. 5) data analysis (see Chap. 5) data analysis (see Chap. 5)
External validity	• use theory in single-case studies • use replication logic in multiple-case studies	research design (see Chap. 2) research design (see Chap. 2)
Reliability	• use case study protocol • develop case study database • maintain a chain of evidence	data collection (see Chap. 3) data collection (see Chap. 4) data collection (see Chap. 4)

Figure 9: Validity test extracted from Yin (2018)

5. Case Companies

Of the 100 European electronic manufacturing companies that were contacted, 10 have responded. Out of the total of 10, a subset of 5 individuals have confirmed their willingness to participate. However, eventually three case companies have participated. The research involved the participation of the following companies: Bosch Siemens Home Appliances (BSH), BlueMovement and Miele. This research may contain competitor sensitive data. Therefore, companies are anonymized during the analysis process. We employ the practice of labelling to ensure that the data remains unattributable to the parties involved. In this chapter, we introduce the case companies.

Bosch Siemens Home Appliances (BSH)

BSH Home Appliances, a prominent multinational producer, functions as a division of the Bosch Group, providing household solutions. BSH is well-known for its brands such as Bosch, Siemens, and Gaggenau. The company places a high value on sustainability and circularity in its operations. BSH is dedicated to environmental stewardship and incorporates energy-efficient technologies into all of its products, resulting in reduced carbon footprints and energy usage. The company promotes circularity through the creation of appliances that prioritize durability, ease of maintenance, and recyclability, thereby reducing waste and resource consumption. The "BSH Circularity" program promotes a closed-loop system to ensure the reuse and recycling of materials. BSH is committed to sustainability and aims to become carbon neutral by 2030. This goal is supported by the company's use of renewable energy and environmentally friendly industrial methods. BSH Home Appliances is in the forefront of promoting a greener and more sustainable future with its emphasis on quality, innovation, and environmental responsibility. The representative of the case company is an active employee in sustainability and circularity at BSH and is up-to-date about BSH strategies and goals in this field.

BlueMovement

BlueMovement is a division of Bosch that specializes in providing home appliances. BlueMovement offers a rental service for household appliances to individual customers, as well as providing services for maintenance, repair, refurbishment, and recycling. Their main emphasis is on providing sustainable, smarter,

and completely hassle-free household appliances. BlueMovement is committed to promoting environmental sustainability by providing a wide spectrum of consumers with access to energy-efficient, recyclable, and high-quality home appliances. The circularity strategy of BlueMovement is characterized by its business model. Consumers lease the appliances. The company retains ownership and takes responsibility for maintenance, repair, collection, and processing of appliances. BlueMovement refurbishes and recycles the appliances once the contract period has ended. The company representatives is well aware of the company's strategies, processes and business model as well as knowledgeable about the CE and I4.0Ts.

Miele

Miele is a premium manufacturer of high-quality Household appliances. The appliances of Miele are known for their durability, performance and timeless design. Miele's slogan "Immer besser" which means "Forever Better" in German shows the strive for continuous improvement and innovations. Miele's sustainability and circularity efforts are marked by eco-friendly practices across its operations. The products are designed for longevity and repairability, ensuring appliances have extended lifespans and contribute less to landfill waste. Initiatives of Miele includes using renewable energy sources, reducing carbon emissions, and optimizing resource efficiency throughout the manufacturing processes and product life-cycles. The company representative is working in the research department and is well informed about Miele's business model, CE, circular strategies and the usage of I4.0Ts.

4. Case company findings

This chapter will outline the results obtained from the data collection. The results will be showcased as fully developed frameworks for each individual case company. We demonstrate through various qualitative analyses how the content of the finalized frameworks is derived from the collected data. The researcher provide an analysis of specific quotes and information from the data, along with an explanation of how these findings contribute to the formulation of answers to the research questions. In addition, the finished case company frameworks are being compared to the default framework. We conduct a GAP analysis between the case company's current CE-I4.0T Nexus Framework and the default framework developed by Tripodis (2023) to eventually propose potential improvements towards a CBM to the case companies. Aside from providing the results from the GAP analysis and propositions for improvements, we ask them to give feedback on the results derived from the framework. The analysed data includes publicly available company reports and articles and interview transcripts. The data is coded according to the predetermined codes shown in the data analysis paragraph of the theoretical framework chapter. By performing network analysis on the quotations which include for example the codes "Product/Offering" and "Greening strategy" we can place a rephrased quote into the CE-I4.0T Nexus Framework. The filled-in CE-I4.0T Nexus Frameworks gives a clear overview of the current implemented circular strategies and practices and I4.0T usage. If data code combinations are found according to the default framework we build our empirical evidence for verification of the framework.

4.1 Case company 1

4.1.1 Findings network analysis

The network analysis of the data codes of case company 1 shows a focus on the cycling, narrowing and extending strategies. Practices from the intensifying strategy are mentioned less respectively 57 times compared to Greening (61x), Narrowing (62x), Cycling (75x), and Extending (80x). Many practices are named in the value proposition and value creation & delivery part of the business model. While not many practices for the value capture are mentioned. The network analysis further shows that the networks from the product/offering, key activities and resource & capabilities elements of the business model includes many quotes. A more detailed look into these quotes results to practices related to design practices and resource reduction or substitution. Not by substituting the products by non-material product/service offerings, but by re-designing the known products with recyclable materials and ease for repairability or maintenance practices. Resulting from the analysis is the approach of the company to green the products and its own processes. The networks show many quotes about the use of renewables, energy optimization

and pollution reduction. Quotes about the intensifying strategies are limited. From the networks we can derive that leasing and sharing models are being employed, but quotes about these practices don't show up as much as practices from the other strategies. Connectivity is mentioned much and I4.0T quotes are mostly related to technologies that help in the designing of the products, data connectivity or predictive models. Figure 11 in Appendix C shows one of the network analysis.

4.1.2 CE-I4.0T Nexus Framework Case company 1

The coded quotations from the data provides the content for the filled-in CE-I4.0T Nexus Framework. By filling in the framework an overview is given about the current circular practices and strategies already in place along the case company's business model and how I4.0T are being exploit to support these practices. The filled-in framework enables performing a GAP analysis with the default framework and shows potential improvements.

The current CBM of case company 1 is shown in Figure 15 in Appendix D. The framework is completed with practices derived indirectly by rephrasing and combining the quotations from the data. In Table 20 in Appendix B the direct quotations, codes and rephrased practices are shown. The framework is filled-in in Miro. The cards include the quotation ID's from which quotations the rephrased practices are derived from. Access the Miro Board through the following link: Miro board link.

4.1.3 GAP analysis

As part of the evaluation of the framework a GAP analysis will be conducted. The current CE-I4.0T Nexus Framework of case company 1 is compared to the default framework. With this comparison gaps in the implemented practices of the case company are identified as well as gaps in the default framework. The gap analysis will be shared with the case company with the request for feedback. The feedback in combination with the results from the gap analysis are input for the conclusion of the usability of the framework. The complete GAP analysis is shown in Table 23 in Appendix F. The key findings are shown below.

Key findings:

1. Greening strategy:
    a. Case company 1 has many practices of the greening strategy in place. Resulting from the framework improvements can be made with transportation. Case company 1 mentions the strategy of reducing CO2 emissions, however not yet the strategy to completely greening transportation.
    b. Case company 1 focusses on sustainable delivery through recyclable packaging and reduce packaging. Delivering case company 1's offer could be improved by using renewable resources for transportation.
    c. Last improvement is the presence of support and promotion of green marketing and sustainability by Human Resources. The presence of this practice was not mentioned in the data. But might be still in place.
2. Narrowing strategy:
    a. Case company 1 manufacturers and offers physical products which are nearly impossible to replace with only services. Service offerings could reduce the amount of physical products, but complete replacement is nearly impossible. This is also what is derived from the GAP analysis. If practices from the narrowing strategy are implemented at the case company, they are focused on material and consumption reduction.
    b. Practices that case company 1 can implement derived from the applied framework is balancing supply and demand. On the supplier page of the case it is shortly mentioned that case company 1 is focussing on balancing supply and demand, however in the collected data it is not mentioned. Industry 4.0 technologies like AI, Big data and Cyber-physical systems can assist in balancing supply and demand.
    c. The case company focuses on resource consumption efficiency for their products, but also offers product features that assists in resource consumption in the usage phase. Products

feature cyber-physical systems with sensors and actuators which's controlling is optimized with AI and ML.

   d. Some and in the future an increasing number of products are connected this in combination with the predictive models can give consumers customized offerings of the consumables for their products.
   e. What is furthermore missing from the data and could be improved by case company 1 is localization of the supply chain. If technically and financially feasible, source resources near factory locations and manufacturing and deliver locally. On a large scale this practices is likely not feasible. However, a practice could be to design the products in a way that the customer can assemble the product themselves. This reduces the manufacturing cost and can have an significant impact on the companies supply chain if for example different parts are manufactured in different locations. Moreover, this will reduce transportation costs which is also a practices resulting from the framework.
   f. Cost reduction by using less material is mentioned. Further cost reduction are not mentioned. Cost reduction could also be achieved by the practice described in key point e.
   g. Opportunities for extra revenue streams are for example different subscription models. Case company 1 offers a connectivity app. Using predictive models, big data an AI through the app recommendations for utilizing the products energy cost effective can be given. As a customer to receive these high-level recommendations you could take a subscription through the app. Same model could be utilized for predictive maintenance including spare part sales and automatic consumables delivery.

3. Cycling strategy:
   a. Case company 1 is focused on using recycled materials in the products. Mostly, the recycled materials are bought from suppliers.
   b. Case company 1 complies to the WEEE directive, whereby it is stated that end-of-life products are being collected and repurposed. Improvements can be made in recycle the materials of EOL product in new products and selling waste to other companies which use this waste as an input.
   c. Product return and recycling can be improved with buy-back schemes and partnerships for repair services, EOL product or used product collection, inspection and reselling.
   d. Improvement suggestions resulting from applying the framework are; setting-up reselling channels. An online marketplace where B2C, B2B or C2C used product can be sold under supervision of the case company. Connected devices with remoter diagnostics, predictive maintenance models and performance monitoring can help reassuring used product quality remotely. Leverage on different social media platforms and incentivise customers to recycle the products. Provide return points for products/parts/materials and develop or partner a reverse logistics system.
   e. Case company 1 could increase the use of recycled materials from their own EOL products. Waste trading or reusing was not mentioned, this could be an improvement. Joint value creation could save manufacturing costs. Products can be developed for easy assembling and customers will get parts delivered which they can assemble themselves.

4. Extending strategy:
   a. Case company 1's products are designed for recyclability and ease of maintenance/repair. Design improvements can be made by focussing on timeless designs, avoid hypes and trends, and for faster obsolete parts design them easy replaceable. It is possible that these practices are already in place but not mentioned in the analysed data.
   b. From the analysed data we have not derived much information about the business model element customer.
   c. Future improvements to enhance product lifetime can be achieved, according to the results of the applied framework, with among others an online training platform for retailers, delivery partners and used product collections. Through this platform digital maintenance support could be provided enabled by Augmented Reality.

d. Instead of remanufacturing and reselling yourself, case company 1 could source partners for remanufacturing and reselling. Potentially local partners to decrease transportation pollution and costs. Case company 1 could leverage on remote quality control through connectivity of the products. A digital product passport provides the partner organization with all the data needed for remanufacturing, refurbishing, upgrade, repurpose, maintenance and reselling. The partner organizations can update the products digital passport, so that the case company and future partner organizations who will encounter the product are informed about the status and maintenance history.
e. Case company 1 can enhance longevity even more by providing upgrades and inform customers about upgrading their products. These upgrades could be software updates or hardware updates. For hardware updates modular product design facilitates this strategy.
f. Case company 1 holds a stock of spare parts for every product for 15 years to ensure product longevity. This practice was not part of the default framework, but can be included as improvement for the framework.
g. From the data we could derive that customers are stating that they find sustainable products important, however they are not willing to pay a premium for more sustainable products. This resulted not from applying the framework, but was mentioned in an interview.

5. Intensifying strategy:
   a. From the data it didn't became clear if the case company has a digital platform from where sharing and leasing customers can manage their contracts.
   b. Case company 1 offers a connectivity app for their products. Improvements resulted from the application of the framework results in improving customer engagement through the app with feedback notifications after service or product delivery and online surveys for product or service improvements. The app could also be adjusted for customers to manage their subscriptions.
   c. Improvements can be made in educate customers about sharing and leasing models according to the framework application.
   d. Partner network improvements for inspection and local refurbishment and reselling.
   e. Online marketplace for C2C used product reselling supervised by case company 1. The platform can be monetized by a subscription model or by selling services like quality inspection, manufacturing warranties.

4.1.4 Framework verification

As further clarified in the research procedure the predetermined codes are based on the three step coding strategy by Gioai et al. (2013). Where the circular strategies fall under the aggregate dimension, the business model elements, complemented by the general codes: "circular practice" and "industry 4.0 technology" fall under the 2nd order themes and the circular practices and industry 4.0 technologies themselves fall under the 1st order concepts. With this strategy data which includes both circular strategies, circular practices, I4.0Ts and business model element(s) are easy to find. Finding data that includes all these concepts in the same way as the framework provides contributes to building empirical evidence for the verification of the framework. The findings for case company 1 are set out below.

Table 5: Case company 1 practices also given by the CE-I4.0T Nexus Framework

Quotation ID	Codes	Description
Quotation 1:215	Greening strategy	Case company 1 is providing a solution through the appliances app which gives the customer insights in current energy prices through connectivity with electricity towers from electricity provider companies. This practices using IoT helps consumers planning using their appliances when energy prices are low and it
	Circular practice Industry 4.0 technology Resources & Capabilities	
	Green-based partnerships IoT for data collection for energy efficiency IoT for connectivity with partners	

		helps energy providers spreading the energy load on the network.
Quotation: 1:217	Extending strategy Circular practice Industry 4.0 technology Resources & Capabilities AI, ML & AR for predictive maintenance for service support Big Data, Cloud computing & Analytics for usage patterns identification for service improvement, upgrades Design for durability/Longevity	Case company 1 is using big data and predictive models to optimize the life cycle of the products by using the predictions and data to change product designs to endure longer. According to the framework this practices using AI and big data and analytics contributes to the extending strategy in the business model element resources & capabilities. This practices is related to the circular practice 'design for durability/longevity'.
Quotation 5:2	Extending strategy Circular practice Industry 4.0 technology Resources & Capabilities Big data, cloud computing & analytics for usage patterns identification for service improvement, upgrade Design for durability/longevity IoT for data collection of usage and customer needs	In this quotation a similar practice is explained as in quotation 1:217. Although added in this quotation is that case company 1 is using data from connected appliances which implies that usage data is used for design purposes from appliances in use.
Quotation 6:1	Cycling strategy Circular practice Industry 4.0 technology Product/Offering AI, ML & AR for material/product condition prediction Recycle Simulations for conceptual design for longevity and performance checks	Case company 1 is promoting the circular economy by implementing recyclable materials into their products. To design these product they claim that simulation software and AI are key. According to the framework this practices of the case company fits into the product/offering business model element with the recycle practice contributing to the recycling strategy and using AI for material/product condition predictions. However, the framework doesn't include simulation software as an enable for cycling strategy practices.
Quotation 6:3	Extending strategy Circular practice Industry 4.0 technology Resources & Capabilities Design for durability/longevity Simulations for conceptual design for longevity and performance checks	Using simulation software case company 1 is enabling sustainable product design. They use the I4.0T to test different materials, production methods and product designs to optimize the life-cycle and environmental footprint of the product. The framework includes this practice and place it under the Resources & Capabilities business model element contributing to the extending strategy

The practices shown in Table *5*5 and implemented by case company 1 show company applications of practices also given by the CE-I4.0T Nexus Framework. This data is empirical evidence for the verification of the framework as the framework implies the practices also observed in a business setting.

In addition to the practices derived from the data which shows correlation to the CE-I4.0T Nexus Framework also practices has been found which includes circular practices enabled by I4.0Ts along the case company's business model wherefore the framework does not provide related practices. These practices are shown in Table *6*6 below.

Table 6: Case company 1 practice not completely provided by the CE-I4.0T Nexus Framework

Quotation ID	Codes	Description
Quotation 4:19	Narrowing strategy Circular practice Industry 4.0 technology Resources & Capabilities Substitute with innovative materials	This quotation explains how case company 1 is leveraging on algorithms with the selection of materials. Case company 1 is using algorithms to map materials and declarations of suppliers to efficiently see which materials are restricted, which regulations apply and what requirements the company has for the use of certain materials. This prevents that case company 1 is designing products with hazardous materials, unsustainable materials and helps making sustainable design choices. The framework does not provide correct practices to incorporate this practice derived from the empirical data.
Quotation 5:3 Quotation 5:10	Narrowing strategy Circular practice Industry 4.0 technology Product/Offering Incentivise to reduce consumption	Case company 1 offers a oven with integrated camera and food recognition. The product uses a combination of smart components and AI to optimize energy consumption in the preparation of food and contributes to make food waste history while consuming less energy due to automatically recognise the type of food in the oven and regulates the oven settings accordingly. The framework does not provide correct practices to incorporate this practice derived from the empirical data. Where companies are leveraging on I4.0Ts in their products to contribute to a circular economy
Quotation 5:6 Quotation 6:17	Narrowing strategy Circular practice Industry 4.0 technology Product/Offering Incentivise to reduce consumption	This quotation is similar to quotation 5:3, but is about an automatic detergent dosing system for laundry machines. Instead of manually add detergents in the laundry machine overconsumption of detergents is common. The framework does not provide correct practices to incorporate this practice derived from the empirical data. Where companies are leveraging on I4.0Ts in their products to contribute to a circular economy
Quotation 6:2	Narrowing strategy Circular practice Industry 4.0 technology Product/Offering AI, ML & AR for prediction algorithms for supply and demand Big data, cloud computing & analytics for data analysis for consumption pattern recognition and reduction Incentivise to reduce consumption	This quotation is similar to quotation 5:3, 5:10 and 5:6, but is about an automatic regulating ventilation system with smart thermostats and controls the ventilation system if the product register that doors/windows are open. The general principle that the framework does not provide is using I4.0Ts in the products that contribute to circular strategies.

Table *66* has shown four practices implemented by case company 1 wherefore the CE-I4.0T Nexus Framework not completely provides an overview for. Although, these practices in business settings are enabled by I4.0Ts, contribute to the implementation of circular strategies and can be leveraged on in the business model.

4.1.5 Feedback

The GAP analysis and the applied framework is shared with the case company representatives with the request for feedback. The data gathered can be incomplete or wrongly interpreted the feedback contributed to a more complete understanding of the practices applied at the case company and the usability of the CE-I4.0T Nexus Framework. The representative of case company 2 has given feedback on the GAP analysis and clarified more practices which were not included in the first interview. Included are the piloting of the delivery of the product with electrical busses and repair technicians who travel with e-bikes. The representative elaborated on a subsidiary of the company which handles communal washing services. Moreover, the feedback included an example of a Green collection fridge which helps reducing carbon emissions. The feedback on the GAP analysis can be found in Table 23 in Appendix F.

4.2 Case company 2

The findings derived from the data of case company 2 are outlined below. The same data analysis are used as in the analysis of case company 1.

4.2.1 Findings network analysis

The network analysis of the data codes of case company 2 shows a focus on the intensifying strategy. Practices from the intensifying strategy are mentioned 16 times compared to Greening (3x), Narrowing (2x), Cycling (11x), and Extending (9x). Case company 2 offers a leasing and sharing business model only. The network analysis further shows that the networks from the customer relationships, resources & capabilities and revenue streams elements of the business model includes many quotes. A more detailed look into these quotes results to practices related to practices to enable sharing, leasing and recycling. Resulting from the analysis is the approach of the company to lease out and offering sharing the products. Connectivity is mentioned much and I4.0T quotes are mostly related to technologies that help in customer relationships and revenue streams of case company 2.

4.2.2 CE-I4.0T Nexus Framework Case company 2

Similar to the findings of case company 1 the coded quotations from the data provides the content for the filled-in CE-I4.0T Nexus Framework. The current CBM of case company 2 is shown in Figure 16 in Appendix D. The framework is completed with practices derived indirectly by rephrasing and combining the quotations from the data. In Table 21 in Appendix B the direct quotations, codes and rephrased practices are shown. The framework is filled-in in Miro. The cards include the quotation ID's from which quotations the rephrased practices are derived from. Access the Miro Board through the following link: Miro board link.

4.2.3 GAP analysis

The current CE-I4.0T Nexus Framework of case company 2 is compared to the default framework. With this comparison gaps in the implemented practices of the case company are identified as well as gaps in the default framework. The GAP analysis will be shared with the case company representative with the request for feedback. The complete GAP analysis is shown in Table 24 in Appendix F. The key findings are shown below.

Key findings:

1. Greening strategy:
    a. The data gathered from case company 2 includes not much information about greening practices. The biggest focus of case company 2 within the greening strategy is delivering green products and reduce energy consumption with the products and with their own processes.
    b. Improvements can be made with sustainable product delivery with the use of non-fossil transport. However, mentioned in the data is the sustainable and recyclable packaging of the product.
    c. The marketing channels can focus more on creating awareness about their green offering and using the appliances in an eco-friendly way.

2. Narrowing strategy:
    a. Case company 2 relies on a manufacturer for their product design, however with co-design and co-manufacturing they can influence the manufacturer to reduce resource consumption and use innovative materials to replace hazardous or unsustainable materials.
    b. Replacing case company 2's offer with software is nearly impossible a narrowing strategy on their product offer will be hard to achieve. Other circular strategies are more suitable for case company 2 to achieve more circularity
    c. By leveraging on the capabilities of data collection from the connected devices in combination with algorithms case company 2 could make predictions about future product demand and buy-in products accordingly to reduce stocks and unused resources.
    d. Partnering with local inspection and refurbishing companies could reduce transportation and energy consumption. Local redistribution for refurbished appliances to nearby new customers could be enables by data analysis and product tracking.
    e. Materials from returned end-of-life or broken parts can be returned to the manufacturer to keep the value resources and repurpose these parts or materials.
    f. Share demand predictions with the manufacturer in order to achieve an order-based manufacturing.
    g. Remote software updates for connected appliances for life extension and consumption reduction due to more efficient consumable consumption.
    h. Subscription model through the customer app for energy insights.
3. Cycling strategy:
    a. In collaboration with the manufacturer the use of recycled materials in the product development can be increased. In addition value from waste can be returned into the system by selling waste to companies who can use it as an input. End-of-life products or parts can be returned to the manufacturer for reuse.
    b. Product returning is implied by the fact that case company 2 remains ownership of the product and customers need to return the products by the ending of the contract.
    c. Deliver the products in parts and provide high quality assembly instructions for new products or repairing products.
    d. An improvement could be to great an extra revenue stream from resource trading.
4. Extending strategy:
    a. The case company could participate in co-development of timeless designs of the product and avoid hypes and trend. Meanwhile, co-design quickly obsolete parts for ease of replacement.
    b. An addition to the framework derived from the data of case company 2 is designing connected appliances which enable other circular practices. Another important addition of the framework is offering refurbished products. While refurbishing products is a practices offering refurbished products is missing.
    c. High quality service provision could be improved by providing online training and instructions or digital maintenance support potentially with AR.
    d. Besides offering a care-free subscription model, the case company could offer warranties to increase customer incentive for refurbished or reused appliances.
    e. Customer customization achieved through modular product design and customer can select and combine different product modules to assemble their customized appliance.
5. Intensifying strategy:
    a. The case company could develop a sharing platform where customers can find, reserve and pay for services of the shared product offering
    b. Increase customer education for product sharing.
    c. A potential improvement for case company 2 could be to incorporate dynamic pricing for shared appliances where lower prices are offered per use when energy prices at that moment are lower or regular customers get discounts or other benefits.

d. An addition to the framework could be subscription buy-outs as an extra revenue stream.

4.2.4 Framework verification

The collect data from case company 2 is analysed in order to find empirical evidence to verify the CE-I4.0T Nexus Framework. We set out the practices of case company 2 that includes circular strategies, practices, I4.0T usage along a business model element.

Table 7: Case company 2 practices also given by the CE-I4.0T Nexus Framework

Quotation ID	Codes	Description
Quotation 2:22	Intensifying strategy Circular practice Customer Relationships Industry 4.0 technology Key Partners Revenue Streams Big data, cloud computing & analytics for usage pattern analysis and sharing Consume collaboratively IoT for resources tracking and condition monitoring Product sharing	Case company 2 provides B2B customers with a platform for usage data tracking and pay-per-use capabilities to support product sharing. IoT and big data, cloud computing & analytics enables this practices. This practice is provided in the developed framework with the circular practices; consume collaboratively and product sharing enabled by IoT and Big data, cloud computing & analytics resulting in practices in the customer relationships, key partners and revenue streams business model elements.
Quotation 2:23	Cycling strategy Extending strategy Circular practice Industry 4.0 technology Key Activities Resources & Capabilities AI, ML & AR for predictive maintenance for service support Big data, cloud computing & analytics for usage patterns identification for service improvement, upgrade IoT for data collection of usage and customer needs IoT for resources tracking and condition monitoring Recycle Service support	Case company 2 uses connected products through IoT to track user data, customer needs, resource tracking for recycling and condition monitoring for predictive maintenance wit AI and data analytics and in the future also energy management. These practices align with practices provided by the framework and contribute to the cycling and extending strategy in the business model elements Key activities and Resources & Capabilities.
Quotation 2:24	Greening strategy Circular practice Customer Relationships Industry 4.0 technology Resources & Capabilities Big data, cloud computing & analytics for energy management and optimisation Green-based partnerships IoT for data collection for energy efficiency	Case company 2 sees the opportunity to use IoT and data analytics technologies to enable partnering with utility companies to offer smart energy management for the appliances to their customers. This practice contributes to the greening strategy along the customer relationships and Resources & capabilities business model elements with green-based partnerships as circular practice as also provided by the framework.
Quotation 2:26	Cycling strategy Intensifying strategy Circular practice Channels	Case company 2 uses IoT and AI to enable service support and resource tracking for predictive maintenance, repair and reverse logistics. Subsequently, this data can be shared

	Industry 4.0 technology Resources & Capabilities	with the customer to be transparent about the product location and performance. Thus contributes to the cycling and intensifying strategy along the Channels and Resources & Capabilities business model elements as provided by the framework.
	AI, ML & AR for material/product condition prediction IoT for resources tracking and condition monitoring IoT for connectivity with customers for products return Service support Take-back system/reverse logistics	

The practice derived from the data of case company 2 provides insights of practices that could be developed from the CE-I4.0T Nexus Framework. In comparison to the derived practices from case company 1, case company 2 is employing a practice to track products for reverse logistics which shows empirical evidence for the cycling strategy enabled by I4.0Ts aside from the practices from case company 1.

Table 8: Case company 2 practices not completely provided by the CE-I4.0T Nexus Framework

Quotation ID	**Codes**	**Description**
Quotation 2:14	Intensifying strategy Narrowing strategy	Case company 2 is looking in to practices to track customer satisfaction and support enabled by AI, Big Data, Cloud computing & Analytics to keep customers or sell them more subscriptions and make them ambassadors. These practices contribute to the intensifying strategy along the Key activities and Resources & Capabilities business model elements according to the framework. However, there is not a certain circular strategy that match this practice.
	Industry 4.0 technology Key Activities Resources & Capabilities	
	AI, ML & AR for connectivity provisions through matching algorithms AI, ML & AR for usage and end-of-life prediction AI, ML & AR for consumption patterns analysis for reselling and efficient redistribution Big data, cloud computing & analytics for usage pattern analysis and sharing	

4.2.5 Feedback

The GAP analysis and the applied framework is shared with the case company representatives with the request for feedback. The data gathered can be incomplete or wrongly interpreted the feedback contributed to a more complete understanding of the practices applied at the case company and the usability of the CE-I4.0T Nexus Framework. From case company 2 there was no feedback received at the time of this writing.

4.3 Case company 3

The findings derived from the data of case company 3 are outlined below. The same data analysis are used as in the analysis of case company 1 & 2.

4.3.1 Findings network analysis

The network analysis of the data codes of case company 3 shows a focus on the intensifying strategy. Practices from the intensifying strategy are mentioned 5 times compared to Greening (18x), Narrowing (13x), Cycling (32x), and Extending (35x). Case company 3 offers a leasing and sharing business model only. The network analysis further shows that the networks from the customer relationships, resources & capabilities and revenue streams elements of the business model includes many quotes. A more detailed

look into these quotes results to practices related to practices to enable sharing, leasing and recycling. Resulting from the analysis is the approach of the company to lease out and offering sharing the products. Connectivity is mentioned much and I4.0T quotes are mostly related to technologies that help in customer relationships and revenue streams of case company 3.

4.3.2 CE-I4.0T Nexus Framework Case company 3

Similar to the findings of case company 1 the coded quotations from the data provides the content for the filled-in CE-I4.0T Nexus Framework. The current CBM of case company 3 is shown in Figure 17 in Appendix D. The framework is completed with practices derived indirectly by rephrasing and combining the quotations from the data. In Table 22 in Appendix B the direct quotations, codes and rephrased practices are shown. The framework is filled-in in Miro. The cards include the quotation ID's from which quotations the rephrased practices are derived from. Access the Miro Board through the following link: Miro board link.

4.3.3 GAP analysis

The current CE-I4.0T Nexus Framework of case company 3 is compared to the default framework. With this comparison gaps in the implemented practices of the case company are identified as well as gaps in the default framework. The complete GAP analysis is shown in Table 25 in Appendix F. The key findings are shown below.

Key findings:

1. Greening strategy:
    a. Case company 3 focusses on reducing CO2 pollution and optimizes transportation efficiency. A next step could be using renewable energy for transportation and localize supply chain to reduce transportation needs.
    b. As a part of delivering the products in a sustainable way case company 3 uses recyclable packaging materials.
2. Narrowing strategy:
    a. Case company 3 sells physical products that are difficult to replace by non-physical products.
    b. Not mentioned in the data, but a potential improvement could be using predictive algorithms, customer data and product monitoring to predict product demand and manufacture accordingly.
    c. The case company offers products with technologies to reduce consumable and energy consumption. Case company provides customer centres where customers can learn about correctly using the appliances to improve energy efficiency and product durability.
    d. Improvements can be made in developing new innovative materials to replace non-recyclable or hazardous materials. However, case company 3 is already replacing non-recyclable and hazardous materials the improvement is focused on developing new materials themselves.
    e. Change manufacturing architecture for order-based manufacturing.
    f. Extra revenue streams could be established based on a subscription model. For example, energy efficiency insights subscriptions or predictive maintenance insights.
3. Cycling strategy:
    a. From the filled-in framework we can see that case company 3 is increasing the amount of recycled materials used in their products. However, not mentioned in the data and what could be an improvement is to sell waste parts/materials to other manufacturers for whom these resources are an input stream.
    b. Use end-of-life materials as input for new product manufacturing. The case company has return initiatives, but is not clear if the products are recycled if repair and resell is not possible. It is stated in the data that end-of-life products are being disposed efficiently, but not what that means.

c. The case company could develop a C2C marketplace for reselling used appliances and create new revenue streams by providing warranties, repair services or provide usage or performance data retrieved from remote diagnostics to the new buyers.
d. Products could be designed modularly and the company could provide extensive instruction for customers to assemble their machines themselves in order to save costs. Another advantage is that customers could customize their products with different modules if multiple modules are interchangeable.
e. Additional profits could be created by giving trade-in credit to customers who return their appliances which they could spend on discounts for new appliances or for consumables.

4. Extension strategy:
   a. Case company 3 has practices in place for remanufacturing and reselling used appliances. However it is not clear if the case company works together with partners for these practices. Potential improvements could be in sourcing partners for inspection, repair/remanufacturing and reselling with the aim to localize supply chains and reduce transportation needs. Enabled by remote diagnostics and digital product passports the case company could remain control over the quality of the resold machines.
   b. An addition for the framework is a practices mentioned in the data from case company 3, namely keeping a stock for spare parts of the products to ensure product life extension.
   c. Extra revenue stream enabled by an app channel to sell recommended consumables. This could also be an addition to the framework.
   d. Another worth mentioning practices applied by case company 3 is that they save maintenance and repair costs by providing helpful information and remote support to customers to do the maintenance and repair themselves.
5. Intensifying strategy:
   a. The case company provides leasing and sharing offerings. A platform that provides consumers to find, reserve and pay for the services could be developed by the case company to support sharing and leasing.
   b. The case company could increase creating awareness and educate consumers about the lease and share offerings. These practices are in place however it is not clear if the case company is engaging in education and creating awareness about these offerings.
   c. Dynamic pricing could be introduced for the shared product services. Where prices are adjusted according to current energy prices or for example customer loyalty discounts for regular customers.

4.3.4 Framework verification

The collect data from case company 3 is analysed in order to find empirical evidence to verify the CE-I4.0T Nexus Framework. We set out the practices of case company 3 that includes circular strategies, practices, I4.0T usage along a business model element.

Table 9: Case company 3 practices also given by the CE-I4.0T Nexus Framework

Quotation ID	**Codes**	**Description**
Quotation 3:3	Cycling strategy Extending strategy	Case company 3 has practices in place to monitor usage data and product performance data enabled by IoT, Big data, cloud computing & analytics and uses AI and predictive algorithms to predict necessary maintenance or repair. These practices are also provided by the framework and contribute to the cycling and extending strategies along the Resources & Capabilities business model elements using the circular practices refurbish, recycle, repair/maintain and reuse/resell.
	Circular practice Industry 4.0 technology Resources & Capabilities	
	AI, ML & AR for usage and end-of-life prediction AI, ML & AR for consumption patterns analysis for reselling and efficient redistribution Big data, cloud computing & analytics for usage patterns	

	identification for service improvement, upgrade IoT for resources tracking and condition monitoring Refurbish Reuse/Resell Recycle Repair/maintain	
Quotation 3:15	Extending strategy Greening strategy	The case company offers an app with energy insights for optimization, maintenance insights and remote technical support to maintain or repair the product yourself. These practices are enabled by AI, AR, Big date, cloud computing & analytics and IoT for the connectivity and data collection from the appliances. The combination of these enabling technologies and circular practices are also provided by the framework and contributing to the extending and greening strategy along the channels and key activities business model elements.
	Channels Circular practice Industry 4.0 technology Key Activities	
	AI, ML & AR for predictive maintenance for service support Big data, cloud computing & analytics for energy management and optimisation Design for ease of maintenance Incentivise for long-lasting usage IoT for data collection for energy efficiency IoT for resources tracking and condition monitoring Repair/Maintain Service support	
Quotation 3:16	Extending strategy	The case company is digitalizing their products which makes remote upgrading possible. This practice is also included in the framework and contributing to implement an extending strategy enabled by AI, ML & AR, and IoT.
	Circular practice Industry 4.0 technology Product/Offering Resources & Capabilities	
	AI, ML & AR for upgradability suggestions and dynamic pricing Incentivise for long-lasting usage IoT for resources tracking and condition monitoring Repair/Maintain Service support Upgrade scheme	
Quotation 3:17	Extending strategy	The case company provides remote support from a technician to maintain and repair the product for product life extension goals. Potentially AR could provide even more sophisticated support in the future. This practices is also provided by the framework along the channels business model element and the implementation of the extending strategy enabled by AR with the circular practices design for ease of maintenance, incentivise for long-lasting usage, repair/maintain and service support.
	Channels Circular practice Industry 4.0 technology	
	AI, ML & AR for predictive maintenance for service support Design for ease of maintenance Incentivise for long-lasting usage Repair/Maintain Service support	

The practice derived from the data of case company 3 provides insights of practices that could be developed from the CE-I4.0T Nexus Framework. In comparison to the derived practices from case company 1 & 2, case company 3 employs practices to remotely upgrade the appliances software for longevity and energy efficiency and to provide remote technical support for reparations or maintenance these practices show empirical evidence for extending strategy enabled by I4.0Ts aside from the practices from case company 1 & 2.

Table 10: Case company 3 practices not completely provided by the CE-I4.0T Nexus Framework

Quotation ID	Codes	Description
Quotation 3:4	Extending strategy Industry 4.0 technology Product/Offering	This quotation contains practices that contribute to a circular business model, but the framework does not particularly provide clarity for this practice. The case company is implementing processes to create digital twins of the products to help partners to repair and remanufacture. These practices contribute to implement the extending strategy, however the framework doesn't include I4.0T capabilities to enable this practices nor circular practices.
Quotation 3:28	Greening strategy Circular practice Industry 4.0 technology Product/Offering Incentivise to reduce consumption Sustain natural ecosystem	In this quotation practices are described where the case company implements CPSs, AI and IoT into to product to prevent food waste and optimise energy consumption. The framework doesn't provide insights that help companies ideate this kind of practices, while these practices contribute to circular strategies and can be leveraged upon in the business model.
Quotation 3:29	Greening strategy Circular practice Industry 4.0 technology Product/Offering Big data, cloud computing & analytics for energy management and optimisation Incentivise to reduce consumption Reduce material usage Sustain natural ecosystem	This quotation contains a similar practices as in quotation 3:28, however it adds that the products uses AI to be self-learning. The product understands food preparation better and better the more the product is used and due to connectivity shares the learnings with other products. Also for this practice the framework doesn't provide insights.
Quotation 7:14	Narrowing strategy Industry 4.0 technology Product/Offering AI, ML & AR for usage and end-of-life prediction	This quotation contains a similar product feature example as the quotations 3:28 and 3:29 however now for a washing machine. The principle that is missing in the framework is the same one.

4.3.5 Feedback

The GAP analysis and the applied framework is shared with the case company representatives with the request for feedback. The data gathered can be incomplete or wrongly interpreted the feedback contributed to a more complete understanding of the practices applied at the case company and the usability of the CE-I4.0T Nexus Framework. During the feedback session with the representative of case company 3 a couple of new insights about circular practices and I4.0Ts were given. The GAP analysis was discussed and the representative stated that indeed the CE-I4.0T Nexus Framework does provide many circular practices which are also being tested at case company 3. The framework gives in the representatives opinion clear options for circular practices with the enablement of I4.0Ts, however nothing much is very new. The reason

for gaps between the CE-I4.0T Nexus Framework and the filled-in framework of case company 3 is not because these practices are not considered, but mostly because they are not economically feasible yet or there are legal boundaries. For example, the Joint customer-manufacturer manufacturing practice is legally not allowed, because the products contain electrical components which are not allowed by uncertified professionals to assemble. Electrical product manufacturers need to comply with the WEEE directive which prescribes that the manufacturers return and recycle or dispose old appliances correctly. At case company 3 this is done through a recycle partner network. Taking back an old appliance and remanufacture the appliance is currently more expensive then manufacture a new appliance. However, this does not mean that in the future this won't become an economically feasible possibility. The recycle partners have a way more efficient process. At the moment, the recycling is outsourced however there are an increasing amount of initiatives where case company 3 works together with the recycle partners to retrieve certain parts of EoL appliances and return them to the manufacturer to be reused. The feedback on the GAP analysis can be found in Table 25 in Appendix F.

4.4 Empirical gathered practices

The data from the case studies provides practices in current business settings also provided by the CE-I4.0T Nexus Framework. Although, the findings also shows missing practices in the framework. The practices currently implemented by the case companies are set out over the CE-I4.0T Nexus Framework in Figure 18 in Appendix F. The practices are numbered and the quotations where these practices are derived from are shown in Table 111.

Table 11: Empirical found practices in the CE-I4.0T Nexus Framework

Number in figure 18	Quotations
1	Quotation 1:215
2	Quotation 1:217 Quotation 5:2
3	Quotation 6:1
4	Quotation 6:3
5	Quotation 2:22
6	Quotation 2:23
7	Quotation 2:24
8	Quotation 2:26
9	Quotation 3:3
10	Quotation 3:15
11	Quotation 3:16
12	Quotation 3:17

Many more practices were found in the data of the case companies. Only the practices that could be linked to a business model element, circular practice and I4.0T in the framework are shown. These practices verify that from the CE-I4.0T Nexus Framework practices result which occur in business settings. A closer look at the practices derived from the data shows that the case companies had no Narrowing strategy circular practices implemented. The technologies CPS and blockchain were not mentioned in the data, while IoT, AI and big data, cloud computing & analytics were often mentioned. 12 implemented practices, including all three concepts, also shown in the framework were found implemented at the case companies. Many more practices were found, however these practices missed one of the concepts. Either an enabling technology missed or a circular practice that it could be connected to.

4.5 Findings related to theoretical propositions

The case research started with stating three propositions and three rival arguments to decrease the bias of the researchers and to state the expectations of the outcome of the case company analysis in order to later verify the results. We reflect back on the propositions and rival arguments by showing quotations from the

data and by argue for and against each proposition or rival argument based on the case company data to eventually be able to draw a conclusion.

Proposition 1: "The adoption of industry 4.0 technologies enhances the value proposition, value creation and value delivery of electronic product manufacturing companies through the implementation of circular strategies."

Proposition 2: "Industry 4.0 technologies act as enablers and/or accelerators of circular business models by providing tools and capabilities that facilitate the adoption of circular strategies in electronic product manufacturing companies."

Proposition 3: "The CE-I4.0T Nexus business model tool provides clear and actionable insights that help manufacturing companies identify and leverage the synergies between industry 4.0 technologies and circular strategies, thereby facilitating an efficient transition towards a circular business model."

Rival argument 1: "Implementing Industry 4.0 technology sometimes requires significant financial investments, training, and a period of adjustment. Internal personnel and maybe partners within the company's current value chain often exhibit opposition against the incorporation of new technology (Vermunt et al., 2019). In addition, there is a possibility of encountering compatibility concerns with current systems and workflows, which could potentially hinder the usefulness of industry 4.0 technology. The market's lack of readiness for circular products may lead to a lack of return on investment in industry 4.0 technology (Geissdoerfer et al., 2020)."

Rival argument 2: "The adoption of industry 4.0 technology may have a contradictory outcome. Introducing new hardware to the items may result in a reduction in recyclability compared to the current level of recyclability. Devices consume more electricity rather than consuming less power. The logistical procedures may encounter increased complexity, leading to inefficiencies (Kumar, 2020; Piscicelli, 2023)."

Rival argument 3: "The efficacy of the CE-I4.0T Nexus business model tool in offering clear insights regarding the utilization of industry 4.0 technology for incorporating circular strategies into the business model is uncertain. The tool inadequately considers organizational culture and stakeholder interaction, resulting in overly general recommendations that lack specificity for individual organizations. Consequently, the tool's use falls short (Guldmann & Huulgaard, 2020)."

Nine quotes from the interviews are related to the propositions and are given in Table 122 below.

Table 12: Quotes from the interviews regarding the propositions and rival arguments

Case company:	Quote:	Proposition/Rival argument
1	"Industry 4.0 technologies have lots of potential. It's more about balancing that with what makes sense economically. Lots of technologies are a bit expensive to adopt at the moment. And we're very much at the beginning phase of when it comes to Industry 4.0 surprisingly."	Proposition 1
3	"In our industry it is clear that you have to have some form of recycling through the WEEE directive, but we want more and you start looking into refurbishment and as a premium brand in increasing the quality standards for very long lasting appliances."	Proposition 1
3	"We also developed an connectivity app which gives you energy consumption insights and recommendations about when to use them because	Proposition 1

	energy prices are lower. The app gives predictive maintenance recommendations and if you need to do reparations you can call in a remote technician. The products become more like computers or smartphones which also enables remote upgradability."	
2	"We've got all the consumer data and behaviour and therefore we are also focusing on how to find patterns that a simple excel analysis doesn't give you right, so also dabbling into AI in order to find these patterns and predict"	Proposition 2
2	"Through the remote diagnostics we think that we'll be able to check the true household use and then we would also be able to potentially diagnose or prognose things that could go wrong before it goes wrong and the enabling of utility optimizations."	Proposition 2
2	"I think technology makes it easier for us to do these new blue ocean business models, whether it's circularity or others, but it is not a need. There are also other ways."	Proposition 2
3	"I think industry 4.0 technologies are usually sort of necessary to make a circular strategy happen. If you think about refurbishment you need to know how long, how old and how much an appliance has been used. Nowadays you have connected appliances you can easily understand how often they're used and whether they need some maintenance."	Proposition 2
2	"We don't waste too much time on saying: we don't do it your way, we only do it our way, because we've done that for the last 40 years. We try to be a little bit more open minded, because at the end of the day the competencies that we need and want may be still relatively new and therefore, sometimes preferences would be rather smaller and hungrier partners then too super established companies. Technology integrations becomes an important criteria to look for in partners."	Rival argument 1
3	"It is still a challenge to have the customer accept the appliances being connected. The customer must allow this".	Rival argument 1
3	"You try to get a constant flow of information back and forth with suppliers concerning the digital product pass. I would say this is a work in progress and it's a challenge for the suppliers to get all the information and it's not easy for them to share this information because they have to protect their intellectual property."	Rival argument 1

For all three propositions, the data provide findings to argue for the propositions. The quotes show that the case companies either see the potential of industry 4.0 technologies to enhance their business models or they are already leveraging on I4.0Ts to enhance their business models. The three case companies all offer connected appliances supported by IoT and offer an app with monitoring and data insights features for their appliances. These offerings are and can only be enabled by I4.0T. The practices implemented by the case companies which are also shown in the CE-I4.0T Nexus Framework verifies that the practices provided by the framework are useful practices in reality.

On the other hand, the interviewees also stated supporting quotes for rival argument 1. The interviewees mentioned the importance of approval from the customer to retrieve usage data from the appliances. Moreover, the representatives of case company 1 and 3 argued that other factors like quality, hygiene and price are drivers for customers to buy their products not the circularity or sustainability of their offer. No support is found in the data for rival argument 2. There is no direct support for rival argument 3 in the data, however 12 practices over three case companies are found that directly relates to practices provided by the framework that includes all three concepts; circular practices, business model element and I4.0T capabilities. If we would have excluded the mentioning of I4.0T capabilities many more practices from the data would have been related to the practices provided by the framework. Some practices provided by the framework are not related to industry 4.0 technologies which make it unclear how companies can effectively leverage I4.0T capabilities to implement these practices. Furthermore, the case companies have practices in place enabled by the capabilities of I4.0T, but the framework does not provide a similar practices or enabling I4.0T capabilities. Like CPS capabilities in the products for energy optimization and consumables reduction.

All in all, the framework does offer clear insights on how to utilize I4.0T capabilities to implement circular practices along the business model and empirical evidence is found in the data. We have to take into account that only one interview per case company has been conducted and that more examples for implemented circular practices with the enablement of I4.0T capabilities are existing at the case companies.

4.6 Conclusion case company findings

The findings of Case Companies 1, 2, and 3 demonstrate varying implementation levels and improvement areas in their circular practices. Interview data and publicly available information form the case companies have been analysed in three ways. By analysing the networks between the codes, by applying the CE-I4.0T Nexus Framework to the case companies, and by conducting a GAP analysis between the current filled-in framework of the case companies and the default framework. Resulting from these analysis the following improvements are provided by the framework. Case Company 1 can enhance their transportation by using renewable energy and green marketing support while leveraging AI for demand management and exploring subscription models. Case Company 2 should focus on sustainable transportation, co-design with manufacturers, and data-driven demand prediction. Case Company 3 emphasizes reducing CO2 emissions, optimizing transportation, and developing a C2C marketplace for used products. All companies could further localize supply chains, increase recycled material usage, and promote customer engagement through digital platforms and educational initiatives. By enhancing resource efficiency, exploring new revenue streams, and leveraging technology, these companies can reduce environmental impact and foster a more circular economy. The overarching goal is to improve circular practices, engage consumers, and achieve a balanced approach to economic and environmental objectives.

We gathered empirical evidence for the framework, based on the three-step coding strategy by Gioia et al. (2013), organizes circular strategies, practices, and Industry 4.0 technologies (I4.0Ts) into an aggregated structure for empirical data analysis. Case Company 1 employs IoT, AI, and big data to enhance energy efficiency, product durability, and sustainable design, providing strong evidence for the CE-I4.0T Nexus Framework. However, some innovative practices, such as material selection algorithms and smart appliances for energy and resource optimization, are not fully encompassed by the framework. Case Company 2 uses I4.0Ts for product sharing, predictive maintenance, and smart energy management, aligning well with the framework, though the framework lacks specific circular strategies for customer satisfaction tracking. Similarly, Case Company 3 leverages I4.0Ts for predictive maintenance, remote support, and digital twin creation, further validating the framework, yet some advanced practices like self-learning appliances fall outside the framework's scope. The verification highlights the framework's applicability but also indicates areas for refinement to fully capture innovative circular practices enabled by I4.0Ts. Overall, the analysis underscores the need for continuous framework updates to accommodate emerging technologies and practices, ensuring comprehensive support for circular business models. The available evidence supports the three propositions, demonstrating that Industry 4.0 technologies effectively improve business models and enable the implementation of circular practices. Nevertheless, rival points of view emphasize the difficulties that arise, such as the acceptability of customers and the problems related to integration. In

general, although the CE-I4.0T Nexus Framework is successful in offering practical insights, it needs additional improvement to tackle certain organizational difficulties and fully utilize the capabilities of Industry 4.0.

5. Discussion

This research made a contribution in two ways. The findings show empirically evidence for the CE-I4.0T Nexus Framework. Similar practices as provided by the framework are indeed present in business settings. The connections made in the framework between circular strategies, practices, I4.0T capabilities and the business model canvas are valid in business settings. From the researchers perspective does the framework give a clear overview of these connections and these connection are also found in the data from the case companies. This strengthen the quality of the framework. Secondly, three companies have been studied and data has been collected of circular practices and strategies electronic product manufacturers are implementing. This data can be used for future research of the current status of the CE. This was not a goal of this research, but it contributes to the research field of the circular economy and circular business models.

5.1 Contribution to the literature

This thesis contributes to the literature of CBMs and the CE. This thesis strengthens the proposed combination of Tripodis (2023) of three CE concepts: CBMs, circular practices & I4.0Ts. In this research we have found evidence that these concepts in business settings indeed are related. Companies are indeed using I4.0T specifically to enable circular practices. Through the literature review we have brought different research streams within the CE space together. For example, the CBM literature and the I4.0T literature.

5.2 Framework enrichment

This thesis gives recommendations for the enrichment of the CE-I4.0T Nexus Framework. The framework has the potential of helping companies ideating circular practices, enabling them using I4.0Ts while leveraging on the practices along their business model. The base framework gives already relevant recommendations, however we have found additional practices at the case companies which can enrich the framework. A proposed improvement is to include practices that propose implementation of I4.0Ts in the products itself which enable circular practices. An example from the findings of the case companies are smart sensors and actuators in combination with AI to reduce energy consumption in ovens. Another example derived from the case company data is the practice to keep stocks of spare parts for a longer period to ensure repair possibilities of appliances to lengthen product life-time. From the case company data of case company 2 an extra revenue stream could be added to the framework, namely the buy-out of subscription contracts where the ownership of the product transfers from the manufacturer to the customer. Furthermore, we would advise to include the I4.0T capabilities in the table also along the business model elements. Right now the CE-I4.0T Nexus Framework table only shows the I4.0T capabilities per circular strategy, but it is possible to also show the enabling capabilities of the different I4.0Ts for each practices under the different business model elements. This will give an even clearer picture for future usage by companies.

6. Conclusion

6.1 Summary and research question answering

The objective of this Master Thesis research was to validate the conceptual framework developed by Tripodis (2023). The literature review provided an in-depth discussion of foundational concepts such as business models, circular business models (CBMs), circular strategies, and Industry 4.0 technologies, examining their interrelationships as derived from existing literature. A business model encompasses the value proposition, value creation and delivery, and value capture. For this research the business model canvas as described by Osterwalder & Pigneur (2010) consisting of the three value components and nine business model elements formed the foundation of the framework. Innovating business models is crucial for maintaining competitiveness as it involves a comprehensive overhaul of the strategies used to generate, deliver, and capture value.

Sustainable business models aim to balance economic, environmental, and social value by minimizing resource use and actively involving stakeholders. Circular business models, a subset of sustainable business models, focus on the reuse, repair, recycling, and refurbishment of resources to extend their lifespan, known as R-strategies. These models enhance the value proposition by emphasizing resource efficiency and sustainability.

The literature review answered the sub-research question: How can circular strategies influence the value proposition, value creation, and value delivery of a company? With that circular strategies can significantly influence a company's value proposition by promoting resource efficiency, sustainability and offer long lasting products or new ways of offering as for example product-as-a-service, which are increasingly important to consumers. By implementing circular practices such as closing, extending, intensifying, and dematerializing resource loops, companies can improve resource efficiency, reduce costs, and enhance their value creation and delivery processes and decrease their environmental impact. This leads to improved product lifecycle management, which not only boosts the company's market appeal but also aligns with broader sustainability goals. Circular strategies additionally provide new ways of value capture with revenue from subscriptions or charge per use revenue streams which enable continuing value capture instead of one time value capture.

Industry 4.0 technologies such as Cyber-Physical Systems, Big Data, Cloud Computing & Analytics, Internet of Things, Additive Manufacturing, Machine Learning, Artificial Intelligence, Blockchain, and Simulations can accelerate or enable the transition to circular business models. To answer the second sub-research question: How can Industry 4.0 Technologies accelerate the transition towards circular business models? Industry 4.0 technologies facilitate real-time monitoring, data analysis, and process optimization, all of which are vital for implementing circular strategies. For example, the integration of CPS and IoT enhances connectivity and data collection. Big Data and AI provide valuable insights for optimizing efficiency and reducing waste. Additive Manufacturing supports just-in-time production, minimizing inefficiency, while Blockchain ensures transparency in managing a product's lifecycle.

Furthermore, in the literature review we have set out the HCBMT-Framework a conceptual framework developed by a former Delft University of Technology student. Based on a comprehensive literature review Tripodis (2023) developed the HCBMT-Framework with the aim to give a clear overview of the concepts circular strategies, circular practices, industry 4.0 technologies along a business model canvas and their interrelations. By providing this framework Tripodis wanted to contribute to companies trying to navigate the CE and ideating way to transition to a CBM. However, this framework missed empirical evidence. In this thesis the focus lay on finding empirical evidence for the usability of the framework in business settings. While Tripodis contribution was literature based and very comprehensive, this work will add to the quality of the framework by finding empirical evidence. We gathered empirical evidence to evaluate the circular practices and I4.0T usage at real companies operating in the electronic products industry.

The case company research included researching three case companies from the electronic household appliances industry. Data was gathered through interviews and by analysing publicly available documents. The data analysis included coding the data with predetermined codes in order to visualize the quotations in a network analysis with which we could fill-in the vacant CE-I4.0T Nexus Framework. This enabled performing a GAP analysis between the CE-I4.0T Nexus Framework and the filled-in frameworks from each case company. By conducting the GAP analysis similarities and discrepancies became visual. When validating a conceptual framework you want to find similarities between the theoretical framework and reality. Discrepancies on the other side show space for improvement.

In total we found 12 similar practices at the case companies as the CE-I4.0T Nexus framework provides. The practices contained a circular practices enabled by I4.0T and leveraged upon a business model element. The CE-I4.0T Nexus framework also provides circular practices without providing how this practices could be enabled by an I4.0T. Similar practices are found in the data of the case companies not enabled by I4.0Ts, however we did not include these as evidence for the usability of the framework as it is not suggesting assistance of I4.0T for implementing these practices.

All three case companies have implemented or are intended to implement a greening practices in which they partner with energy companies for energy consumption insights to them and to the customer for energy consumption of their products tracked by smart sensors and enabled by IoT for connectivity. AI enables predictions for energy costs at certain times and communicates this automatically to the customer to advice when to use the product energy cost wise efficiently. The CE-I4.0T Nexus Framework provides this practices as well through the greening strategy with green-based partnerships as circular practices and enabling capabilities from IoT describes as 'IoT for data collection for energy efficiency' and the enabling capabilities of Big data, cloud computing & analytics described as 'Big data, cloud computing & analytics for energy management and optimisation'. The framework shows that this practice can be implemented in the key activities business model element with the default practice 'Create awareness about green actions and incentivise customers', in the key partners business model element with the default practice 'Collaborative initiatives to restore and regreen natural ecosystem' and in the channels business model element with 'Sustainable insights promotion through social media for customer and stakeholder education'.

The CE-I4.0T Nexus framework provides extending practices for designing durable products using simulation software and big data, cloud computing & analytics to optimize the design of the product for achieve a long usage product cycle. I4.0T supporting extending the product usage by predictive maintenance enabled by AI and IoT for usage monitoring. Evidence for similar practice implemented by the case companies has been found. Case company 1 and 3 are using big data and predictive models to optimise the life cycle of the products in the design phase of the products. The data is retrieved from the connected products enabled by IoT. All three the case companies are using data and AI to predict maintenance and informs customers to perform maintenance to ensure product endurance. Furthermore, the same data is used to understand the repair or maintenance needs of the products when returned and prepare for reselling by refurbishment. These practices are also provided by the framework in the extending strategy with the extending practices 'repair/maintain', 'remanufacture/refurbish', 'design for durability/longevity' and 'incentivise for long-lasting usage'. The I4.0T capabilities described in the CE-I4.0T Nexus Framework which align with the practices found at the case companies are: 'IoT for data collection of usage and customer needs', 'Big data, cloud computing & analytics for usage patterns identification for service improvement and upgrades', 'AI, ML & AR for predictive maintenance for service support' and 'simulation software for conceptual design for longevity and performance checks'. The practices shown in the framework and also found in the data from the case companies are: 'product is designed in a durable way to last longer' in the product/service business model element, 'initiate repair plans and accompany products with service' in the key activities business model element, 'technological capabilities and life prediction models which will ensure product life extension' in the resources & capabilities business model element. In the data from case company 3 also upgrade practices are found enabled by I4.0Ts which are also provided by the framework in the extending strategy and described in the framework in the key activities business model element by the practice 'provide upgrade plan to gain commitment' and 'upgrade to new modes with additional features and high quality' in the product/service business model element.

All three case companies are active in the electrical product industry and are bound by the WEEE directive which obliges them to recycle old product. The case companies all show the intension to take-back old appliances and improve this system using I4.0Ts. The practices provided by the CE-I4.0T Nexus Framework and found in the data at all three case companies are: 'Second-hand/second-chance products which are being redistributed to the market for reselling and reuse' and 'products made of recycled elements/materials/components' from the product/service business model element, and 'reassure that recycled or second-life products have good quality and can serve the intended functionalities and purpose' from the key activities business model element. I4.0T capabilities which the case companies use to enable these practices are 'IoT for resource tracking and condition monitoring', 'AI, ML & AR for material/product condition prediction' and 'AI, ML & AR for consumption patterns analysis for reselling and efficient redistribution'.

Furthermore, similar practices mentioned in the CE-I4.0T Nexus Framework in the intensifying strategy are also found in the data of the case companies. Only at case company 2 practices were found which

included the enablement of the intensifying practice with I4.0Ts. Case company 2 provides B2B customers with a platform for usage data tracking and pay-per-use capabilities to support product sharing. The I4.0T capabilities shown in the framework and implemented by case company 2 are 'IoT for resource tracking and condition monitoring', 'big data, cloud computing & analytics for real-time data exchange and connectivity', 'big data, cloud computing & analytics for usage pattern analysis and sharing'. Case company 2 has the practice 'connection channels and platform for material/products sharing in a B2B basis' in the key partners business model element from the framework in place.

All in all we can conclude that circular practices enabled by I4.0T capabilities provided by the CE-I4.0T Nexus Framework are implemented in business settings. In this research we tried to gather empirical evidence for the usability of the CE-I4.0T Nexus Framework by analysing companies in the electronic products industry and searching for similar strategies and practices as provided by the framework. The research question we want to draw a conclusion for is:

"How can the CE-I4.0T Nexus Framework assist in the transition towards circular business models for Electronic products manufacturing companies?"

As stated in the literature review circular strategies can significantly enhance the value proposition, value creation & delivery and value capture of the company's business model. By promoting resource efficiency, sustainability and offering long lasting products. I4.0Ts facilitate real-time monitoring, data analysis, and process optimization all of which are vital for circular practices. I4.0T capabilities could enable or accelerate circular practices like product and resource tracking by IoT for reverse logistics. IoT for connectivity and real-time product monitoring and AI for predictive maintenance. The CE-I4.0T Nexus Framework includes these practices and I4.0T capabilities to show their relationships and help ideating circular practices to transition towards a CBM.

We can conclude from the case company findings that from the CE-I4.0T Nexus Framework it should be possible to derive circular practices enabled by I4.0Ts and implement them along the business model. Empirical evidence is found for similar practices as provided by the framework. Thus it could be implied that the CE-I4.0T Nexus Framework can assist electronic products manufacturing companies with ideating new circular practices which will result in incorporating circular strategies which can be leveraged upon in the company's business model. Furthermore, the framework shows how these practices can be enabled by the capabilities of Industry 4.0 Technologies. However, due to the restricted data we were able to retrieve and the approach of the research it is hard to state anything about the usability of the framework and explanation is set out in the limitations and recommendations.

6.2 Relevance to Management of Technology

This thesis closely aligns with the themes of the Management of Technology (MoT) program, especially in the areas of circular strategies, management, and new Industry 4.0 technologies. It investigates the implementation of circular strategies and technologies within circular business models (CBMs) using a thorough qualitative research strategy. This aids in understanding how businesses may effectively implement circular strategies and leverage Industry 4.0 technology to successfully move to circular business models and practices.

Building on the MoT program's principles, this study emphasizes the significance of new technologies in building circular strategies and offers insights into how CBM aspects should be designed and are designed in business settings. The use of these concepts in the business contexts reveals how technology and strategy are used to drive the circularity transformation. Thus, technology management, as described in this paper, can enable the adoption of circular practices, overcome environmental concerns, minimize resource consumption, and enhance long-term competitive advantage.

The research adheres to the MoT program's concepts and curriculum, drawing on knowledge gained from its core courses. The Research Methods course helped develop a rigorous research strategy, the Leadership and Technology Management course provided insights into management strategies used in a variety of company settings. Furthermore, the principles from the Technology, Strategy, and Entrepreneurship and

Emerging & Breakthrough Technologies courses provided important guidelines for the technological components of this project. With this knowledge, the thesis examines the technological capabilities of CBM components and demonstrates how technology affects a company's strategy. Overall, the thesis has a strong connection to the MoT curriculum and is consistent with the program's objectives of exploring the intersection of technology and business management, understanding technology as a corporate resource, and applying scientific methods to analyse current trending topics.

6.3 Limitations

This research has shown empirical evidence for the usability of the CE-I4.0T Nexus Framework and how the framework can assist electronic product manufacturing companies in ideating practices to transition to a circular business model. Additionally, the findings of the case company data also shows some limitations of the framework and missing elements.

The framework in table format shows per circular strategy the I4.0T capabilities, but doesn't include them in the practices shown in each business model element. When applying the CE-I4.0T Nexus Framework to the case companies it was unclear how certain circular practices can be enabled by I4.0Ts. While in the framework development the I4.0T are connected to the practices along the business model elements. This resulted in that less practices employed by the case companies could be linked to the CE-I4.0T Nexus Framework. The framework can be enhanced to include in the practices mentioned under the business model elements the enabling I4.0T capabilities. This would also provide clearer recommendations for implementing the practices for companies.

Further limitations are regarding the research itself. The research included three case companies. From each case company only one interview was conducted. In order to get a full picture of all the circular practices and industry 4.0 technology usage more interviews with multiple representatives is recommended. During the interviews certain topics were not complete thoroughly discussed as the interview time was also bound. This resulted in that in the data some circular practices were mentioned however the enabling technology was not discussed, while it could be implied that a I4.0T must be in place to enable the circular practice. More interview rounds give the opportunity to ask questions to fill in these gaps and will result in a more comprehensive picture of the case companies and eventually more empirical evidence for the framework. Beforehand it was clear that the time was limited and unless this restriction there has still been found empirical evidence that verifies that the CE-I4.0T Nexus Framework does provide circular practices that can be observed in business settings.

This research contributes to empirically verify the CE-I4.0T Nexus framework. The framework was derived from the literature, but is now strengthened by empirical evidence.

6.4 Future Research

In future research, I would recommend to extent the empirical evidence for the CE-I4.0T Nexus Framework. In this thesis we have shown that empirical evidence can be found, however the amount of case companies were limited as well as the amount of data that could be gathered during only one interview. If future researchers work further on this topic I would firstly recommend to change the table format of the framework. As Tripodis (2023) in his work has set out how I4.0Ts capabilities can influence each business model element, he left this part out of the final table. In my research I experienced this as a disadvantage as when the I4.0T in the framework table will be included in the practices in the business model elements more empirical evidence could be verified and it would give more clarity to future companies who will work with the framework. With more and more empirically found evidence for the framework eventually a strong framework can be developed. In a later study the verified framework could be applied at a case company who not yet has circular practices or strategies in place. With a case approach where the case company gets access to the framework and starts ideating new circular practices the usability of the framework can be analysed. I would start with analysing the business model before having access to the CE-I4.0T Nexus Framework. Then grant access to the framework and track the ideation process. Eventually the usability can be measured through interviewing different company representatives which were granted access to the CE-I4.0T Nexus Framework.

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Appendix A

Table 13: Publication analysis for the Unit of analysis determination

Source	Industry	Search Quary	Number of Articles
Scopus	Automotive	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (automotive AND industry) AND TITLE-ABS-KEY (industry 4.0)) AND (LIMIT-TO (DOCTYPE , "ar"))	13
Scopus	Automotive	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (automotive) AND TITLE-ABS-KEY (digital AND technologies)) AND (LIMIT-TO (DOCTYPE , "ar"))	5
Scopus	Automotive	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (automotive)) AND (LIMIT-TO (DOCTYPE , "ar"))	233
Scopus	Automotive	(TITLE-ABS-KEY (circular AND business AND models) AND TITLE-ABS-KEY (automotive)) AND (LIMIT-TO (DOCTYPE , "ar"))	26
Wiley Online	Automotive	"Circular economy" in Abstract and "automotive" in Abstract and "Industry 4.0" in Abstract	1
Wiley Online	Automotive	"Circular economy" in Abstract and "automotive" in Abstract and "Digital Technologies" in Abstract	0
Wiley Online	Automotive	"Circular economy" in Abstract and "automotive" in Abstract	15
Wiley Online	Automotive	"Circular business models" in Abstract and "automotive" in Abstract	0
Google Scholar	Automotive	allintitle: Circular Economy Automotive Industry 4.0	3
Google Scholar	Automotive	allintitle: Circular Economy Automotive Digital Technologies	0
Google Scholar	Automotive	allintitle: Circular Economy Automotive	85
Google Scholar	Automotive	allintitle: Circular business model Automotive	0
Scopus	Electronic products	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (electronic AND products) AND TITLE-ABS-KEY (industry 4.0)) AND (LIMIT-TO (DOCTYPE , "ar"))	5
Scopus	Electronic products	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (electronic AND products) AND TITLE-ABS-KEY (digital AND technologies)) AND (LIMIT-TO (DOCTYPE , "ar"))	5
Scopus	Electronic products	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (electronic AND products) AND TITLE-ABS-KEY (industry 4.0)) AND (LIMIT-TO (DOCTYPE , "ar"))	5
Scopus	Electronic products	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (electronic AND products) AND NOT TITLE-ABS-KEY (automotive) AND NOT TITLE-ABS-KEY (ev AND battery)) AND (LIMIT-TO (DOCTYPE , "ar"))	309

Scopus	Electronic products	(TITLE-ABS-KEY (circular AND business AND models) AND TITLE-ABS-KEY (electronic AND products) AND NOT TITLE-ABS-KEY (automotive) AND NOT TITLE-ABS-KEY (ev AND battery)) AND (LIMIT-TO (DOCTYPE , "ar"))	33
Wiley Online	Electronic products	"Circular economy" in Abstract and "Electronic products" in Abstract and "Industry 4.0" in Abstract	0
Wiley Online	Electronic products	"Circular economy" in Abstract and "Electronic products" in Abstract and "Digital Technologies" in Abstract	0
Wiley Online	Electronic products	"Circular economy" in Abstract and "Electronic products" in Abstract	38
Wiley Online	Electronic products	"Circular business models" in Abstract and "Electronic products" in Abstract	1
Google Scholar	Electronic products	allintitle: Circular Economy Electronic Products Industry 4.0	0
Google Scholar	Electronic products	allintitle: Circular Economy Electronic Products Digital Technologies	0
Google Scholar	Electronic products	allintitle: Circular Economy Electronic Products	10
Google Scholar	Electronic products	allintitle: Circular Business Model Electronic Products	0
Scopus	Battery manufacturing	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (battery) AND TITLE-ABS-KEY (industry 4.0)) AND (LIMIT-TO (DOCTYPE , "ar"))	4
Scopus	Battery manufacturing	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (battery) AND TITLE-ABS-KEY (digital AND technologies)) AND (LIMIT-TO (DOCTYPE , "ar"))	2
Scopus	Battery manufacturing	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (battery) AND TITLE-ABS-KEY (industry 4.0)) AND (LIMIT-TO (DOCTYPE , "ar"))	4
Scopus	Battery manufacturing	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (battery) AND NOT TITLE-ABS-KEY (automotive)) AND (LIMIT-TO (DOCTYPE , "ar"))	437
Scopus	Battery manufacturing	(TITLE-ABS-KEY (circular AND business AND models) AND TITLE-ABS-KEY (battery) AND NOT TITLE-ABS-KEY (automotive)) AND (LIMIT-TO (DOCTYPE , "ar"))	36
Wiley Online	Battery manufacturing	"Circular economy" in Abstract and "Battery" in Abstract and "Industry 4.0" in Abstract	0
		"Circular economy" in Abstract and "battery" in Abstract and "Digital Technologies" in Abstract	0
Wiley Online	Battery manufacturing	"Circular economy" in Abstract and "Battery" in Abstract	56
Wiley Online	Battery manufacturing	"Circular economy" in Abstract and "Battery" in Abstract and "NOT automotive" in Abstract	54
Wiley Online	Battery manufacturing	"Circular business models" in Abstract and "Battery" in Abstract	0

Google Scholar	Battery manufacturing	allintitle: Circular Economy Battery Industry 4.0	0
Google Scholar	Battery manufacturing	allintitle: Circular Economy Battery Digital Technologies	0
Google Scholar	Battery manufacturing	allintitle: Circular Economy Battery	76
Google Scholar	Battery manufacturing	allintitle: Circular Business model Battery	6
Scopus	Wind turbines	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (wind AND turbine) AND TITLE-ABS-KEY (industry 4.0)) AND (LIMIT-TO (DOCTYPE , "ar"))	1
Scopus	Wind turbines	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (wind AND turbine) AND TITLE-ABS-KEY (digital AND technologies)) AND (LIMIT-TO (DOCTYPE , "ar"))	0
Scopus	Wind turbines	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (wind AND turbine) AND TITLE-ABS-KEY (manufacturing)) AND (LIMIT-TO (DOCTYPE , "ar"))	10
Scopus	Wind turbines	(TITLE-ABS-KEY (circular AND business AND models) AND TITLE-ABS-KEY (wind AND turbine)) AND (LIMIT-TO (DOCTYPE , "ar"))	4
Wiley Online	Wind turbines	"Circular economy" in Abstract and "Wind turbines" in Abstract and "Industry 4.0" in Abstract	0
Wiley Online	Wind turbines	"Circular economy" in Abstract and "Wind turbines" in Abstract and "Digital Technologies" in Abstract	0
Wiley Online	Wind turbines	"Circular economy" in Abstract and "Wind turbines" in Abstract	1
Wiley Online	Wind turbines	"Circular business models" in Abstract and "Wind turbines" in Abstract	0
Google Scholar	Wind turbines	allintitle: Circular Economy Wind turbines Industry 4.0	0
Google Scholar	Wind turbines	allintitle: Circular Economy Wind turbines Digital Technologies	0
Google Scholar	Wind turbines	allintitle: Circular Economy Wind turbines	6
Google Scholar	Wind turbines	allintitle: Circular business models Wind turbines	0
Scopus	Solar panels	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (solar AND panel AND industry) AND TITLE-ABS-KEY (industry 4.0)) AND (LIMIT-TO (DOCTYPE , "ar"))	0
Scopus	Solar panels	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (solar AND panel) AND TITLE-ABS-KEY (digital AND technologies)) AND (LIMIT-TO (DOCTYPE , "ar"))	2
Scopus	Solar panels	(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (solar AND panel) AND TITLE-ABS-KEY (manufacturing)) AND (LIMIT-TO (DOCTYPE , "ar"))	4

Scopus	Solar panels	(TITLE-ABS-KEY (circular AND business AND models) AND TITLE-ABS-KEY (solar AND panel)) AND (LIMIT-TO (DOCTYPE , "ar"))	5
Wiley Online	Solar panels	"Circular economy" in Abstract and "Solar panel" in Abstract and "Industry 4.0"	0
Wiley Online	Solar panels	"Circular economy" in Abstract and "Solar panel" in Abstract and "Digital Technologies" in Abstract	0
Wiley Online	Solar panels	"Circular economy" in Abstract and "Solar panel" in Abstract	5
Wiley Online	Solar panels	"Circular business models" in Abstract and "Solar panel" in Abstract	0
Google Scholar	Solar panels	allintitle: Circular Economy solar panels industry 4.0	0
Google Scholar	Solar panels	allintitle: Circular Economy solar panels Digital Technologies	0
Google Scholar	Solar panels	allintitle: Circular Economy solar panels	4
Google Scholar	Solar panels	allintitle: Circular business models solar panels	0

Table 14: Industry 4.0 Technologies

Technology:	**Reference:**
Cyber-physical systems (CPS)	(Lopes de Sousa Jabbour et al., 2018) (Rajput & Singh, 2020) (Nascimento et al., 2019)
Big Data, Cloud computing & analytics	(Lopes de Sousa Jabbour et al., 2018) (Moreno & Charnley, 2016) (Pagoropoulos et al., 2017) (Hennemann Hilario Da Silva & Sehnem, 2022) (Rajput & Singh, 2020) (Bag & Pretorius, 2020) (Nascimento et al., 2019) (Toth-Peter et al., 2023)
Internet of Things (IoT)	(Lopes de Sousa Jabbour et al., 2018) (Pagoropoulos et al., 2017) (Bag et al., 2021) (Rajput & Singh, 2020) (Rosa et al., 2019) (Hennemann Hilario Da Silva & Sehnem, 2022) (Toth-Peter et al., 2023)
Additive manufacturing (AM)	(Lopes de Sousa Jabbour et al., 2018) (Rosa et al., 2019) (Tavares et al., 2020) (Hennemann Hilario Da Silva & Sehnem, 2022) (Nascimento et al., 2019) (Toth-Peter et al., 2023)
Machine Learning (ML) & Artificial Intelligence (AI)	(Pagoropoulos et al., 2017) (Hennemann Hilario Da Silva & Sehnem, 2022) (Akanbi et al., 2020) (Lieder et al., 2020) (Toth-Peter et al., 2023)
Blockchain	(Kouhizadeh et al., 2019) (Ma et al., 2020) (Hennemann Hilario Da Silva & Sehnem, 2022)

	(Toth-Peter et al., 2023)
Simulations	(Rosa et al., 2019) (Tavera Romero et al., 2021)

Table 15: I4.0T enabled circular practices per Business model component

Business Model components	Industry 4.0 Technology	Enabling circular practice	Reference
Value proposition	Internet of things	Enables product customisation, collaboration for design and facilitates services development for PSS	(Lopes de Sousa Jabbour et al., 2018)
		Enables tracking of materials/products and flow mapping ensuring recycled materials quality for reuse	(Rosa et al., 2019)
		Supports data collection regarding customer needs	(Lopes de Sousa Jabbour et al., 2018)
		Supports data collection regarding energy consumption	(Lopes de Sousa Jabbour et al., 2018)
	Big Data & Analytics & Cloud computing	Facilitates analysis of product requirements and optimises design processes to reduce resource utilization	(Toth-Peter et al., 2023)
		Promotes reuse by enabling the development of "product passports"	(Pagoropoulos et al., 2017)
		Facilitates real-time data collection for process or design optimisation and resource efficiency	(Toth-Peter et al., 2023)
		Enables live product performance monitoring allowing for modifications to increase customer satisfaction	(Lopes de Sousa Jabbour et al., 2018; Toth-Peter et al., 2023)
		Supports upgradeability and constant software support through platform integration	(Lopes de Sousa Jabbour et al., 2018; Toth-Peter et al., 2023)
		Enhances customer experience through live tracking, logistics monitoring and product-service performance	(Lopes de Sousa Jabbour et al., 2018)
	ML & AI & AR	Processes optimisation and energy consumption minimization through prediction models based on previously produced products	(Pagoropoulos et al., 2017; Toth-Peter et al., 2023)
		Enhance customer experience through virtual product demonstrations and training	(Pagoropoulos et al., 2017; Toth-Peter et al., 2023)
		Prediction models for product performance to reduce deficiencies and keep customer satisfied	(Pagoropoulos et al., 2017; Toth-Peter et al., 2023)
	Blockchain	Enables reliable informational of financial transactions with verifiability and security	(I. S. Khan et al., 2021)
	CPS & AM	Enables remanufacturing and assembly/disassembly in an energy and	(Rosa et al., 2019)

		resources efficient manner based on automated process control	
		Allows for interaction between manufacturing workforce and robots for process optimisation	(Rosa et al., 2019)
		Enhances customization and connects customers with product design, prototyping, assembly and direct material collection from suppliers	(Nascimento et al., 2019; Toth-Peter et al., 2023)
		Reduces energy consumption in terms of transportation due to mobile options, brings customer closer to production	(Nascimento et al., 2019)
		Supports quick product repair and printing of damaged parts for product life extension	(Lopes de Sousa Jabbour et al., 2018; Nascimento et al., 2019)
		Efficient maintenance processes through automation	(Lopes de Sousa Jabbour et al., 2018; Nascimento et al., 2019)
	Simulations	Company-customer digital product co-development to increase customisability and enhance proposition while reducing rework and waste	(Rosa et al., 2019)
		Supports digital design of products for easier recycling and repurposing	(Rosa et al., 2019)
Value creation & delivery	IoT	Facilitate data collection through RFID, sensors and barcodes	(Lopes de Sousa Jabbour et al., 2018; Pagoropoulos et al., 2017)
		Facilitates resource flow tracking through the life cycle and along the value chain	(Pagoropoulos et al., 2017)
	Big Data & Analytics & Cloud computing	Connection between service providers and users via communication platform, hyperconnectivity.	(Toth-Peter et al., 2023)
		Large data processing as collected by IoT for product lifecycle tracking and resource use optimization	(Toth-Peter et al., 2023)
		Analysis of energy consumption (through sensors) and optimization for increasing renewable share and reduce overall cost	(Toth-Peter et al., 2023)
		Updated and live data to keep a balances between supply and demand for resource efficiency	(Lopes de Sousa Jabbour et al., 2018)
	ML & AI & AR	Prediction models for remaining useful life and maintenance planning for product use extension	(Rosa et al., 2019)
	Blockchain	Secures product traceability and accuracy in data collection from sensors and IoT	(I. S. Khan et al., 2021)
		Offers transparency in information flows especially in complex supply chains with multiple connections and actors	(Toth-Peter et al., 2023)
		Supports reverse logistics systems with transparency and enhances customers	(Toth-Peter et al., 2023)

		trust and confidence regarding processes and product quality	
	CPS & AM	Automation of production and waste shorting to minimize energy consumption and increase material separation	(Lopes de Sousa Jabbour et al., 2018)
		3D printing facilitates waste repurposing and material reuse for new product development which reduces energy and resources emissions.	(Nascimento et al., 2019)
	Simulations	Facilitates prognostics models for process optimization and product lifecycle management through digital trails	(Rosa et al., 2019; Toth-Peter et al., 2023)
		Allow for performance calculations in closed-loop supply chains and optimization for maximum resource efficiency	(Rosa et al., 2019; Toth-Peter et al., 2023)
		Facilitates the development of product digital twins in the design and conceptualization stage and indicate potential value creation which reduces waste needed otherwise for trails	(Rosa et al., 2019; Toth-Peter et al., 2023)
Value capture	IoT	Data collection for process or product optimization purposes which will reduce overall cost.	(Toth-Peter et al., 2023)
		Supports platform and app integration for sharing purposes creating new revenue streams	(Lopes de Sousa Jabbour et al., 2018; Rosa et al., 2019)
	Big Data & Analytics & Cloud computing	Provides open-source capabilities and data access for recycled products which enhances resources trading (new revenue stream)	(Lopes de Sousa Jabbour et al., 2018; Rosa et al., 2019)
		Operating cost reduction for storing and analysis of data	(Pagoropoulos et al., 2017)
	ML & AI & AR	Financial predictions and efficient optimisation of processes for energy, resources and cost reduction	(Toth-Peter et al., 2023)
	Blockchain	Facilitates safe contract and connections between customer, supplier and company which reduces digitalization risks	(I. S. Khan et al., 2021)
		Transparent financial transactions which increase customers trust and willingness to pay	(I. S. Khan et al., 2021)
	CPS & AM	New revenue streams through manufacturing-as-a-service subscription pricing	(Rosa et al., 2019)
		Savings on prototyping costs with use of by-materials in lower and customized prices	(Toth-Peter et al., 2023)
	Simulations	Enables error identification in design phases before the process is performed	(Rosa et al., 2019)

Circular Strategies	Circular Business Model Elements								
	Value Proposition			Value Creation & Delivery				Value Capture	
	Product/Service	Customer	Customer Relationships	Key Activities	Key Partners	Resources & Capabilities	Channels	Cost structure	Revenue Streams
Greening **Sustain & Regreen**	- Processes use renewable energy to transform materials into green products. - Products have low environmental footprint while being powered by renewable resources (solar panels, scalable wind turbines).	- Incentivised customers which purchase only products which have been produced with green power. - Customers with high environmental awareness.	- Transportation is initiated based on renewably powered means (electric-based mobility, bikes, etc.). - Collaborative initiatives to sustain or regreen natural reserves and ecosystems. - Collaboration only with suppliers which support green initiatives.	- Educate customers to use only green products. - Create awareness about green actions and incentivise customers.	- Collaborative initiatives to restore and regreen natural ecosystems. - Delivery of supplies with the utilisation of renewable resources and non-fossil mean.	- Build-up renewables capacity and use it in production and by-processes. - Delivery of products in a sustainable way. - Make creative partnerships which embrace green energy. - Human resources to support green marketing and promote sustainability.	- Sustainable transportation and delivery. - Sustainable insights promotion through social media for customer and stakeholder education.	- Savings from renewable energy consumption. - Savings on transportation costs.	- Reputation due to green initiatives, can attract incentivised customers with high environmental awareness.
Narrowing **Reduce & Localize**	- Products offered are build based on the minimum possible material consumption. - Service offering which completely substitutes the functionalities and capabilities of a physical product. - Products are being produced based on the demand, supply-demand ratio is balanced. - Products made of innovative materials which are purposed at reducing the consumption of conventional materials.	- Proactive customers willing to reduce consumption.	- Exploitation of local suppliers and partners in order to reduce energy consumed from transportation and materials trading. - Ensure product functionality besides the reduced materials utilisation during production. - Ensure service performance besides the lack of a physical product.	- Educate customers to reduce consumption where possible. - Reduce product consumption with service offerings. - Reassure that the service offered can cover customer needs. - Reduce resources utilisation by initiating recycling and reuse actions.	- Supply resources in local basis. - Innovate materials with advanced properties along with institutes which can substitute the traditional non-ecological materials.	- Substitute product with an equal service which can serve the same functionalities. - Capacity management in order to have an equilibrium between supply and demand. - Technological capabilities which can assist with service offerings and demand prediction.	- Software delivery instead of product via performance/functionality provision. - Social media and online channels for offerings delivery. - Apps and online tools for service delivery (product virtualisation). - Direct sales of non-ownership products.	- Savings from on demand production and efficiency due to innovative materials. - Savings from transportation cost reduction due to local supplies.	- Revenue from new non-ownership contracts. - Profit from subscription schemes for software utilisation.
Cycling **Reversing & Reuse**	- Products made of recycled elements/materials/components. - Second-hand/second-chance products which are being redistributed to market for reselling and reuse. - Value from biomass is returned to the ecosystem, cascading.	- Incentivised customers willing to purchase redistributed goods. - Customer segments with high environmental awareness.	- Facilitating suppliers and collectors which support reverse logistics activities. - Material/parts trade among industries to cover needs without additional resources input to the system.	- Incentivise customers to return products for reuse and redistribution. - Reassure that recycled or second-life products have good quality and can serve the intended functionalities and purpose. - Access end-of-life products and retrieve useful resources from waste.	- Reverse logistics partners which are purposed for product return and resources circulation. - Cooperation with facilitators and redistributors for product collection, inspection and direct selling. - Resources trading through cooperatives and by-products exchange.	- Take-back systems and products/materials return point. - Recycling processes and reverse supply chains. - By-products exchanging with industries, waste from a manufacturer can be used as a valuable input. - Mange product traceability with IoT and cloud technology.	- Direct channels for resell either through retailers or online means. - Social media and apps to communicate recycling value to customers. - Virtual channels (media, platforms) for resources trading. - Reverse flow infrastructure as a channel for recycling.	- Savings from reduced production costs. - Savings in material inputs with the exploitation of by-products. - Joint (customer, manufacturer) cost reduction and new production lines.	- Revenue from product offerings in lower price, reselling revenue streams. - Revenue from resources trading. - Reputation gains in "green" customer segments. - Direct and indirect sales (transaction fees) and revenue streams from reselling. - Additional profit from buy-back scheme, take-back service fee and trade-in credit.
Extending **Slow & Maintain**	- Product is designed in a durable way to last longer. - Product is based on timeless design (does not fade out of style). - Defected or damaged products are being repaired to retrieve their capabilities without resources waste. - Upgrade to new modes (product or service) with additional features and high quality. - Product design is easy to maintain, disassembly, remanufacture and refurbish.	- Conscious customers willing to use the product for longer. - Customers segments which lengthen consumption to save on capital costs.	- Suppliers and external partners which remanufacture and directly offer products to customers. - High quality service provision through network of actors.	- Attract customers which are willing to keep products for longer time. - Provide warranties for the product functionality and performance. - Provide upgrade plan to gain commitment. - Upgrade plan for B2B customers which require constant performance and results from the product in use. - Educate customers on how to use products in order to achieve longevity. - Initiate repair plans and accompany products with services.	- Ecosystem collaborations which will support repair and remanufacturing activities. - Make network and outsource activities related to maintenance and repair while the service offering remains with the initial manufacturer.	- Design products to last longer in order to reduce faults, damages and eventually faster disposal. - Offer product upgrade and modules which will make the customer keep the product for longer. Upgrade with additions, software, service. - Technological resources to support upgradability, real-time data transfer and performance monitoring. - Technological capabilities and life prediction models which will ensure product life extension.	- Online and virtual channels to support after-sales services and upgrades. - Direct and online sales for remanufactured and refurbished products. - Virtual service for design customisation and long use support.	- Financial savings from material savings since remanufactured products can be resold without the need for making new products.	- Revenue from "premium" products with durable design. - Revenue from services for repair and upgrading. - Profit from performance- and function-based contracts, charging per use or for results. - Non-financial gains from customer lock-in and long-term relationships.
Intensifying **Share & Collaborate**	- Shared value with increased availability and lower price. - Temporary exploitation of product functionality, product owing remains by the manufacturer. - Structured platforms which support product/parts/components sharing or pooling.	- Network of users/consumers which aim for lower pricing and broad range of choices. - Customers which aim at making a profit from sharing or resources trading.	- Suppliers and external partners which promote products sharing for temporary use. - Customers engagement through platform and shared reviews regarding service quality.	- Sharing initiatives among consumers and educate to share. - Educate for collaborative consumption. - Management of customer relationships as a practice to ensure satisfaction and loyalty. - Design product-service-system which can support both the product being shared and the service which accompanies it.	- Suppliers management, connect internal and external capabilities to support sharing models. - Connection channels and platform for material/products sharing in a B2B basis. - Create network to inspect products in use and ensure quality, longevity and abuse reduction.	- Product ownership remains with the manufacturer which manages repair and redistribution. - Online platforms to manage product leasing/pooling and embrace sharing among users. - Technology-related resources to support digitalisation and product monitoring during collaborative usage.	- Apps and online webs for users connectivity and service delivery. - Online platforms for products/material sharing/trading. - Online advertisements as indirect communication channels to promote sharing and collaborative consumption. - Indirect sales through C2C channels.	- Savings from products reuse by multiple users, benefits from extended lifecycles. - Savings from resources reduction and energy efficiency due to multi-usage.	- Charging per use, temporary contracts. - Increase profit through customer loyalty. - Non-financial gains from customer lock-in and long-term relationships. - Profit from platform fee for resources trading (subscription pricing). - Dynamic pricing through usage monitoring.

Figure 10: Circular practices & strategies along the CBM (derived from Tripodis, 2023)

Table 16: Industry 4.0 technology contributions per circular strategy (Tripodis, 2023)

I4.0 Technologies	Contribution per Circular Strategy	
IoT	***Greening:*** - Data collection for energy efficiency - Connectivity with partners ***Narrowing:*** - Data collection for service monitoring - Connectivity for supply and demand monitoring ***Cycling:*** - Resources tracking and condition monitoring - Connectivity with customers for products return	***Extending:*** - Data collection of usage and customer needs - Resources tracking and condition monitoring ***Intensifying:*** - Resources tracking and condition monitoring - Connectivity with customers for products return
Big data, Analystics & Cloud Computing	***Narrowing:*** - Data analysis for consumption pattern recognition and reduction	***Extending:*** - Usage patterns identification for services improvement, upgrade ***Intensifying:*** - Real-time data exchange and connectivity - Usage pattern analysis and sharing
CPS & AM	***Cycling:*** - Automation for optimised resources recovery - Efficient resources collection and shorting	***Extending:*** - Automation for efficient maintenance and manufacturing/remamufacturing - Customised manufacturing and product designs ***Intensifying:*** - Multi-user access to automated manufacturingas-a-service (3D printing)
ML, AI & AR	***Narrowing:*** - Prediction algorithms for supply and demand - Life-cycle expectancy prediction ***Cycling:*** - Material/product condition prediction - Consumption patterns analysis for reselling and efficient redistribution	***Extending:*** - Predictive maintenance for service support - Upgradability suggestions and dynamic pricing ***Intensifying:*** - Usage and end-of-life prediction - Dynamic pricing - Connectivity provisions through matching algorithms
Blockchain	***Cycling:*** - Data transparency and verifiability - Secure resources trading among stakeholders	***Extending:*** - Secure product information management for disassembly, repair and maintenance ***Intensifying:*** - Transparent intra-user transactions - Privacy and security insurance
Simulations	***Greening:*** - System (energy, ecosystem) modelling - Scenario testing (weather conditions, energy loads) ***Narrowing:*** - Conceptual service development and user education - Scenario testing for product development with alternative or less materials	***Extending:*** - Conceptual design for longevity and performance checks - Design and maintenance scenario testing ***Intensifying:*** - Scenario testing for complex supply chain management - Customer education and experience improvement

Table 17: HCBMT-Framework (Tripodis, 2023)

Circular Strategies	Circular Practices	Enabling Technologies (Industry 4.0)	Circular Business Model Elements								
			Value Proposition			Value Creation & Delivery				Value Capture	
			Product/Service	Customer	Customer Relationships	Key Activities	Key Partners	Resources & Capabilities	Channels	Cost structure	Revenue Streams
Greening **Sustain & Regreen**	- Use renewables (logistics, production) - Sustain natural ecosystems - Power products with renewables - Green-based partnerships	- Data collection for energy efficiency - Connectivity with partners - Energy management and optimisation - System (energy, ecosystem) modelling - Scenario testing (weather conditions, energy loads)	- Processes use renewable energy to transform materials into green products. - Products have low environmental footprint while being powered by renewable resources (solar panels, scalable wind turbines).	- Incentivised customers which purchase only products which have been produced with green power. - Customers with high environmental awareness.	- Transportation is initiated based on renewably powered means (electric-based mobility, bikes, etc.). - Collaborative initiatives to sustain or regreen natural reserves and ecosystems. - Collaboration only with suppliers which support green initiatives.	- Educate customers to use only green products. - Create awareness about green actions and incentivise customers.	- Collaborative initiatives to restore and regreen natural ecosystems. - Delivery of supplies with the utilisation of renewable resources and non-fossil mean.	- Build-up renewables capacity and use it in production and by-processes. - Delivery of products in a sustainable way. - Make creative partnerships which embrace green energy. - Human resources to support green marketing and promote sustainability.	- Sustainable transportation and delivery. - Sustainable insights promotion through social media for customer and stakeholder education.	- Savings from renewable energy consumption. - Savings on transportation costs.	- Reputation due to green initiatives, can attract incentivised customers with high environmental awareness.
Narrowing **Reduce & Localize**	- Reduce materials usage - Substitute with innovative materials - Balance supply and demand - Service vs. Product - Incentivise to reduce consumption - Localise supply chain	- Data collection for service monitoring - Connectivity for supply and demand monitoring - Data analysis for consumption pattern recognition and reduction - Prediction algorithms for supply and demand - Life-cycle expectancy prediction - Conceptual service development and user education - Scenario testing for product development with alternative or less materials	- Products offered are build based on the minimum possible material consumption. - Service offering which completely substitutes the functionalities and capabilities of a physical product. - Products are being produced based on the demand, supply-demand ratio is balanced. - Products made of innovative materials which are purposed at reducing the consumption of conventional materials.	- Proactive customers willing to reduce consumption.	- Exploitation of local suppliers and partners in order to reduce energy consumed from transportation and materials trading. - Ensure product functionality besides the reduced materials utilisation during production. - Ensure service performance besides the lack of a physical product.	- Educate customers to reduce consumption where possible. - Reduce product consumption with service offerings. - Reassure that the service offered can cover customer needs. - Reduce resources utilisation by initiating recycling and reuse actions.	- Supply resources in local basis. - Innovate materials with advanced properties along with institutes which can substitute the traditional non-ecological materials.	- Substitute product with an equal service which can serve the same functionalities. - Capacity management in order to have an equilibrium between supply and demand. - Technological capabilities which can assist with service offerings and demand prediction.	- Software delivery instead of product via performance/functionality provision. - Social media and online channels for offerings delivery. - Apps and online tools for service delivery (product virtualisation). - Direct sales of non-ownership products.	- Savings from on demand production and efficiency due to innovative materials. - Savings from transportation cost reduction due to local supplies.	- Revenue from new non-ownership contracts. - Profit from subscription schemes for software utilisation.
Cycling **Reversing & Reuse**	- Reuse/Resell - Recycle - Redistribute - Take-back system / Reverse logistics - Incentivise to return - Cascade/Repurpose - Recover elements/materials/parts - Industrial Symbiosis	- Resources tracking and condition monitoring - Connectivity with customers for products return - Data transparency and verifiability - Secure resources trading among stakeholders - Material/product condition prediction - Consumption patterns analysis for reselling and efficient redistribution - Automation for optimised resources recovery - Efficient resources collection and shorting	- Products made of recycled elements/materials/components. - Second-hand/second-chance products which are being redistributed to market for reselling and reuse. - Value from biomass is returned to the ecosystem, cascading.	- Incentivised customers willing to purchase redistributed goods. - Customer segments with high environmental awareness.	- Facilitating suppliers and collectors which support reverse logistics activities. - Material/parts trade among industries to cover needs without additional resources input to the system.	- Incentivise customers to return products for reuse and redistribution. - Reassure that recycled or second-life products have good quality and can serve the intended functionalities and purpose. - Access end-of-life products and retrieve useful resources from waste.	- Reverse logistics partners which are purposed for product return and resources circulation. - Cooperation with facilitators and redistributors for product collection, inspection and direct selling. - Resources trading through cooperatives and by-products exchange.	- Take-back systems and products/materials return point. - Recycling processes and reverse supply chains. - By-products exchanging with industries, waste from a manufacturer can be used as a valuable input. - Mange product traceability with IoT and cloud technology.	- Direct channels for resell either through retailers or online means. - Social media and apps to communicate recycling value to customers. - Virtual channels (media, platforms) for resources trading. - Reverse flow infrastructure as a channel for recycling.	- Savings from reduced production costs. - Savings in material inputs with the exploitation of by-products. - Joint (customer, manufacturer) cost reduction and new production lines.	- Revenue from product offerings in lower price, reselling revenue streams. - Revenue from resources trading. - Reputation gains in "green" customer segments. - Direct and indirect sales (transaction fees) and revenue streams from reselling. - Additional profit from buy-back scheme, take-back service fee and trade-in credit.
Extending **Slow & Maintain**	- Repair/Maintain - Remanufacture/Refurbish - Service support (after-sales service) - Design for ease of maintenance - Always-in-style design - Incentivise for long-lasting usage - Upgrade scheme - Design for durability/longevity	- Data collection of usage and customer needs - Resources tracking and condition monitoring - Usage patterns identification for services improvement, upgrade - Automation for efficient maintenance and manufacturing/remanufacturing - Customised manufacturing and product designs - Predictive maintenance for service support - Upgradability suggestions and dynamic pricing - Secure product information management for disassembly, repair and maintenance - Conceptual design for longevity and performance checks - Design and maintenance scenario testing	- Product is designed in a durable way to last longer. - Product is based on timeless design (does not fade out of style). - Defected or damaged products are being repaired to retrieve their capabilities without resources waste. - Upgrade to new modes (product or service) with additional features and high quality. - Product design is easy to maintain, disassembly, remanufacture and refurbish.	- Conscious customers willing to use the product for longer. - Customers segments which lengthen consumption to save on capital costs.	- Suppliers and external partners which remanufacture and directly offer products to customers. - High quality service provision through network of actors.	- Attract customers which are willing to keep products for longer time. - Provide warranties for the product functionality and performance. - Provide upgrade plan to gain commitment. - Upgrade plan for B2B customers which require constant performance and results from the product in use. - Educate customers on how to use products in order to achieve longevity. - Initiate repair plans and accompany products with services.	- Ecosystem collaborations which will support repair and remanufacturing activities. - Make network and outsource activities related to maintenance and repair while the service offering remains with the initial manufacturer.	- Design products to last longer in order to reduce faults, damages and eventually faster disposal. - Offer product upgrade and modules which will make the customer keep the product for longer. Upgrade with additions, software, service. - Technological resources to support upgradability, real-time data transfer and performance monitoring. - Technological capabilities and life prediction models which will ensure product life extension.	- Online and virtual channels to support after-sales services and upgrades. - Direct and online sales for remanufactured and refurbished products. - Virtual service for design customisation and long use support.	- Financial savings from material savings since remanufactured products can be resold without the need for making new products.	- Revenue from "premium" products with durable design. - Revenue from services for repair and upgrading. - Profit from performance- and function-based contracts, charging per use or for results. - Non-financial gains from customer lock-in and long-term relationships.
Intensifying **Share & Collaborate**	- Product sharing - Product-as-a-Service (PaaS) - Leasing/Pooling - Educate to share - Consume collaboratively - Resources trade (platforms)	- Resources tracking and condition monitoring - Connectivity with customers for products return - Real-time data exchange and connectivity - Usage pattern analysis and sharing - Multi-user access to automated manufacturing as-a-service (3D printing) - Usage and end-of-life prediction - Dynamic pricing - Connectivity provisions through matching algorithms	- Shared value with increased availability and lower price. - Temporary exploitation of product functionality, product owing remains by the manufacturer. - Structured platforms which support product/parts/components sharing or pooling.	- Network of users/consumers which aim for lower pricing and broad range of choices. - Customers which aim at making a profit from sharing or resources trading.	- Suppliers and external partners which promote products sharing for temporary use. - Customers engagement through platform and shared reviews regarding service quality.	- Sharing initiatives among consumers and educate to share. - Educate for collaborative consumption. - Management of customer relationships as a practice to ensure satisfaction and loyalty. - Design product-service-system which can support both the product being shared and the service which accompanies it.	- Suppliers management, connect internal and external capabilities to support sharing models. - Connection channels and platform for material/products sharing in a B2B basis. - Create network to inspect products in use and ensure quality, longevity and abuse reduction.	- Product ownership remains with the manufacturer which manages repair and redistribution. - Online platforms to manage product leasing/pooling and embrace sharing among users. - Technology-related resources to support digitalisation and product monitoring during collaborative usage.	- Apps and online webs for users connectivity and service delivery. - Online platforms for products/material sharing/trading. - Online advertisements as indirect communication channels to promote sharing and collaborative consumption. - Indirect sales through C2C channels.	- Savings from products reuse by multiple users, benefits from extended lifecycles. - Savings from resources reduction and energy efficiency due to multi-usage.	- Charging per use, temporary contracts. - Increase profit through customer loyalty. - Non-financial gains from customer lock-in and long-term relationships. - Profit from platform fee for resources trading (subscription pricing). - Dynamic pricing through usage monitoring.

Table 18: Predetermined interview questions

Business model element	Nr	Interview question
General:	1.	Could you explain the circular strategies implemented within your organization? Additionally, how have these strategies influenced the business model of your organization?
	2.	In the context of Industry 4.0, could you provide the specific technologies and advancements adopted by your organization? Furthermore, how do these technologies contribute to enhancing circularity or sustainability within your industrial processes?
Key Partners	3.	How does your organization evaluate and prioritize key partners based on specific criteria and characteristics, such as alignment of values, technological capabilities, and market influence, within the context of sustainable development goals and circular economy principles?
	4.	Could you provide insights into the technological frameworks and platforms utilized to facilitate collaboration and knowledge exchange with key partners, ensuring seamless integration of sustainability-driven initiatives and fostering innovation in circular practices?
	5.	In what ways do your collaborative efforts with key partners incorporate circular practices, such as resource efficiency, closed-loop systems, and waste reduction, to promote sustainable value chains and mitigate environmental impact throughout the product lifecycle?
Key activities:	6.	Through which key activities does your company orchestrate the creation and delivery of its offerings, considering factors like value co-creation, process optimization, and ecosystem integration, in alignment with circular economy principles?
	7.	How do the identified key activities contribute to your organization's competitive advantage, particularly in terms of differentiation, cost efficiency, and value proposition, within the context of circular strategies and sustainability initiatives?
	8.	Which specific key activities within your organizational framework are strategically aligned with circular strategies, such as remanufacturing, recycling, or eco-design, to minimize resource consumption, reduce waste generation, and maximize value retention? How are technologies involved in this?
Key resources:	9.	How do the allocated key resources of your organization, including physical, financial, and intellectual assets, contribute to establishing and sustaining a competitive edge, particularly in the context of resource efficiency, resilience, and sustainability?
	10.	Could you elaborate on the role and impact of circular strategies in the management of key resources within your organization, encompassing aspects such as materials sourcing, resource optimization, and waste management, to drive sustainable value creation and long-term resilience?
	11.	What technologies does your organization employ to effectively manage and optimize key resources, ensuring transparency, traceability, and accountability throughout the value chain, in alignment with circular economy principles?
	12.	In what ways do you perceive gaps or inefficiencies in current technological solutions or practices related to the management of key resources from a circular perspective, and what advancements or innovations do you believe could address these challenges effectively?

Value proposition:	13.	How are circular practices integrated into the overarching value proposition of your company, aligning with customer needs, societal expectations, and environmental imperatives to deliver sustainable and resilient solutions?
	14.	Could you provide insights into the incorporation of circular practices in the product design process within your organization, including considerations such as eco-design principles, material selection, and product life extension strategies, to enhance sustainability and value creation?
	15.	In what ways does your organization derive value from the implementation of circular strategies within the value proposition, encompassing aspects such as cost savings, brand reputation, customer loyalty, and market differentiation?
Customer segments:	16.	From the perspective of circularity; how would you characterize and segment your customer base, and how does this segmentation inform your approach to product development, marketing, and customer engagement? How do industry 4.0 technologies assist here?
Channels:	17.	What channels and mediums does your company utilize to effectively reach and engage with its target customers, considering factors such as accessibility, reach, cost-effectiveness, and alignment with brand values and messaging?
	18.	How does your organization leverage technology, such as digital marketing platforms, customer relationship management systems, and data analytics tools, to optimize customer reach, engagement, and retention across various channels and touchpoints? How would you describe the connection here with circular practises?
Cost structures:	19.	In what ways does your organization capitalize on cost-saving opportunities stemming from the implementation of circular strategies, such as resource efficiency, waste reduction, and operational optimization, to enhance profitability and financial sustainability?
	20.	What potential role do technological innovations or digital solutions play in enabling and enhancing cost-saving opportunities derived from circular strategies, such as predictive analytics, automation, and blockchain-enabled supply chain transparency?
Revenue streams:	21.	Could you provide insights into the existing revenue stream models employed by your organization, including sources of revenue generation, pricing strategies, and monetization approaches, and how these models align with circular economy principles and sustainability goals? What technologies are deployed to assist in enabling these models?
	22.	What emerging opportunities do you envision for the development of new revenue streams within your organization, leveraging circular strategies and sustainable business models, and how might these opportunities contribute to diversifying revenue sources and enhancing overall financial resilience?

Table 19: Predetermined codes and code levels

Aggregate dimensions	**2nd order Themes**	**1st Order concepts**
Greening strategy	Product/service	Use renewables (logistics, production)
	Customer	Sustain natural ecosystems
	Customer relationships	Power products with renewables
	Key activities	Green-based partnerships
	Key partners	IoT for data collection for energy efficiency
	Resources & capabilities	IoT for connectivity with partners
	Channels	Big data, cloud computing & analytics for energy management and optimisation
	Cost structure	Simulation system (energy, ecosystem modelling)
	Revenue streams	Simulation scenario testing
	Circular practice	
	Industry 4.0 technology	
Narrowing strategy	Product/service	Reduce materials usage
	Customer	Substitute with innovative materials
	Customer relationships	Balance supply and demand
	Key activities	Service vs. product
	Key partners	Incentivise to reduce consumption
	Resources & capabilities	Localise supply chain
	Channels	IoT for data collection for service monitoring
	Cost structure	IoT for connectivity for supply and demand monitoring
	Revenue streams	Big data, cloud computing & analytics for data analysis for consumption pattern recognition and reduction
	Circular practice	AI, ML & AR for prediction algorithms for supply and demand
	Industry 4.0 technology	AI, ML & AR for life-cycle expectancy prediction
		Simulations for conceptual service development and user education
		Simulations for scenario testing for product development with alternative or less materials
Cycling strategy	Product/service	Reuse/resell
	Customer	Recycle
	Customer relationships	Redistribute
	Key activities	Take-back system/reserves logistics
	Key partners	Incentive to return
	Resources & capabilities	Cascade/repurpose
	Channels	Recover elements/materials/parts
	Cost structure	Industrial symbiosis
	Revenue streams	IoT for resources tracking and condition monitoring
	Circular practice	IoT for connectivity with customers for products return

	Industry 4.0 technology	Blockchain for data transparency and verifiability
		Blockchain for secure resources trading among stakeholders
		AI, ML & AR for material/product condition prediction
		AI, ML & AR for consumption patterns analysis for reselling and efficient redistribution
		Cyber-physical & additive manufacturing for automation for optimised resources recovery
		Cyber-physical & additive manufacturing for efficient resources collection and shorting
Extending strategy	Product/service	Repair/Maintain
	Customer	Remanufacture/Refurbish
	Customer relationships	Service support (after-sales service)
	Key activities	Design for ease of maintenance
	Key partners	Always-in-style design
	Resources & capabilities	Incentive for long-lasting usage
	Channels	Upgrade scheme
	Cost structure	Design for durability/longevity
	Revenue streams	IoT for data collection of usage and customer needs
	Circular practice	IoT for resources tracking and condition monitoring
	Industry 4.0 technology	Big data, cloud computing & analytics for usage patterns identification for service improvement, upgrade
		Cyber-physical & additive manufacturing for automation for efficient maintenance and manufacturing/remanufacturing
		Cyber-physical & additive manufacturing for customised manufacturing and product designs
		AI, ML & AR for predictive maintenance for service support
		AI, ML & AR for upgradability suggestions and dynamic pricing
		Blockchain for secure product information management for disassembly, repair and maintenance
		Simulations for conceptual design for longevity and performance checks
		Simulations for design and maintenance scenario testing
Intensifying strategy	Product/service	Product sharing
	Customer	Product-as-a-service
	Customer relationships	Leasing/Pooling
	Key activities	Educate to share
	Key partners	Consume collaboratively

	Resources & capabilities	Resources trade
	Channels	IoT for resources tracking and condition monitoring
	Cost structure	IoT for connectivity with customers for product return
	Revenue streams	Big data, cloud computing & analytics for real-time data exchange and connectivity
	Circular practice	Big data, cloud computing & analytics for usage pattern analysis and sharing
	Industry 4.0 technology	Cyber-physical & additive manufacturing for multi-user access to automated manufacturing as-a-service
		AI, ML & AR for usage and end-of-life prediction
		AI, ML & AR for dynamic pricing
		AI, ML & AR for connectivity provisions through matching algorithms
		Blockchain for transparent intra-user transactions
		Blockchain for privacy and security insurance
		Simulations for scenario testing for complex supply chain management
		Simulations for customer education and experience improvement

Appendix B

Table 20: Code report Case company 1

ID	Document	Quotation Content	Codes	Rephrased for framework
1:188	Transcript Interview Case company 1	so let me start with the first layer what sort of strategies have been implemented at . . . we focus a lot on recyclability	Cycling strategy Product/Offering Circular practice Recycle	1. Products made of recycled materials.
1:189	Transcript Interview Case company 1	home appliances they come with you know the energy efficiency labels	Greening strategy Product/Offering	2. Products have low environmental footprint and are energy efficient.
1:190	Transcript Interview Case company 1	so in France specifically they introduced something called the repairability index	Extending strategy Circular practice Key Activities Product/Offering Incentivise for long-lasting usage Repair/Maintain	3. Products are designed for ease to maintain and repair. 4. Repairability index gives a certain warranty on the repairability of the product.
1:191	Transcript Interview Case company 1	and they're planning to introduce something called the durability index . . . we're also very focused on the durability aspect of our products business model	Extending strategy Circular practice Product/Offering Design for durability/longevity Design for ease of maintenance Incentivise for long-lasting usage Repair/Maintain	3. Products are designed for ease to maintain and repair. 5. Products are design for durability/longevity.
1:192	Transcript Interview Case company 1	business model wise you probably already know that we have something called . . . and this is where we lease out our appliances and where we provide appliances in communal settings so also like sharing the products	Intensifying strategy Circular practice Customer Product/Offering Revenue Streams Consume collaboratively Leasing/Pooling Product sharing Product-as-a-service	6. Products offered as a service. 7. Sharing products offering. 8. Network of users of the same product for communal settings.
1:193	Transcript Interview Case company 1	because of our recyclability and recycled content targets we have to think about how we reach these targets by changing our architecture for example what sort of. So for example how do we integrate recycled plastics into our products recycle whatever material that there	Cycling strategy Circular practice Product/Offering Recycle	1. Products made of recycled materials.
1:194	Transcript Interview Case company 1	I can imagine that in the products there are sensors or you retrieve maybe data from the products while they are in use or while they are in production	Cycling strategy	9. Product traceability with IoT. 10. IoT and cloud computing for real-time

		and it could be possible that these technologies are deployed by . . . or over there so do you have any knowledge of if this is happening? Speaker A: indeed it is happening it's more just I can't share because it's not public sorry	Industry 4.0 technology Resources & Capabilities AI, ML & AR for connectivity provisions through matching algorithms Big data, cloud computing & analytics for real-time data exchange and connectivity IoT for resources tracking and condition monitoring	data tracking and performance monitoring. 11. IoT and cloud computing to support product monitoring during collaborative usage.
1:195	Transcript Interview Case company 1	we're looking into how we change our architecture so that manufacturing for sure cloud computing I would say less so at the moment but simulations yes AI no doubt IoT uncertain for me at the moment.	Extending strategy Industry 4.0 technology Resources & Capabilities AI, ML & AR for life-cycle expectancy prediction Simulations for conceptual design for longevity and performance checks	12. Simulation software for manufacturing optimization/product development. 13. AI for prediction models.
1:196	Transcript Interview Case company 1	Speaker A: to maybe share your view on that yes for sure as I mentioned we we're looking into how we change our architecture so that manufacturing for sure cloud computing I would say less so at the moment but simulations yes AI no doubt IoT uncertain for me at the moment.	Extending strategy Industry 4.0 technology Resources & Capabilities AI, ML & AR for life-cycle expectancy prediction Simulations for conceptual design for longevity and performance checks	12. Simulation software for manufacturing optimization/product development. 13. AI for prediction models.
1:197	Transcript Interview Case company 1	it's obviously a mix of a few different factors what we care about most is the transparency . . . we have certain index to evaluate potential partners we get bonus and malice depending on these criteria that is adapted according to our sustainability strategy	Greening strategy Circular practice Customer Relationships Key Partners Green-based partnerships	14. Supplier assessment for collaboration with partners based on a sustainability index

1:198	Transcript Interview Case company 1	could you provide insights into the technological frameworks and platforms utilize to facilitate this collaboration with your partners? Speaker A: it's a few different tools that are being used at the moment we have a sustainability rating service that we use, which you probably know. It's called Ecovados. And we have another tool that is really focused on supplier assessment. But I can't disclose that yet.	Greening strategy Resources & Capabilities	15. Supplier assessment software to promote sustainable value chain.
1:199	Transcript Interview Case company 1	I think there's also a huge risk related to greenwashing.	Greening strategy Key Activities	16. Educate customers to use only green products and not greenwashed products.
1:200	Transcript Interview Case company 1	Does … has users platforms or software where they collaborate with their partners, with distributors or suppliers? Speaker A: Yes, there is a startup that we're piloting with, but it's not public information. So I can't share that yet	Cycling strategy Channels	17. Software platform for collaboration with partners.
1:201	Transcript Interview Case company 1	In what ways do your collaborative efforts with key partners incorporate circular practices? Speaker A: in the home appliance industry, we're part of the WEEE directive, Waste, Electronic and Equipment Directive which mandates us to collect, to take care of our home appliances, to take care of that electronic waste that's taken care of at the end of life.	Cycling strategy Circular practice Key Activities Resources & Capabilities Incentivise to return Recycle Take-back/Reverse logistics	18. Collecting end-of-life products. 19. Recycle end-of-life products.
1:202	Transcript Interview Case company 1	There is something called the Producer Compliance Scheme that is related to WEEE. . . . we have a network of WEEE partners who help collaborate on this topic. In terms of resource efficiency, . . .	Cycling strategy Key Partners	20. WEEE partners for reverse logistics, resource circulation and product collection.
1:203	Transcript Interview Case company 1	we have targets for recycled content. . . . we do need to procure, obviously, recycled material, be it recycled metal, green metal, be it recycled plastics or... . . Let's put it like that.	Cycling strategy Circular practice Product/Offering Recycle	1. Products made of recycled materials.
1:204		I think what we really do is partner. We seek out a way to also incorporate	Cycling strategy Extending strategy	21. Local redistributors for reselling used

	Transcript Interview Case company 1	local elements into this. . . . we partner in the Netherlands with the Kringloper. And in Belgium, we have something called the Papillon Project.	Circular practice Key activities Product/Offering localise supply chain Recycle Redistribute Reuse/Resell Take-back/Reverse logistics	products. 22. Non-financial benefits, reputational benefits from working with semi-charity organizations for reselling used products.
1:205	Transcript Interview Case company 1	Are there, for example, reverse logistic loops in place? Or is it recycled material second-hand? Speaker A: It's a really, really complex field. Of course, ideally, you have a digital passport for every single product and then you collect it back and then it goes and it's in a very beautiful circular way. That's usually not the case.	Cycling strategy Circular practice Resources & Capabilities Recycle Take-back/Reverse logistics	No digital passport yet
1:206	Transcript Interview Case company 1	we as a home appliance manufacturer don't have the know-how or we're not the best in the industry when it comes to reverse logistics.	Cycling strategy Key Partners Resources & Capabilities Take-back/Reverse logistics	No own reverse logistics
1:207	Transcript Interview Case company 1	But it's kind of impossible to say we take out 20% of the product that is plastic and put 20% of that back into our production loop. It doesn't really work like that in practice.	Cycling strategy Circular practice Product/Offering Recycle	
1:208	Transcript Interview Case company 1	If you ask if we do a lot of marketing activities, I would say less because of what I mentioned beforehand that we're a bit careful not to be accused of greenwashing. We're extremely careful and we take care of the products of what we communicate externally compared to other home appliance manufacturers	Greening strategy Key Activities	16. Educate customers to use only green products and not greenwashed products.
1:209	Transcript Interview Case company 1	the B2C retailers who do it. We are exchanging with the retailers, obviously, on this topic to make sure that they're taken care of. So we keep track, for example, of how much waste is taken back for our brands in each country. But if you're asking if we're directly involved in it, we are getting into it. Because as I mentioned, there's a really established network out there.	Cycling strategy Channels Circular practice localise supply chain Recycle Take-back/Reverse logistics	23. Channels for recycle information flows with retailers

1:210	Transcript Interview Case company 1	how is ... profiting from these circular key activities for example, making cost efficiencies or in the value proposition, for example, you mentioned the recycling and using recycled material. Do you see that … is profiting from that because the costs are lower or do you see the opposite? Speaker A: It's the opposite, as you can probably guess. There are certain sustainability activities that go hand in hand with economic benefit. For example, if you're pushing for energy efficiency, yes. In the case of circular economy, most of the time, no. Recycled content is actually more expensive to acquire.	Cycling strategy Greening strategy Cost structure	24. Economic benefits for energy efficiency. 24. Higher cost for recycled materials.
1:211	Transcript Interview Case company 1	So, we have a business called … whereby we rent out appliances and, so, think of it as a subscription. So, think of it as a Netflix for home appliances. Every month, you would pay a certain amount of money. And, we take care of the delivery, the maintenance, and the take-back at the end of the use, at the end of the contract, let's put it like that.	Intensifying strategy Circular practice Key activities Resources & Capabilities Leasing/Pooling Repair/Maintain Service support	25. Product ownership remains with the manufacturer which manage repair, redistribution and recycling. 26. Product-service-system which supports product sharing and the accompanied services.
1:212	Transcript Interview Case company 1	a lot of upfront costs are of course, you get paid over time, right? Speaker A: That, as well as just venturing into a new business field, it's very different selling something compared to rent, leasing something out. And, having to take care of a certain appliance throughout its entire lifetime is, it requires a lot of knowledge collection	Intensifying strategy Circular practice Cost structure Product-as-a-service	27. High upfront cost for leasing/renting model.
1:213	Transcript Interview Case company 1	do you have predictive models of the lifetime, for example? And, with this data, are you then optimizing your subscription model? Speaker A: I'm afraid that I'm not the expert in this. But, yes, we have models, obviously, to predict what, definitely	Intensifying strategy Resources & Capabilities Big data, cloud computing & analytics for usage pattern analysis and sharing Product sharing	28. Predictive models to achieve product life extension
1:214	Transcript Interview Case company 1	Is dynamic pricing involved? Speaker A: Not at the moment.	Intensifying strategy Revenue Streams AI, ML & AR for dynamic pricing	29. No dynamic pricing.

1:215	Transcript Interview Case company 1	a feature which we share in Spain, I think, where the electricity towers have dynamic pricing. And with Home Connect, you could actually set up alerts to figure out when it makes most sense cost-wise for you to, to use, to run your appliances.	Greening strategy Circular practice Industry 4.0 technology Resources & Capabilities Green-based partnerships IoT for data collection for energy efficiency IoT for connectivity with partners	30. Assist customers about energy efficiency actions through app.
1:216	Transcript Interview Case company 1	How we introduced this in the Netherlands first, because I think we learned that Dutch customers are a bit more receptive towards sustainability related offerings. But, after a rather successful pilot, we launched in Germany as well. So, we're active in these two markets	Greening strategy Customer	31. Dutch customers more receptive towards sustainable offering.
1:217	Transcript Interview Case company 1	So are we using predictive models to optimize the life cycle, the lifetime, how shall I say it, the life cycle of our products? Yes, from a quality perspective, for sure.	Extending strategy Circular practice Industry 4.0 technology Resources & Capabilities AI, ML & AR for predictive maintenance for service support Big data, cloud computing & analytics for usage patterns identification for service improvement, upgrade Design for durability/longevity	28. Predictive models to achieve product life extension
1:218	Transcript Interview Case company 1	Could you see, for example, that with Internet of Things it would help with certain circular practices in general first? Speaker A: , for sure. I mean, lots of potential and theory. Again, how shall I answer this? Lots of	Industry 4.0 technology	Not usable for framework

		potential. It's more about balancing that with what makes sense economically. Lots of technologies are a bit expensive to adopt at the moment.		
1:219	Transcript Interview Case company 1	There are also opportunities to manage the energy usage in the manufacturing, but also during a consumption. Speaker A: Sure. Jeffrey Chantrel: do it gives advice when to use some appliances but is this also in place in the manufacturing where you optimize energy consumption. Speaker A: yes, . . . we've been carbon neutral in terms of scope one and two and we have four viewers to achieve that one of them definitely involving energy efficiency.	Greening strategy Circular practice Cost structure Industry 4.0 technology Product/Offering Big data, cloud computing & analytics for energy management and optimisation Use renewables	24. Economic benefits for energy efficiency. 32. Optimize energy consumption in manufacturing.
1:220	Transcript Interview Case company 1	Okay. Non-financial benefits are extremely prominent. we won a lot of awards related to sustainability for how cutting edge it was as a new business model. We also benefited from it in terms of attracting young people. . . . . I can really attest to the fact that the younger generation cares a lot about what companies, especially large companies, do with regards to sustainability. I think in terms of financial, it's a little bit. I say it with less conviction.	Greening strategy Revenue Streams	33. Reputational benefits for sustainability practices.
1:221	Transcript Interview Case company 1	in the theory, they sometimes speak of a premium, right, for very durable or lifelong products. But also in that case customers in general are not prepared to pay that premium usually, . Speaker A: Definitely. And durability is actually a rather better example because durability provides the benefit in an economic sense . . . . You get to use your appliance longer. Sustainability as the first... As the main marketing message, I would say doesn't really work at the moment, at least for the home appliance industry. . . . , we do it because for knowledge gain. And also for the non-financial benefits that I mentioned to you beforehand.	Extending strategy Circular practice Revenue Streams Design for durability/longevity Incentivise for long-lasting usage	34. Premium price for durability. 35. No financial benefits for more sustainable product.
1:222		Okay. So, different... So, obviously, different stakeholders, different	Extending strategy	36. Online channels

	Transcript Interview Case company 1	channels. . . . So, obviously, we were quite focused on the online bit, I would say	Channels	
1:223	Transcript Interview Case company 1	We as a home appliance manufacturer don't have the know-how or we're not the best in the industry when it comes to reverse logistics. . . . And starting from scratch is extremely resource intensive which also doesn't necessarily pay off.	Cycling strategy Key Partners Take-back/Reverse logistics	37. Partners for reverse logistics.
1:224	Transcript Interview Case company 1	Trainings for employees to introduce to them what does it mean, like, what are our targets, what sort of end picture do we work towards? Like, what does circular economy mean? Because it's not necessarily something that is well-known outside the sustainability organizational units.	Key Activities Resources & Capabilities	Not usable for framework
1:225	Transcript Interview Case company 1	With retailers, of course, we have engagement from time to time. We have something called the Supplier Engagement Day, where we introduce to them what sort of progress we've made so far and what are our expectations towards them.	Greening strategy Channels	38. stakeholder engagement on sustainability and circularity topic.
4:1	Sustainability report: Case company 1	advancing the expansion of renewables and striving continuously for energy efficiency	Greening strategy Resources & Capabilities	39. Build-up renewables capacity by buying and producing.
4:2	Sustainability report: Case company 1	reducing its ecological footprint	Greening strategy Product/Offering	2. Products have low environmental footprint and are energy efficient.
4:3	Sustainability report: Case company 1	increasing energy efficiency, generating our own energy from renewable sources (new clean power), purchasing electricity from renewable sources (green electricity), and – as the last resort – using carbon credits to offset residual CO_2 emissions.	Greening strategy Circular practice Product/Offering Resources & Capabilities Use renewables	39. Build-up renewables capacity by buying and producing. 40. Using renewable energy in own processes.
4:4	Sustainability report: Case company 1	For years, materials efficiency has been a fixed criterion in the *company's name* product development process, where it is anchored in our Design for Environment (DfE) principle	Narrowing strategy Product/Offering	41. Product offering is based on the minimum possible material consumption.
4:5	Sustainability report: Case company 1	Our activities range from reusing products and their components to repairs and right through to	Cycling strategy Extending strategy	1. Products made of recycled materials. 42. Reusing and

		remanufacturing – in each case with the objective of extending product and component life cycles.	Circular practice Product/Offering Recover elements/materials/ parts Remanufacture/Refurbish Reuse/Resell	remanufacturing components and products.
4:6	Sustainability report: Case company 1	This is characterized by three core levers: increasing efficiency, purchasing resources from renewable sources, and changing the technology used. The three core levers can be applied to all value creation stages – from purchasing materials and goods (upstream) to subsequent processing at our plants (own operations) through to use of the products by our customers (downstream).	Greening strategy Resources & Capabilities	39. Build-up renewables capacity by buying and producing.
4:7	Sustainability report: Case company 1	for example at suppliers, in logistics, or when our products are used. Our aim is to reduce these upstream and downstream emissions by 15 percent in absolute terms by 2030, compared with the baseline year 2018 – irrespective of our company's growth.	Greening strategy Key Partners	43. Emission reduction with logistic partners.
4:9	Sustainability report: Case company 1	In a joint initiative . . . to increase packing density in a bid to use less packaging material, storage space, and transport capacity – in turn, reducing CO_2 emissions. Packaging design centres have been set up . . . to improve and standardize packaging. At the same time, we want to use packaging material with a higher recycling content.	Cycling strategy Narrowing strategy Product/Offering	44. Product packaging is designed to use as less possible packaging material. 45. Product packaging is designed to use recycled packaging material.
4:10	Sustainability report: Case company 1	Improvements in materials utilization can reduce resource consumption and also cut the manufacturing cost of a product.	Narrowing strategy Circular practice Cost structure Reduce material usage	46. Manufacturing cost reduction due to efficient resource utilization.
4:11	Sustainability report: Case company 1	improvements in materials efficiency in production processes and the materials efficiency of our products have therefore been an essential element of our product development process, where it is anchored in an internal standard via the Design for Environment (DfE) principle.	Narrowing strategy Circular practice Product/Offering Reduce material usage	41. Product offering is based on the minimum possible material consumption.
4:12	Sustainability report: Case company 1	The concepts and activities of the divisions range from reusing products and their components to repairs and	Cycling strategy Extending strategy	1. Products made of recycled materials. 42. Reusing and

		right through to remanufacturing – in each case with the objective of extending product and component life cycles.	Circular practice Product/Offering Recover elements/materials/ parts Remanufacture/Ref urbish Reuse/Resell	remanufacturing components and products.
4:13	Sustainability report: Case company 1	reduce negative effects – which arise, for example, during the extraction of raw materials – by closing the materials and products loop.	Cycling strategy Resources & Capabilities	47. Closing materials and products loops.
4:14	Sustainability report: Case company 1	program has been offering customers the option to have defective vehicle components replaced with remanufactured products at specialist workshops.	Extending strategy Circular practice Product/Offering Remanufacture/Ref urbish	42. Reusing and remanufacturing components and products.
4:15	Sustainability report: Case company 1	recycled materials – covers all measures to close the loop by established recycling processes for materials such as steel, aluminium, and plastics. This way, we can reduce the use of primary materials and lessen our environmental impact – as well as mitigate human rights risks associated with the extraction of raw materials.	Cycling strategy Circular practice Product/Offering Resources & Capabilities Recycle	1. Products made of recycled materials. 47. Closing materials and products loops.
4:16	Sustainability report: Case company 1	increase the proportion of recycled material used in all products and at the same time improve the recyclability of the products.	Cycling strategy Product/Offering	1. Products made of recycled materials. 48. Products are designed for recyclability
4:17	Sustainability report: Case company 1	All production locations have a clearly designated organizational unit responsible for sorting, classifying, and handing over waste to disposal companies.	Cycling strategy Resources & Capabilities	47. Closing materials and products loops.
4:18	Sustainability report: Case company 1	For example, where technically feasible, we intend to dispense with substances on the EU's REACH candidate list in new developments.	Narrowing strategy Circular practice Product/Offering Substitute with innovative materials	49. Substitute materials from the EU's REACH candidate list for other materials if technically feasible.
4:19	Sustainability report: Case company 1	Algorithms that map the relevant materials restrictions and declaration regulations automate the process of matching bills of materials and associated supplier declarations against the pertinent requirements. To enable checks, MaCS maps the individual	Narrowing strategy Circular practice Industry 4.0 technology Resources & Capabilities	50. Algorithms that help selecting recyclable and regulation compliant materials.

		components of a product in the form of a bill of materials.	Substitute with innovative materials	
4:20	Sustainability report: Case company 1	MaCS also includes information from the supplier declarations that is made available to us via systems such as the International Material Data System (IMDS), Compliance Data Exchange (CDX), and *Company's Name* declaration format. MaCS – Material Data Management for Compliance and Sustainability. . . . Legal requirements Industry-specific requirements Customer requirements Materials restrictions and limits depending on intended use and sales markets Bills of materials and supplier declarations, and information on intended use and sales markets. Automated matching. This information indicates the substances contained in the individual components as well as their concentration levels. By linking bills of materials and supplier declarations, it is possible to make accurate statements about the substances contained in each component.	Cycling strategy Industry 4.0 technology Resources & Capabilities	50. Algorithms that help selecting recyclable and regulation compliant materials.
5:1	Brochure Case company 1	Ranging from product finders on our websites and different purchasing options to value adding services from our Home Connect ecosystem or customer service.	Extending strategy Intensifying strategy Channels Circular practice Resources & Capabilities Service support	51. Value added services sales through app.
5:2	Brochure Case company 1	We also analyse the usage data of connected appliances to incorporate the results into the enhancement of our solutions. In collaboration with designers, engineers and sales experts, this leads to innovations that ensure better quality of life in harmony with the environment.	Extending strategy Circular practice Industry 4.0 technology Resources & Capabilities Big data, cloud computing & analytics for usage patterns identification for service improvement, upgrade Design for durability/longevity IoT for data collection of usage and customer needs	28. Predictive models to achieve product life extension

5:3	Brochure Case company 1	Oven with integrated camera and food recognition	Narrowing strategy Circular practice Industry 4.0 technology Product/Offering Incentivise to reduce consumption	52. Product uses cyber-physical systems and AI to reduce or optimize consumption.
5:4	Brochure Case company 1	fridge freezer with reduced CO 2 - material footprint	Greening strategy Product/Offering	2. Products have low environmental footprint and are energy efficient.
5:5	Brochure Case company 1	Completely connectable dishwasher generation	Internet of Things Product/Offering	Not usable for framework
5:6	Brochure Case company 1	automatic detergent dosing	Narrowing strategy Circular practice Industry 4.0 technology Product/Offering Incentivise to reduce consumption	52. Product uses cyber-physical systems and AI to reduce or optimize consumption.
5:7	Brochure Case company 1	BSH develops and manufactures in a CO 2 -neutral manner at all locations worldwide	Greening strategy Product/Offering	32. Optimize energy consumption in manufacturing.
5:8	Brochure Case company 1	The Home Connect app offers an ever-growing choice of features and services to personalize consumer experience.	Extending strategy Greening strategy Intensifying strategy Narrowing strategy Channels	53. App for online user connectivity, service delivery and customization. 51. Value added services sales through app.
5:9	Brochure Case company 1	Home Connect's ever-expanding partner network offers a wide range of additional uses, like energy management, for example.	Greening strategy Key activities	30. Assist customers about energy efficiency actions through app.
5:10	Brochure Case company 1	FOOD RECOGNITION THANKS TO THE INTEGRATED OVEN CAMERA AND ARTIFICIAL INTELLIGENCE	Narrowing strategy Industry 4.0 technology Product/Offering	52. Product uses cyber-physical systems and AI to reduce or optimize consumption.
5:11	Brochure Case company 1	we have been developing and manufacturing in a CO2 -neutral manner	Greening strategy Product/Offering	32. Optimize energy consumption in manufacturing.
5:12	Brochure Case company 1	he two biggest levers for CO2 -neutral manufacturing are the efficient use of energy and the use of green electricity.	Greening strategy Product/Offering	32. Optimize energy consumption in manufacturing.
5:13			Extending strategy	

	Brochure Case company 1	In the event of maintenance questions or technical issues, we ensure prompt and expert customer service.	Key Activities	54. Provide technical customers service for product life extension.
5:14	Brochure Case company 1	appliances and offers spare parts for large appliances for usually up to 15 years. As many models and series are produced for longer, spare parts are often available even for a longer time. This refers to all functionally relevant and storable parts for appliances produced after 1 January 2023.	Extending strategy Resources & Capabilities	55. Provide spare parts up to 15 years to support product life extension.
5:15	Brochure Case company 1	by implementing new circular business models like leasing and sharing. These circular business models help consumers make their homes more sustainable while also providing carefree and affordable solutions.	Intensifying strategy Product/Offering	6. Products offered as a service. 7. Sharing products offering.
6:1	Blog articles Case company 1	promoting the circular economy through sustainable product design and the use of recyclable materials. Virtual development methods and artificial intelligence are key in this effort.	Cycling strategy Circular practice Industry 4.0 technology Product/Offering AI, ML & AR for material/product condition prediction Recycle Simulations for conceptual design for longevity and performance checks	56. Using AI in sustainable product development. 1. Products made of recycled materials.
6:2	Blog articles Case company 1	The pre-configured "Sustainable ventilation" service is the star among the fully automatic control systems for smart thermostats. . . . This way, none of the heat goes out the window and you save energy.	Narrowing strategy Circular practice Industry 4.0 technology Product/Offering AI, ML & AR for prediction algorithms for supply and demand Big data, cloud computing & analytics for data analysis for consumption pattern recognition and reduction Incentivise to reduce consumption	52. Product uses cyber-physical systems and AI to reduce or optimize consumption.
6:3	Blog articles Case company 1	Life cycle assessment (LCA) can be used to depict complete product life cycles and identify potential for ecological improvements. These can be individual materials, components or	Extending strategy	12. Simulation software for manufacturing optimization/product development.

		production steps. With these methods, *Company's name* can find out how sustainable a product will be while it is still being developed. The simulations obtained show how products can be made more sustainable by changing the materials, production environment or the product design. . . . The findings gained from applying these methods enable us to identify the most critical aspects in the life cycle of our products and make specific changes during the design phase. This sustainable and futuristic approach is known as eco design.	Circular practice Industry 4.0 technology Resources & Capabilities Design for durability/longevity Repair/Maintain Service support Upgrade scheme Simulations for conceptual design for longevity and performance checks	
6:4	Blog articles Case company 1	Circular value creation involves upgrading a product in whole or in part for further use during and after the initial use phase.	Extending strategy Circular practice Product/Offering Upgrade scheme	57. Providing product upgrades to extent the products life-time.
6:5	Blog articles Case company 1	The decisive factor for circular value creation is eco-design, which addresses key stages of product creation and use as early as the product conception and development stage, while at the same time optimally preparing the necessary steps for the further use and reuse of the product. This includes processes such as repairing and re-manufacturing the entire product or reusing individual parts.	Cycling strategy Extending strategy Circular practice Product/Offering Design for durability/longevity Design for ease of maintenance Recover elements/materials/parts Remanufacture/Refurbish Repair/Maintain Reuse/Resell	48. Products are designed for recyclability. 58. Products are designed for refurbishment and remanufacturing.
6:6	Blog articles Case company 1	In the context of the circular economy, another aim is to recover valuable materials at the end of the product's life and to use them for the manufacture of new products (recycling).	Cycling strategy Key Activities	59. Access end-of-life products and retrieve useful resources from waste.
6:7	Blog articles Case company 1	A first step when it comes to extending the service life of products involves maintaining and caring for them or updating them via software updates for example to ensure they can be used for a long time. Regular, proper maintenance, for example changing the oil in an engine or maintaining heating systems, can prevent products breaking down prematurely. If possible, they should also be updated to maintain	Extending strategy Key Activities Product/Offering	60. Initiate repair plans and accompanies products and services. 57. Providing product upgrades to extent the products life-time.

		their functionality and performance or even improve them.		
6:8	Blog articles Case company 1	All products break down at some point or the material they are made from wears out. Repairing them extends their service life. This means that defective parts are repaired or replaced in order to get the product working again.	Extending strategy Product/Offering	42. Reusing and remanufacturing components and products.
6:9	Blog articles Case company 1	shared washing machines in residential buildings and the associated digital billing systems for shared laundry rooms.	Intensifying strategy Customer Revenue Streams	8. Network of users of the same product for communal settings. 61. Digital billing system for shared laundry services.
6:10	Blog articles Case company 1	In the circular economy, products should be designed so that they can be reused by someone else in other applications after their first life or shared.	Cycling strategy Product/Offering	48. Products are designed for recyclability.
6:11	Blog articles Case company 1	If products which still work are overhauled and refurbished, they can be put back on the market later on. This extends their service life. Product quality is always checked in the process.	Cycling strategy Extending strategy Key Activities Product/Offering Revenue streams	62. Reselling refurbished or used products. 63. Reassure that recycled or second-life products have good quality and can serve the intended functionalities and purpose. 64. Revenue from reselling second-life appliances.
6:12	Blog articles Case company 1	During remanufacturing, a product's components are removed and checked. Damaged parts are repaired or replaced and the product is then put together again. The aim is to come up with a recycled product which meets the same quality standards as a new product.	Cycling strategy Key activities	63. Reassure that recycled or second-life products have good quality and can serve the intended functionalities and purpose.
6:13	Blog articles Case company 1	Product recycling, as opposed to second-life approaches, involves recovering the recyclable materials used. The original product is destroyed in the process and the materials are recovered, for example by melting them down. The old material thus becomes a secondary raw material from which new products can be manufactured.	Cycling strategy Key Activities	59. Access end-of-life products and retrieve useful resources from waste.

6:14	Blog articles Case company 1	Selecting the right materials when developing new products is an important part of eco design. At *Company's name*, we are constantly looking for ways to increase the proportion of sustainable materials in our products. . . . The main focus is on finding the right material. Old car batteries have already been used successfully to produce housings for ultrasonic sensors that are used in vehicle parking pilots.	Cycling strategy Customer relationships Key Activities Product/Offering	1. Products made of recycled materials. 65. Parts and material trade among industries to cover material needs without additional resource input to the system.
6:15	Blog articles Case company 1	One approach which is being followed at the moment is urban mining — for example the recovery of precious metals from defective electrical appliances and electronic components as opposed to obtaining them from natural sources such as ores.	Cycling strategy Customer Relationships	65. Parts and material trade among industries to cover material needs without additional resource input to the system.
6:16	Blog articles Case company 1	A dishwasher that uses natural minerals for drying your dishes, a smart washing machine that knows the precise dosing, a fridge with cameras and Connect app to check what's in your fridge anytime and anywhere so you can buy consciously, a dryer that re-uses warm air to dry clothes more efficiently. Around the world, we're working on innovative and efficient solutions like these to help you save water and energy and reduce food waste.	Greening strategy Narrowing strategy Circular practice Product/Offering Incentivise to reduce consumption Sustain natural ecosystem	52. Product uses cyber-physical systems and AI to reduce or optimize consumption. 41. Product offering is based on the minimum possible material consumption.
6:17	Blog articles Case company 1	Fill up the detergent/s and softener chambers just once, and *Product's name* sensors automatically measure the precise amount of detergent and water needed for each load, without refilling. So there's never again too much detergent and unnecessary rinse cycles – and you'll save up to 10 Liters of water per cycle.	Greening strategy Narrowing strategy Industry 4.0 technology Product/Offering	52. Product uses cyber-physical systems and AI to reduce or optimize consumption.

Table 21: Code report Case company 2

ID	Document	Quotation Content	Codes	Rephrased for framework
2:1	Transcript Interview Case company 2	So at…, our offering is the … Home Appliances. And instead of selling in a linear transactional way, we actually rent it out, right?	Intensifying strategy Circular practice Product/Offering Leasing/Pooling Question 1	1. Leasing/renting offering of appliances.
2:2	Transcript Interview Case company 2	So basically, we rent not just the appliance, but the service behind the appliance in that we ensure that the consumer who pays us a fixed monthly fee for this product and service will always have a working appliance during the contract duration	Intensifying strategy Circular practice Resources & Capabilities Revenue Streams Leasing/Pooling Product-as-a-service Service support	2. Managing repair, recycle, maintenance and redistribution of the leased product. 3. Revenue stream from subscription model with monthly fixed fees.
2:3	Transcript Interview Case company 2	And they have the flexibility at the end of the contract duration to buy out, to renew, to upgrade, to transfer, etc. . . . At the end of the day, why is it circular? Because at the end of the contract duration, they are free to terminate. And therefore, we take it back. And as direct manufacturers, basically, so that's our USP.	Cycling strategy Extending strategy Intensifying strategy Circular practice Key Activities Resources & Capabilities Revenue streams Incentivise to return Leasing/Pooling Redistribute Take-back/Reverse logistics Upgrade scheme	4. Take-back systems after end of contract or termination. 5. Offer upgrades to new appliances. 6. Buy-out the appliances from the contract. 7. Provide upgrade plan to gain commitment. 8. Upgrade appliances or services for longer product use.
2:4	Transcript Interview Case company 2	We refurbish the appliance as good as new and bring it to the next consumer	Cycling strategy Extending strategy Circular practice Key Activities Product/Offering Recover elements/materials/ parts Recycle Redistribute Remanufacture/Refurbish Take-back/Reverse logistics	9. Reassure that refurbished products have good quality by refurbish it just as new. 10. Offer refurbished appliances.
2:5	Transcript Interview Case company 2	we rent direct to the end consumer	Channels	Not used in framework
2:6	Transcript Interview Case company 2	But now we are also looking at trying to grow the reach by having some partners and B2B customers. For	Intensifying strategy	11. Partner organizations which promote products

		example, service apartments, assisted living.	Circular practice Customer Customer relationships Consume collaboratively Product sharing Question 22	sharing like service appartments and assisted living. 12. B2B customers who provide sharing the rented appliances.
2:7	Transcript Interview Case company 2	So and by doing that, we are able to reach more consumers who otherwise may not have been, for example, buying customers. Because whether it's affordability or accessibility or the wish to have a more flexible approach that they can upgrade to the next model and not just, you know, have an upfront high investment purchase cost.	Intensifying strategy Circular practice Customer Consume collaboratively Question 22	13. Customers who cannot afford or have access to buying the appliances can become rental customer. 14. Customers who want to be more flexible and upgrade frequently to new appliances.
2:8	Transcript Interview Case company 2	We are using an e-commerce web shop, which is actually our own because the web shop.	Intensifying strategy Channels	15. Webshop for online subscription sales
2:9	Transcript Interview Case company 2	If you want to do bundling, et cetera, then we can actually react faster. And then the infrastructure instead of SAP for the big … organization, we also have our own because of the unique processes that we have in recurring subscription circular models, as opposed to transactional sales models.	Intensifying strategy Resources & Capabilities	16. Online platform to manage subscription sales and recurring transactions + KYC.
2:10	Transcript Interview Case company 2	if you have recurring models, then you need to be able to check the financial soundness of the end consumer, ... So, and that's why this part of it is something that is a new competence that we need to build into our ecosystem of IT infrastructure	Intensifying strategy Resources & Capabilities Revenue Streams	16. Online platform to manage subscription, sales and recurring transactions + KYC. 3. Revenue stream from subcription model with monthly fixed fees.
2:11	Transcript Interview Case company 2	Again, very different from linear models. And then, of course, reverse logistics and non-reversal. Not just the logistics to the first consumer, but also reverse and the multiple part of that element.	Cycling strategy Resources & Capabilities Question 8 Take-back/Reverse logistics	4. Take-back systems after end of contract or termination.
2:12	Transcript Interview Case company 2	And on the payment side, again, should the payment stop after X months, then there is also this unique process of Planning, right? So basically, you've got to follow up with the customer, also with partners, . . . with reminders and all these things, which is also extremely unique to this recurring revenue subscription model. Right?	Intensifying strategy Customer Relationships Revenue Streams Question 21	17. Regulary customer engagement about payments, upgrades, subscription extensions. 16. Online platform to manage subscription, sales and recurring transactions + KYC.

2:13	Transcript Interview Case company 2	but work with different, let's say companies, which are already specializing in all these elements, all the way to customer service and our customer interaction as well. So that's how we track the entire journey! Right. This is internal but then of course we are also trying to enable that the consumer is also able to track and follow through the orders so that it is also transparent to them right so this is how we approach it.	Intensifying strategy Channels Customer Relationships Industry 4.0 technology Key Activities Key Partners Resources & Capabilities Big data, cloud computing & analytics for real-time data exchange and connectivity Big data, cloud computing & analytics for usage pattern analysis and sharing IoT for connectivity with partners IoT for resources tracking and condition monitoring Question 18	18. Supplier management, to connect internal and external capabilities to support leasing and sharing models. 19. Apps and online webs for user connectivity and service delivery. 20. Technology-related resources to support digitalization and product monitoring. 21. Management of customer support as a practice to ensure satisfaction and transparency.
2:14	Transcript Interview Case company 2	Okay and what are the technologies you use for that? Are there analytics, big data involved in order to track or build predictive models? Speaker A: potentially yes so we are not so good at that to be honest but definitely a huge potential . . . we've got all the consumer data and behaviour and therefore we are also focusing on how to find patterns that a simple excel analysis it doesn't give you right so also dabbling a little bit into AI in order to find these patterns and predict for example churn . . . we track the consumer happiness or net promoter score etc and therefore we know that . . . So to use AI to potentially spot these patterns so that we can be ahead and not be reactive after they want to cancel or you know just stay as is with the existing contract but to make them even so to bring the customer lifetime value and customer happiness to the next level right	Intensifying strategy Narrowing strategy Industry 4.0 technology Key Activities Resources & Capabilities	22. Predictive models which assist in customer satisfaction, service offerings and demand prediction. 21. Management of customer support as a practice to ensure satisfaction and transparency.

			AI, ML & AR for connectivity provisions through matching algorithms AI, ML & AR for usage and end-of-life prediction AI, ML & AR for consumption patterns analysis for reselling and efficient redistribution Big data, cloud computing & analytics for usage pattern analysis and sharing	
2:15	Transcript Interview Case company 2	and AI is also useful for scalability . . . and therefore AI chatbots the generative AI would be able to help us do these routine work pattern recognition but also potentially you know personalize certain offerings to the customer's need or potential customers like prospecting right so those are the areas that we're looking into.	Intensifying strategy Circular practice Customer Relationships Industry 4.0 technology Resources & Capabilities AI, ML & AR for connectivity provisions through matching algorithms Service support	23. Using AI for customer support. 24. Using AI for customer pattern predictions and make customized offerings.
2:16	Transcript Interview Case company 2	so not all the appliances in our portfolio are connected right just as the portfolio of … so unfortunately it is not the majority because it's reflective of the portfolio that … has today but of course the trend is promising in that we are going to have more and more connected appliances and therefore we can rent out more and more connected appliances as well	Cycling strategy Extending strategy Industry 4.0 technology Resources & Capabilities IoT for resources tracking and condition monitoring Question 2	25. IoT to support real-time data transfer and performance monitoring. 26. IoT to support traceability
2:17	Transcript Interview Case company 2	how do you evaluate to with which partners you work and are here circular economy criteria involved? yes so to begin with the most specific part on circularity, right? So obviously circularity means repair, refurbish, right, and reverse logistics as well. And therefore we are now looking at more partners to do this end of life part for us, right?	Cycling strategy Extending strategy Circular practice Key Partners	28. Reverse logistics partners which are purposed for product return and resource circulation. 29. Cooperation with facilitators and redistributors for product collection, inspection and direct selling. 30. Ecosystem

			Recycle Remanufacture/Refurbish Repair/Maintain Take-back/Reverse logistics	collaboration which will support repair, refurbish activities and recycling.
2:18	Transcript Interview Case company 2	So, because there will be certain cases where it is no longer the best for people planet and profit in order to bring it for the fifth life or something like that. And therefore there will also be partners who not only can do the usual refurbishment for us to our standards, so that's one, then of course the repair part as well, but then also potentially to recycle it and to, or bring it to truly another exit strategy, right?	Cycling strategy Extending strategy Circular practice Key Activities Key Partners Cascade/Repurpose Recover elements/materials/parts Recycle Remanufacture/Refurbish Take-back/Reverse logistics	30. Ecosystem collaboration which will support repair, refurbish activities and recycling. 31. End-of-life strategies when other re-routes are non-beneficial.
2:19	Transcript Interview Case company 2	So obviously the competencies are important to our standards, but also that means transparency of documentation, so that we can really trace them from cradle to cradle the resources live. So it is very important that we have this transparency, even though it has officially left our jurisdiction and go at the end of life to another partner, but it is still, we feel it is totally our responsibility to ensure that we find and only work with partners who are responsible to make sure that it meets all our internal standards besides any regulatory requirements, right?	Cycling strategy Circular practice Key Partners Cascade/Repurpose Take-back/Reverse logistics	32. Recycle and reverse logistics partners which ensure transparency and traceability
2:20		in fact, the ones that we're looking for, to have a strategic longer-term	Cycling strategy	33. Collaboration technologies to

	Transcript Interview Case company 2	partnership with, right. To learn together, to be ready to test new models, new partnerships together, nimble enough for that, but still serious enough to push through challenges, which are bound to happen when you try something out new. . . . exciting. – Jeffrey Chantrel Does perhaps technology make it easier? I heard you saying you collaborate with a lot of partners also for the refurbishing and repairing, also for the reverse logistics. – Jeffrey Chantrel I can imagine that certain technologies could really help making that collaboration easier. How is your view on this? So basically, when we have different modules and work with different partners, so the interfaces become super important, right? So, it's always going through like a journey. . . . And therefore, it is always, let's say, , little, little IT projects, so to speak, software integration projects that we need to integrate in. So, that's like almost a daily process, especially since I truly, believe in the power of partnering, partnerships. And therefore, it is, you know, we've got to be even better with that through time, right? So, but we don't waste too much time on saying, okay, you've got to have this SAP or whatever, you know, so we try to be a little bit more open minded, because at the end of the day, the competencies, that we need and want may be still relatively new. And therefore, sometimes preferences would be rather smaller and hungrier partners than too super established, and we don't do it your way, we only do it our way, because we've done that for the last 40 years, right? So, that becomes important also as part of the criteria to look for partners. and technology integration.	Customer Relationships	efficiently manage information and product flows with partners.

2:21	Transcript Interview Case company 2	And on the upstream side, on the raw material elements and all that, obviously is also important. what I mentioned is that we also try to make the appliances more sustainable in the way of energy efficiency, water efficiency, as well as durability and lifetime usage, and of course CO2 emission. And that goes for our factories as well, and we have the net zero targets as well for these. And at the end of the day, the appliance side is also with the packing, and therefore the packaging is also with recycled material, less is more, without Styrofoam, etc. So basically it's quite holistic and it's got to be, because when we bring it to the end consumer in a circular model, then we want to make sure that it's all this that I mentioned and more. And the end more part is the part that it is easy to repair. But all the durability, efficient appliances, connected appliances, it's all tick, tick, tick, tick, tick, right? And it's in line with the sustainable value proposition and approach that we have. But the fact that it is easy to repair, and since we know our products, we are the best to repair it. So we use also our internal customer service to do the repair and refurbishment. And so that it all plays together, how it is developed, manufactured, brought to the customer, repaired, refurbished, and circularly brought to the next consumers, right? So this is all linked.	Cycling strategy Extending strategy Greening strategy Circular practice Product/Offering Revenue Streams Design for durability/longevity Design for ease of maintenance Reduce material usage Remanufacture/Refurbish Take-back/Reverse logistics Use renewables	34. Appliances are designed to have a low environmental footprint, with energy efficiency, water efficiency and CO2 emission. 35. Appliances are designed for durability. 36. Processes with Zero targets. Energy efficiency. 37. Using environmentally friendly packaging from recycled materials. 38. Design for ease of maintenance and repair. 39. Design connected appliances. 40. Resell refurbished appliances.
2:22	Transcript Interview Case company 2	There's another unit which is doing this rewash. So, and they actually do washing solutions for laundromats, for let's say student housing, et cetera. And so they actually capture this usage data, but it's not household use as our appliances are meant for. So, it is especially approbated, so approbation for commercial use, because it is a shared model, alright, and its pay-per-use. So, they capture the usage data, . . . it's just capturing the how much the washing machine and dryer is being used right in our case.	Intensifying strategy Circular practice Customer relationships Industry 4.0 technology Key Partners Revenue Streams Big data, cloud computing & analytics for usage pattern analysis and sharing Consume collaboratively IoT for resources tracking and	41. B2B leasing customers that want to make a profit from sharing (laundromats, student housing). 42. Connection channels and platforms for product sharing in B2B. 43. Charge per use revenue.

			condition monitoring Product sharing	
2:23	Transcript Interview Case company 2	the connected appliances become the easier platform to jump on right so things like remote diagnostics etc . . . through the remote diagnostics we think that we'll be able to not only check the true household use right so not like a laundromat use but really the household use which is in fact the mainstay of our company household appliances . . . potentially diagnose or prognose things that could go wrong before it goes wrong so I think that element of course utility management as well	Cycling strategy Extending strategy Circular practice Industry 4.0 technology Key Activities Resources & Capabilities AI, ML & AR for predictive maintenance for service support Big data, cloud computing & analytics for usage patterns identification for service improvement, upgrade IoT for data collection of usage and customer needs IoT for resources tracking and condition monitoring Recycle Service support	25. IoT to support real-time data transfer and performance monitoring. 26. IoT to support traceability. 44. IoT, data analytics and predictive models exploision to ensure product life extension. 45. Initiate repair plan and predicted maintenance with IoT, data analytics.
2:24	Transcript Interview Case company 2	but the remote diagnostics part is also very interesting to look at the utility part and the you know consumption part I think there's a huge potential there too but I do believe that there we should partner for example utility companies because a lot of smart energy management projects are ongoing and that's where my belief in the power of partnering comes in again	Greening strategy Circular practice Customer Relationships Industry 4.0 technology Resources & Capabilities Big data, cloud computing & analytics for energy management and optimisation Green-based partnerships IoT for data collection for energy efficiency	46. Make creative partnerships which embrace green energy, enabled by connected appliances and data sharing.
2:25	Transcript Interview Case company 2	because … consumers are very eager to support us to grow and again super thankful for that so we have already	Intensifying strategy	47. Customer engagement through platform and shared

		our usual surveys whether it's a promoter score or whatever or product and service but we can also reach out quite often to them and ask them if they are willing to do a special survey with us right and or a special test case and monitoring case and therefore this is for me this huge potential that we need to be better at	Customer Relationships Industry 4.0 technology Big data, cloud computing & analytics for usage pattern analysis and sharing	reviews regarding service quality.
2:26	Transcript Interview Case company 2	so basically I mentioned the infrastructure where we can trace where the product is and you know that if it needs repair and reverse logistics etc. and that's what we see and track and the same platform we also have the what the consumers see right so they do have a … account and they can log in and also see parts of this journey right so we have that as the foundational element	Cycling strategy Intensifying strategy Circular practice Channels Industry 4.0 technology Resources & Capabilities AI, ML & AR for material/product condition prediction IoT for resources tracking and condition monitoring IoT for connectivity with customers for products return Service support Take-back system/Reverse logistics	19. Apps and online webs for user connectivity and service delivery. 26. IoT to support traceability
2:27	Transcript Interview Case company 2	30 percent of our customers actually own more than two or more subscriptions with us and we definitely want to with our loyalty program boost that right and therefore we have also started to kick off some kind of loyalty program but it's in early stages to have potentially also benefits for them should they you know perhaps increase based on skill and software optimization as well and when the consumers have more subscriptions with us or even refer us to friends and their network. And that is very much part and parcel of building up a new	Intensifying strategy	48. Increase profit through customer loyalty and multiple appliance subscriptions. 47. Customer engagement through platform and shared reviews regarding service quality.

		norm, a new trend, right? . . . So we send out net promoter score surveys. So short after the delivery and then after a month to check always, you know, are they happy? Where we can improve? How we can do better, right? And also half a year, all the way every half a year with our consumers. And, then additional to that, we've got also our ad hoc surveys where we chatted with them. And that's why I mentioned, you know, they're always willing to be, you know, a part of our focus groups, etc. When we say, okay, we've got now a hypothesis to seek out a potential and they help us shape all these things, right? So those are the various platforms to be integrated into our business model.	Circular practice Customer Relationships Revenue streams Service support Upgrade scheme	
2:28	Transcript Interview Case company 2	So I think, so my firm belief is for sure. Is it a must-have that the entire appliance throughout the, all the features of the product is connected? I think, no. That's why I also mentioned, like, it could be just a data logger that you retrospectively put into the machine, right? So again, I'm an innovator and business developer. From that viewpoint, nothing is a hurdle that you cannot go over. That's where I'm coming from, right? So I think technology makes it easier for us to do these new, blue ocean business models, whether it's circularity or others, right?	 Industry 4.0 technology	Not used in framework

Table 22: Code report Case company 3

ID	Document	Quotation Content	Codes	Rephrased for framework
3:1	Transcript Interview Case company 3	we have corresponding strategies on circular solutions resource preservations as well as which is quite important for us for quality and longevity of the appliances which is sort of special and we follow all the different routes that you usually say the re-routes like reuse repair re-manufacture reduce or recycle all these things that translate the former linear model to a more circular one so that is certainly part of the overall strategy even today	Cycling strategy Extending strategy Circular practice Key Activities Product/Offering Resources & Capabilities Revenue streams Design for durability/longevity Design for ease of maintenance Recover elements/materials/ parts Recycle Reduce material usage Remanufacture/Refurbish Repair/Maintain Sustain natural ecosystem	1. Offer high quality and longevity home appliances 2. Design products for longevity/durability. 3. Design products for ease of repair. 4. Recycle end-of-life appliances. 5. Refurbish and resell used appliances.
3:2	Transcript Interview Case company 3	usually what's happening is that you test out different routes like the recycling route where you use even recycled plastics for instance then also what we also test are the refurbished areas say you have a washing machine or dishwasher and you refurbish it after eight to ten years and bring it back to the in the market so this is not a conceptual part it's really happening but at the same time the challenge is to get the economics right and that's an issue I would say for all of the industries. So in the sense you can say that you've asked about business models so I would put it it's since we're in a sort of test phase it's an enhancement model that we're talking about.	Cycling strategy Circular practice Product/Offering Revenue streams Recycle Remanufacture/Refurbish	6. Using recycled materials. 5. Refurbish and resell used appliances.
3:3	Transcript Interview Case company 3	If you think about refurbishment you need to know okay how long not only how old an appliance is but also how much it has been used so the use phase is sort of the important thing and nowadays you have connected appliances you can easily understand	Cycling strategy Extending strategy Circular practice Industry 4.0 technology Resources & Capabilities	7. IoT and real-time data registration/transfer of performance of the appliances. 8. Using data and predictive models for

		how often they're used and whether they need some maintenance or whether they can be you know are still in a good condition and could be sold again and others that are used whatever, two times a day after 10 years, are more likely, there's a chance it does not make, for different reasons, sense to go into the refurbished, but then go to a recycling mode for these type of appliances. And I would say, and I usually refer to it as in the digital space, that you need these new technologies, really, and to make this sort of happen, because otherwise, the amount of work is most likely even too high.	AI, ML & AR for usage and end-of-life prediction AI, ML & AR for consumption patterns analysis for reselling and efficient redistribution Big data, cloud computing & analytics for usage patterns identification for service improvement, upgrade IoT for resources tracking and condition monitoring Refurbish Reuse/Resell Recycle Repair/maintain	maintenance or recycle route.
3:4	Transcript Interview Case company 3	It's a little bit like what you know about the car industry, think about digital twins, so sort of a digital status, virtual one that really makes you understand about the appliances and other things. That's sort of very helpful. And you start, of course, in the production side to develop these things. So that's the point where the industry 4.0 hits, but it also goes to the R&D part, because you need to develop the appliances in such a way that they are able to be supported during their use phase.	Extending strategy Industry 4.0 technology Product/Offering Question 2 Question 8	9. Design appliances to support I4.0T for data sharing and traceability.
3:5	Transcript Interview Case company 3	So if you think about your kitchen or washing machines or room care aspects, it's not obvious that these devices and appliances are connected. And I think it's a matter of development over time that this becomes more and more natural.	Extending strategy Industry 4.0 technology Product/Offering IoT for resources tracking and condition monitoring	9. Design appliances to support I4.0T for data sharing and traceability.

3:6	Transcript Interview Case company 3	I'll give you examples. So in the materials area, for instance, we have steel and plastics. And, of course, we talk with suppliers from the plastics or chemical industry on the capability of circularity. But the chemical industry itself is not that far. And therefore, it's not easy for us to drive circularity with respect to plastics. . . . So we support that. We discuss with them. That's a constant dialogue. On the other hand, if you think about recycled plastics, which you can use, they're usually today more expensive than the virgin materials, which is also a challenge because that would mean you have higher prices, or lower profitability on the appliance side, . . . Another example would be steel industry. And you can also think about green steel, which wasn't really an option. . . . And you have to have it, a high availability must be there, and then you can go in circles. But also there, you have different grades, and not everything can be easily replaced with recycled materials. At the same time, and that's a challenge, if you think about longevity, you can calculate that if you think about life cycle assessment, the longer you have an appliance, the better. And so we go for high quality, and it's better for us and for the customer, and for the whole of the system, if you have 20 years lifetime of appliances, which is our focus. So therefore, we also have high standards, for materials, which is a challenge with, if you think about recycled materials. So that's a balance you have to find, how this all fits. So it's not easy to replace one material by the other one, if you think about 20 years.	Cycling strategy Circular practice Cost structure Key Partners Product/Offering Recycle	6. Using recycled materials. 10. Collaboration with recycled material suppliers 11. Recycled materials more expensive then virgin raw materials.
3:7	Transcript Interview Case company 3	But we discuss that with the suppliers so that they know what we really need. So it's not only a question of costs, but it's also a question of meeting the demand of the appliance site.	Cycling strategy Key Partners	10. Collaboration with recycled material suppliers
3:8	Transcript Interview Case company 3	You have a constant flow of information back and forth concerning the digital product pass. I would say this is a work in progress. And it's a challenge for the suppliers to get all the information because you really go downstream, don't you? I mean, with respect to the value chain and not	Cycling strategy Channels Key Partners	10. Collaboration with recycled material suppliers. 37. Data flow for material properties from and to suppliers and reverse logistics providers.

		everybody can do that, especially if you are not a big company. It's not easy for you to provide all this information.		
3:9	Transcript Interview Case company 3	And in some areas, it's even not easy for the suppliers because they have to protect their IP. And if they give out specific information, they might lose it and give away too much of information. And they're not happy to do that currently. That's a challenge for the value chain and also for the suppliers, but also for the regulators to do that. And to balance the right amount of information. . . . The point is really to go for circular economies and circular value chains.	Cycling strategy Channels	37. Data flow for material properties from and to suppliers and reverse logistics providers.
3:10	Transcript Interview Case company 3	It's already clear that you have to take back the old appliances and give it sort of back to some kind of recycling. But we want more, of course. . . . If you think about recycling of the whole materials, go back for and want to use recycled materials. But that's something that you drive, but it goes stepwise. It's not as easy. So since we are a premium brand and the customer of … appliances really want to have a high quality, long lasting appliance. . . So we have to be very careful on our choices.	Cycling strategy Circular practice Resources & Capabilities Recover elements/materials/ parts Recycle Remanufacture/Refurbish Question 10	4. Recycle end-of-life appliances.
3:11	Transcript Interview Case company 3	So, I mean. infrastructure what you're asking about internet of things simulation software cloud computing big data yes all of this is happening actually at the same time	Cycling strategy Narrowing strategy Industry 4.0 technology Resources & Capabilities Big data, cloud computing & analytics for usage patterns identification for service improvement, upgrade IoT for resources tracking and condition monitoring Simulations for conceptual design	38. Big data, Cloud computing and simulation software for product resource consumption optimalization, recyclability and durability.

			for longevity and performance checks Question 2 Question 8	
3:12	Transcript Interview Case company 3	now you have to be more precise and start an R&D to design for circularity that certainly at the end will mean some changes how you design the appliances how you connect different parts of the appliances what kind of materials you use of course you if you go back to the you know steal you think about materials that you might replace one that cannot be go and in a cycle was one that can go into the cycle and of course you do that and at the same time one has to understand that developing appliances is a little bit of a cyclic business . . . the important strategic point from our side is that we really need to develop new appliances and we need to really test our appliances for the promise of the 20 years and I think that is a difference to other competitors and players in the business which requires therefore maybe different materials again with higher quality and other specifics	Cycling strategy Extending strategy Circular practice Product/Offering Design for durability/longevity Design for ease of maintenance	12. Design for recyclability by selecting recyclable materials. 13. Design the connection of the appliances part for ease of maintenance/repair. 14. Test appliances for longevity. 15. Material selection for recyclability and high quality.
3:13	Transcript Interview Case company 3	then you can ask yourself okay can I reuse for instance the plastics and in some cases you have the fact that some of the plastic that has been used in the appliances 20 years ago which were plastics natural at that time for the market are forbidden now so I'm going to ask you what's the point of that so you cannot put them back into the business even not as recycled materials because new regulations are now in place that's one thing the other thing is that there are cases where it does not make any sense to go for repair and refurbishment because the label the energy consumption or power consumption of the appliances you buy today are so much better than the ones you've say you sold 10 or 20 years ago that it's better for the customer to go for a new appliance yes	Cycling strategy Circular practice Key Activities Recycle Remanufacture/Refurbish	16. Reassure that reselling appliances meet quality requirements and energy efficiency performance.
3:14	Transcript Interview Case company 3	And that's also an important point that we have for way more than 10 years, all the spare parts available, which is also	Extending strategy	17. Keeping a 10 year stock of spare-parts to

		a topic in the appliance business. So we have that for the customers. Also not as easy. So the point is really to be able to repair the appliances as long as you can. And that's for sure.	Circular practice Resources & Capabilities Question 8 Service support	support longevity of the appliances
3:15	Transcript Interview Case company 3	in addition to the standalone appliances, we also developed an app where you can sort of, you know, position all your different appliances in your home. And you can see how much energy they consume. You can see how much they have been used. You can even use them later on and maybe for a predictive maintenance. Even today, it's already used. If you want to repair it, you can, you know, use it and have a look together with a technician who's not at your home how to repair it. You can even download. Recommendations how to repair if you have a certain type of faults that you can see. That is already in place today	Extending strategy Greening strategy Channels Circular practice Industry 4.0 technology Key Activities AI, ML & AR for predictive maintenance for service support Big data, cloud computing & analytics for energy management and optimisation Design for ease of maintenance Incentivise for long-lasting usage IoT for data collection for energy efficiency IoT for resources tracking and condition monitoring Repair/Maintain Service support	18. Virtual service support for longevity through app. Potentially using AR. 19. Sustainable insights promotion for energy consumption through the app. 20. Create awareness about green actions for energy consumption and incentive customer through the app. 21. Initiate repair plan through the app and offer help services for repair through the app.
3:16	Transcript Interview Case company 3	So let's see. It's the shift from the, say, hardware to the software part and digitalizing everything. . . .The machines more and more work like, like computers or smartphones. So that you have also software components that you can easily upgrade without going to shops. This is what is the future in all of these appliances business.	Extending strategy Circular practice Industry 4.0 technology Resources & Capabilities AI, ML & AR for upgradability suggestions and dynamic pricing Incentivise for long-lasting usage IoT for resources tracking and condition monitoring	22. Digitalizing appliances to offer upgradability of the appliances through software for longevity

			Repair/Maintain Service support Upgrade scheme	
3:17	Transcript Interview Case company 3	Oh, okay. So through that, if I understand well through that app you can, for example. call in a technician and he is helping you repairing the machine, right. And to have a link with technologies is here also augmented reality involved or not yet. Speaker A: That's good. I think it's currently not in place for the for the end user, but certainly that is something that will come into place that service technicians who are located can use these type of technologies more and more.	Extending strategy Channels Circular practice Industry 4.0 technology AI, ML & AR for predictive maintenance for service support Design for ease of maintenance Incentivise for long-lasting usage Repair/Maintain Service support	18. Virtual service support for longevity through app. Potentially using AR.
3:18	Transcript Interview Case company 3	It is possible and you give more and more of the capabilities to the, to the consumer themselves, because there's no, I mean, you don't want to go the best thing for an appliance is that it's running and running and running. No repairs necessary. And even if it, the repair is necessary, if you can do it by yourself, that's even better.	Extending strategy Channels Circular practice Cost structure Design for durability/longevity Design for ease of maintenance Repair/Maintain Service support	18. Virtual service support for longevity through app. Potentially using AR. 23. Service cost savings by support and incentive consumer to do own maintenance and repairs.
3:19	Transcript Interview Case company 3	On YouTube or on the media internet page there, you find all these, recommendations, you can solve. . . . You can easily buy it online, get it, in whatever, one, two, three days, and repair it by yourself. Very easy, very convenient. And I think that's what the customer wants. But it's also, you know, the easiest way to use the appliance as long as possible.	Extending strategy Channels Circular practice Design for ease of maintenance Incentivise for long-lasting usage Repair/Maintain Service support	24.Virtual service support for longevity through YouTube and website.
3:21	Transcript Interview Case company 3	Easily you can do that. And if you have the dosing system, you need the consumables and they are optimally designed. So the point is not to, to leave the customer after the appliances has been sold, but to connect during	Extending strategy Narrowing strategy	25. Appliances are designed to reduce consumables and energy consumption. Using AI, ML and smart components.

		the whole lifetime of the appliances with the consumer and support and help as much as necessary. And that was a change in the business model. Yes. At the same time, , it is also enhancement because,, say 20 years ago, I would say. I think that our consumables business wasn't as important and strategic as it is today. And again the media app goes also into place because it must be convenient, to buy consumables, and that also is, is one of the aspects of the media app.	Channels Circular practice Customer Relationships Product/Offering Revenue Streams Incentivise to reduce consumption Service support	27. Revenue stream from optimized consumables. 28. Ensure reduced product consumption through optimized consumables offering. 39. App to support after-sales for consumables.
3:22	Transcript Interview Case company 3	You can read a lot in the press and the media about sustainability, right? But there's an ambiguity. I would say people expect it, but do they really want to pay more for it or are they really interested? There are some question marks.	Extending strategy Customer Question 16	35. Conscious customers willing to use the product for longer with expectation of buying sustainable appliances.
3:23	Transcript Interview Case company 3	What I truly believe is if you use the system, if you use the app, if you use the consumables then you're satisfied to stay with it. . . . And if you understand the for instance, also power consumption aspects that they can really reduce the power you need for your home, it's really going down.	Extending strategy Greening strategy Narrowing strategy Circular practice Customer relationships Product/Offering Incentivise for long-lasting usage Incentivise to reduce consumption Reduce material usage	25. Appliances are designed to reduce consumables and energy consumption. Using AI, ML and smart components. 28. Ensure reduced product consumption through optimized consumables offering. 36. Appliances are designed to reduce energy consumption and waste with AI.
3:24	Transcript Interview Case company 3	stay at a brand but I'm not totally convinced right now that,, this makes customers stay or that they say, I,, I go for,, for a typical,, appliance of this company or that company because they are more sustainable. There are these customers, yes. But, I would say. Most of them, also understand that, they need, you know, quality. They need, for instance, also hygiene,, topics. , they need, you know, low energy consumption. These topics are important. I have not seen any analytics or something that proves this.	Extending strategy Greening strategy Customer	40. Customer with High quality incentive. 41. Eco-conscious customers for energy consumption of the appliances.

3:25	Transcript Interview Case company 3	opportunities are there leasing or renting out appliances . . . I would say a niche what we do have we have a special business unit for professional hospitals . . . and homes for elderly and these kind of things even doctors and of course they have a different value proposition and for this customer leasing options are make more sense and then there's sometimes special countries perspectives so in Switzerland for instance it's not unusual to have a washing machine for you know a community whereas in Germany you have it for yourself for a family or something like that a little bit of different and you of course you adjust your business model to that but you know these leasing systems looks good they are in place you can do this you can even use it with the app say okay I only pay for how much I use it you use it also for student dormitories and these kind of things it's all there and it works . . . . I think it's a little bit more of a different approach but I think it's more related to the customer perspective all these type of business people are very conservative and they want to have it like it was the year before so going with trends there it really takes a while.	Intensifying strategy Circular practice Customer Product/Offering Revenue Streams Consume collaboratively Leasing/Pooling Product sharing Product-as-a-service	29. Options of appliance leasing/renting. 30. Product sharing offer for communal settings 31. Revenue from charging per use model. 32. Network usage by cultural incentive in Switzerland. 33. Network usage of consumers which aim for lower pricing (student dorms)
3:26	Transcript Interview Case company 3	I would say in the domestic area, we certainly are and want to be a premium brand. So there's no intention to move from this brand position away, right? And professional is a little bit different and we have more, you know, special type of business. But in the domestic part, very clear premium positioning. And at the same time, as said already, the customers in that customer segment, they expect natural forms of sustainability and certainly we develop and provide that.	Extending strategy Circular practice Customer Revenue Streams Design for durability/longevity Question 16	34. Revenue from "premium" appliances designed for durability. 35. Conscious customers willing to use the product for longer with expectation of buying sustainable appliances.

3:27	Transcript Interview Case company 3	So what we have developed, say all over the planet, but do very specifically is what we call the experience centres. So the appliances and the connectivity and what you can do, you can't do, how you should use them. It's, it's more special, right? It's, it's not as easy. You push just one button and then everything happens miraculously. Right. So that's why we have these experience centres. So you can go there and then have, you know, a corresponding support and, and, and can consult and people help you to find the right appliances, the right way, how to use it. They could even do trainings up there. You have even events, how to cook, how to use your cooking devices and how to clean, say corresponding appliances in the kitchen, how to do that, why to do that like this. So usually you don't learn that. You think, you know, it because of the past because you've seen it from your parents, but that's centuries ago, the technology has moved far away from this. . . . And the other thing, of course, what we enhance more and more is, say, the online business that you can find things online, see how it's used, find spare parts, find manuals, find explanations, how to use it. Again, it's also necessary more and more because it gets more specialized over time	Extending strategy Greening strategy Circular practice Channels Key Activities Incentivise for long-lasting usage Service support	24.Virtual service support for longvity through Youtube and website. 19. Sustainable insights promotion for energy consumption through the app. 20. Create awareness about green actions for energy consumption and incentive customer through the app. 42. Educate customers how to consume less energy with the appliances online and in experience centres. 43. Educate customers on how to use the appliances in order to achieve longevity online and in experience centres.
3:28	Transcript Interview Case company 3	Exactly. I'll give you another example. I mean, if you think about food waste we have an oven with a camera inside. So the camera sees what's in the oven, and you apply, corresponding, you know, program. And if you put in a pizza, for instance, it cannot burn anymore because the oven knows it's a pizza. And if it's say, done, the oven is switched off. No food waste.	Greening strategy Circular practice Industry 4.0 technology Product/Offering Incentivise to reduce consumption Question 2 Sustain natural ecosystem	36. Appliances are designed to reduce energy consumption and waste with AI.
3:29	Transcript Interview Case company 3	The oven more or less understands what you put inside. And in the past you simply say, okay, I put it on 200	Greening strategy	25. Appliances are designed to reduce consumables and

		degrees for whatever 15 minutes. But actually this way of heating the oven is non-sustainable. It's simple but it's better to do it, you know, stepwise to reach a certain point and then go down. But it depends on what is inside the oven. With the camera and understanding the oven gets more and more intelligent. And then the food gets better and you even reduce the power consumption. So that, that's a very simple example. And it's the same thing if you go for a dosing system. the machine understands how much clothes are in the washing machine. And then you dose correspondingly, you can even put in whatever, just one piece and, and, and wash that. Again it's more and more intelligent appliance that, that you, that you have at home.	Circular practice Industry 4.0 technology Product/Offering Big data, cloud computing & analytics for energy management and optimisation Incentivise to reduce consumption Reduce material usage Sustain natural ecosystem	energy consumption. Using AI, ML and smart components
3:30	Transcript Interview Case company 3	Is here also AI or machine learning involved into these devices itself? Speaker A: Of course. And it constantly like learns and gets better over time.	Narrowing strategy Industry 4.0 technology Product/Offering AI, ML & AR for usage and end-of-life prediction Question 2 Question 8	25. Appliances are designed to reduce consumables and energy consumption. Using AI, ML and smart components
3:31	Transcript Interview Case company 3	And I think that the recycled material is more expensive than the Virgin one. Currently is also an effect. You can argue based on additional regulations, because companies are forced to, to use recycled materials more and more, which I can understand from a, you know, general societal point of view, but you would just turn the markets and it's not easy to, to react on that. So it's the way how you regulate this market and really develop it in such a way that it really becomes circular and not only more expensive or circular and more expensive. It's not easy.	Cycling strategy Cost structure	11. Recycled materials more expensive then virgin raw materials.
3:32	Transcript Interview Case company 3	Do you see potential cost savings there, ... Speaker A: I'm not sure. I mean, this is a modular approach. . . . If you do that, or for, for, say, a lifetime of 20 years after 20 years, you have totally different device there. . . . . And so there's a tipping point sort of	Extending strategy	44. Remanufacture/refurbishing of old devices not always feasible due to energy efficiency or old fashioned appearence and non-compliance

		where, where this modularity does not really help you because the whole thing is, is different. And it's not totally only related to appliance industry. Think about, you know, computer systems. I mean, would you think about a computer 20 years ago, right? And you, and someone says, okay, use it right now. You can switch the board a little bit, but then still use and say, well, you know what? It doesn't work anymore. So that's a little bit of the same story.	Circular practice Cost structure Remanufacture/Refurbish	materials. 45. Modular production for remanufacturing doesn't save costs yet.
3:51	Transcript Interview Case company 3	new appliance and then you have a chance really to go for new different types of materials	Narrowing strategy Circular practice Product/Offering Substitute with innovative materials	46. Products made of innovative materials to reduce material consumption or increase recyclability.
7:1	Sustainability report Case company 3	The second field of focus looks at *Company's name* products and the way they are packaged. As the aim here is to further improve their sustainability scorecard, the tasks at hand include closing material cycles through the use of recycles or by improving the ability to repair products, to name just two examples.	Cycling strategy Extending strategy Circular practice Product/Offering Design for ease of maintenance	3. Design products for ease of repair. 6. Using recycled materials.
7:2	Sustainability report Case company 3	The latter contributes to the exceptional durability of *Company's name* products, which has proven to be valuable from an ecological perspective.	Extending strategy Circular practice Product/Offering Design for durability/longevity	1. Offer high quality and longevity home appliances
7:3	Sustainability report Case company 3	Increasing resource efficiency is another item on the agenda. The goal is to ensure supply security for *Company's name* in the long term while preserving reserves of raw materials for future generations. *Company's name* plans to lay the groundwork for achieving this goal during product development.	Narrowing strategy Circular practice Product/Offering Reduce material usage	47. Products offered are build based on the minimum possible material consumption.
7:4	Sustainability report Case company 3	With regard to the packaging used in shipping, a project team is tasked with continuously reviewing alternative materials so that *Company's name* can continue switching to more environmentally friendly solutions. *Company's name* also strives to use recycled or recyclable materials more often for the packaging of cleaning and care products.	Cycling strategy Narrowing strategy Product/Offering	48. Product packaging is designed to use as less possible packaging material.
7:5	Sustainability report Case company 3	With its durable and recyclable products, *Company's name* is already	Circular practice Cycling strategy Extending strategy	1. Offer high quality and longevity home appliances

		making a positive contribution to resource conservation today	Product/Offering Design for durability/longevity	6. Using recycled materials.
7:6	Sustainability report Case company 3	Featuring timelessly elegant design they are also crafted to be intuitive and as accessible as possible for all users.	Extending strategy Circular practice Product/Offering Design for durability/longevity	49. Products have a timeless design.
7:7	Sustainability report Case company 3	There are various areas of focus here, including durability, recyclability, repairability and the energy and resource efficiency of appliances in real-world use.	Cycling strategy Extending strategy Greening strategy Product/Offering	36. Appliances are designed to reduce energy consumption and waste. 12. Design for recyclability by selecting recyclable materials. 3. Design products for ease of repair.
7:8	Sustainability report Case company 3	app helps consumers use leftover foods creatively.	Greening strategy Channels	19. Sustainable insights promotion for energy consumption through the app.
7:9	Sustainability report Case company 3	the *Company's subsidiary name* concept for shared use of *Company's name* washing machines and tumble dryers, including online reservations and cashless payment. The idea of using *Company's subsidiary name* to make it easier and more flexible to use and manage appliances provided centrally – in larger apartment complexes or student housing, for example – arose in the smart home area of expertise.	Intensifying strategy Channels Product/Offering Revenue Streams	30. Product sharing offer for communal settings. 50. Online platform to manage product sharing. 31. Revenue from charging per use model.
7:10	Sustainability report Case company 3	Under the "pay-per-use" model, customers only pay for individual units of output rather than buying an appliance.	Intensifying strategy Revenue Streams	31. Revenue from charging per use model.
7:11	Sustainability report Case company 3	offering a leasing service for washing machines since 2016. The service involves billing users on the basis of their actual use. The low-cost leasing model allows even price-conscious households such as groups of flatmates to conserve resources by using high-quality, efficient appliances	Intensifying strategy Customer Revenue Streams	31. Revenue from charging per use model. 33. Network usage of consumers which aim for lower pricing (student dorms)
7:12	Sustainability report Case company 3	The low-cost leasing model allows even price-conscious households such as groups of flatmates to conserve resources by using high-quality, efficient appliances.	Intensifying strategy Circular practice Customer Consume collaboratively	33. Network usage of consumers which aim for lower pricing (student dorms)
7:13		*Company's subsidiary name*, another start-up, to offer the programme. When	Cycling strategy	

	Sustainability report Case company 3	users terminate the leasing contract, the appliance is returned to *Company's subsidiary name* and prepared for the next user.	Key Partners	51. Partners for shared product collection and redistributing.
7:14	Sustainability report Case company 3	washing machines and dishwashers are capable of using sensor data to dispense exactly the right amount of detergent.	Narrowing strategy Industry 4.0 technology Product/Offering AI, ML & AR for usage and end-of-life prediction	25. Appliances are designed to reduce consumables and energy consumption. Using AI, ML and cyber-physical systems.
7:15	Sustainability report Case company 3	function in dishwashers, also allows for smart inventory management, including convenient ordering of replacement supplies of cleaning products via the *Company's name* app	Narrowing strategy Resources & Capabilities	52. Smart inventory management for consumables and ordering through app.
7:16	Sustainability report Case company 3	advises business customers on the cost-effective use of efficient washing machines, tumble dryers and dishwashers in shared facilities such as utility rooms or employee kitchenettes.	Greening strategy Key Activities	42. Educate customers how to consume less energy with the appliances online and in experience centres.
7:17	Sustainability report Case company 3	Depending on the model, coffee machines from *Company's name* feature automatic cleaning and descaling functions for which *Company's name* offers special cartridges. This ensures efficient cleaning, which in turn contributes to the durability of the product.	Extending strategy Circular practice Key Activities Incentivise for long-lasting usage	53. Offer maintenance products to ensure longevity.
7:18	Sustainability report Case company 3	customers can use this function to get information about their appliances' operating status, control them using voice commands or get explanations of features.	Extending strategy Key Activities	54. Product status insights through app for consumer.
7:19	Sustainability report Case company 3	offers a remote maintenance function for connected machines to handle software updates that may be necessary. Available updates can be downloaded and installed on the machine in question remotely if the customer wishes.	Extending strategy Channels Circular practice Service support	18. Virtual service support for longevity through app. Potentially using AR.
7:20	Sustainability report Case company 3	The app provides information on machine status and sends a signal when detergent is running low.	Narrowing strategy Resources & Capabilities	52. Smart inventory management for consumables and ordering through app.
7:21	Sustainability report Case company 3	These activities focused on the digital transformation of customer service, with customers' possible future expectations as one area of analysis.	Extending strategy Resources & Capabilities	55. Digital transformation of customer service and analysis.

7:22	Sustainability report Case company 3	product philosophy has been to offer its customers products of exceptional quality and with a particularly long service life. As a company focused on sustainability, *Company's name* also pays great attention to energy efficiency.	Extending strategy Product/Offering	1. Offer high quality and longevity home appliances
7:23	Sustainability report Case company 3	users have the current consumption values of their dishwasher under control. Even before the cycle starts, they receive a forecast on the water and electricity consumption for the selected programme. They can therefore find out at a glance, for example, that a programme operating at a longer cycle time or lower temperature will require less energy. At the end of the programme, the appliance displays the actual consumption in kilowatt-hours and litres.	Greening strategy Channels	19. Sustainable insights promotion for energy consumption through the app.
7:24	Sustainability report Case company 3	include timeless design, good repairability and the ability to update control software to the latest version later on.	Extending strategy Product/Offering	49. Products have a timeless design. 3. Design products for ease of repair. 56. Offering software or module upgrades.
7:25	Sustainability report Case company 3	software improvements can be installed not just on new appliances, but also on those that have already been produced.	Extending strategy Product/Offering	56. Offering software or module upgrades.
7:26	Sustainability report Case company 3	The company also introduced a remote maintenance function in 2020, which has already made it possible to optimise or expand the software in domestic appliances in many countries around the world from a distance.	Extending strategy Channels	18. Virtual service support for longevity through app. Potentially using AR.
7:27	Sustainability report Case company 3	appliances are renowned for their reliability. Nevertheless, over the course of a long appliance life, faults may occur that require the assistance of the service team. In order to keep customer costs low in such cases, the appliances are designed to be "repair-friendly". This means that as little effort as possible should be required to repair or replace a component.	Extending strategy Circular practice Product/Offering Design for ease of maintenance	3. Design products for ease of repair.
7:28	Sustainability report Case company 3	various channels of communication to inform its customers about sustainability, including information provided on the product (EU energy consumption labelling), operating instructions, product brochures and	Channels	Not usable for framework

		consultations with dealers and in showrooms around the world, as well as international trade fairs.		
7:29	Sustainability report Case company 3	From material defects to manufacturing errors, *Company's name* two-year manufacturer warranty means > repairs are free of charge for customers. For added peace of mind, customers can extend the warranty to five or ten years as long as it has not yet expired	Extending strategy Key Activities	57. Product warranties to ensure product quality and durability.
7:30	Sustainability report Case company 3	Virtual reality is increasingly important in the visualisation of kitchen designs at kitchen and furniture stores.	Narrowing strategy Resources & Capabilities Simulations	58. visualization software with simulation software to reduce resource utilization.
7:31	Sustainability report Case company 3	The collection, storage, processing and use of all personal customer data are performed according to data protection rules.	Cycling strategy Extending strategy Industry 4.0 technology Resources & Capabilities Big data, cloud computing & analytics for usage patterns identification for service improvement, upgrade	38. Big data, Cloud computing and simulation software for product resource consumption optimalization, recyclability and durability.
7:32	Sustainability report Case company 3	product reaches the end of its typical long useful life, the next step is to send it for recycling or for further disposal via a return system.	Cycling strategy Resources & Capabilities	4. Recycle end-of-life appliances. 59. Further disposal via return system.
7:33	Sustainability report Case company 3	actively works on continuously improving the return systems. The company's special focus here is on the areas of logistics and protecting the environment.	Cycling strategy Channels Key Partners Resources & Capabilities	Not usable for framework
7:34	Sustainability report Case company 3	engages with consumers in particular through various channels, initiatives and campaigns, sharing information on how to properly return old appliances for environmentally responsible disposal.	Cycling strategy Channels Circular practice Key Activities	60. Engage with customers to communicate the recycling value. 61. Incentivise and educate customers to return products for

			Incentivise to return	reuse and redistribution in the right way.
7:35	Sustainability report Case company 3	Making sure an appliance is recyclable down the line is a factor as early as during > product development. For example, *Company's name* works with waste management companies and operators of treatment plants to study the potential effects on disposal or initial treatment and recycling of appliances at the end of a product's life. Both domestic and commercial appliances from *Company's name* are characterised by a very high level of recyclability. This is achieved through various means, including careful selection of materials and bonding techniques.	Cycling strategy Product/Offering	12. Design for recyclability by selecting recyclable materials.
7:36	Sustainability report Case company 3	Wherever it may be possible and practical without affecting quality, *Company's name* investigates whether secondary or alternative, more recyclable materials can be used.	Cycling strategy Narrowing strategy Circular practice Product/Offering Substitute with innovative materials	6. Using recycled materials. 46. Products made of innovative materials to reduce material consumption or increase recyclability
7:37	Sustainability report Case company 3	and has implemented various projects to recycle components from old *Company's name* appliances	Cycling strategy Resources & Capabilities	4. Recycle end-of-life appliances.
7:38	Sustainability report Case company 3	Increasingly focusing on circular models to boost the use of recycled and recyclable materials.	Cycling strategy Product/Offering	12. Design for recyclability by selecting recyclable materials.
7:39	Sustainability report Case company 3	Throughout the world, *Company's name* strives to ensure that its materials are recycled in an environmentally friendly manner along the entire waste management chain	Greening strategy Customer Relationships Key Partners	62. Partnering for environmentally friendly recycling of materials along the entire waste management chain.
7:40	Sustainability report Case company 3	*Company's name* partners with waste management companies to pick up and properly dispose of the quantities of waste equipment that stiftung ear has assigned to the company throughout Germany.	Cycling strategy Circular practice Key Partners localise supply chain	63. Partner with waste management companies to collect and properly dispose of waste equipment.
7:41	Sustainability report Case company 3	In other EU countries, *Company's name* uses similar – and in some cases state-run – return and recycling systems,	Greening strategy	64. Local waste management partners, for shorter

		such as *State's Subsidiary name* in Belgium, *State's Subsidiary name* in France and *State's Subsidiary name* in Austria. Outside the EU, *Company's name* makes use of the established disposal systems already in place.	Circular practice Key Partners localise supply chain Take-back/Reverse logistics	environmentally friendly waste chain
7:42	Sustainability report Case company 3	*Company's name* offers to accept returns of old appliances of the same type when a new appliance is purchased online as well.	Cycling strategy Resources & Capabilities	65. Take-back system of old appliance when new one is purchased.
7:43	Sustainability report Case company 3	When buying a new appliance, customers can state whether they would like to have the dealer dispose of the old one. When the new product is delivered, the dealer takes the registered old appliance and delivers it either to a municipal collection point or directly to initial handling and recycling.	Cycling strategy Channels Circular practice Key Partners Resources & Capabilities localise supply chain	65. Take-back system of old appliance when new one is purchased. 66. Partner with retailers for used appliances collection and recycling.
7:44	Sustainability report Case company 3	This campaign aims to raise awareness among consumers of how to properly return old appliances.	Cycling strategy Key Activities	61. Incentivise and educate customers to return products for reuse and redistribution in the right way.
7:45	Sustainability report Case company 3	*Name* online information platform. This website provides waste management companies and other interested parties with recycling information for various types of appliance directly from the manufacturer, including information on hazardous substances and components.	Cycling strategy Customer Relationships	67. Facilitating third recycling parties with information about hazardous substances and components online.
7:46	Sustainability report Case company 3	products are mainly produced in Germany and other European countries; 84 percent of deliveries to *Company's name* plants – based on purchasing volume – come from Europe. This, coupled with > optimised transport logistics and the bundling of goods flows, saves on transport costs and reduces transport-related CO2 emissions.	Greening strategy Circular practice Cost structure Key Activities localise supply chain	68. Savings because of localized and optimized logistics. 69. Optimized logistics to reduce CO2 pollution.
7:47	Sustainability report Case company 3	is in the process of switching its energy supply to fully renewable sources, with all global sites set to procure green electricity by the end of 2021.	Greening strategy Product/Offering	70. Use renewable energy for own processes.
8:1	Sustainability update report Case company 3	we offer our customers warranties of up to 10 years.	Extending strategy Key Activities	57. Product warranties to ensure product quality and durability.
8:2			Cycling strategy	

	Sustainability update report Case company 3	Suitable old machines are overhauled and offered to consumers as an attractively priced alternative to a new machine. Beforehand, they are thoroughly inspected by trained service technicians, fitted with new spare parts and updated with the latest software.	Key Activities Product/Offering Revenue Streams	16. Reassure that reselling appliances meet quality requirements and energy efficiency performance. 5. Refurbish and resell used appliances.
8:3	Sustainability update report Case company 3	app records consumption in the programmes used, provides tips on more efficient machine usage and helps to further reduce water and electricity consumption.	Greening strategy Channels	19. Sustainable insights promotion for energy consumption through the app.
8:4	Sustainability update report Case company 3	Reducing emissions and the use of resources, improving energy efficiency and expanding power generation using renewable sources: All this is promoted at our production locations.	Greening strategy Product/Offering	70. Use renewable energy for own processes.
9:1	Blog articles Case company 3	sourcing green steel from its partner	Cycling strategy Key Partners	10. Collaboration with recycled material suppliers.
9:2	Blog articles Case company 3	Over 80% basically want to save more energy	Greening strategy Customer	41. Eco-conscious customers for energy consumption of the appliances.

Appendix C

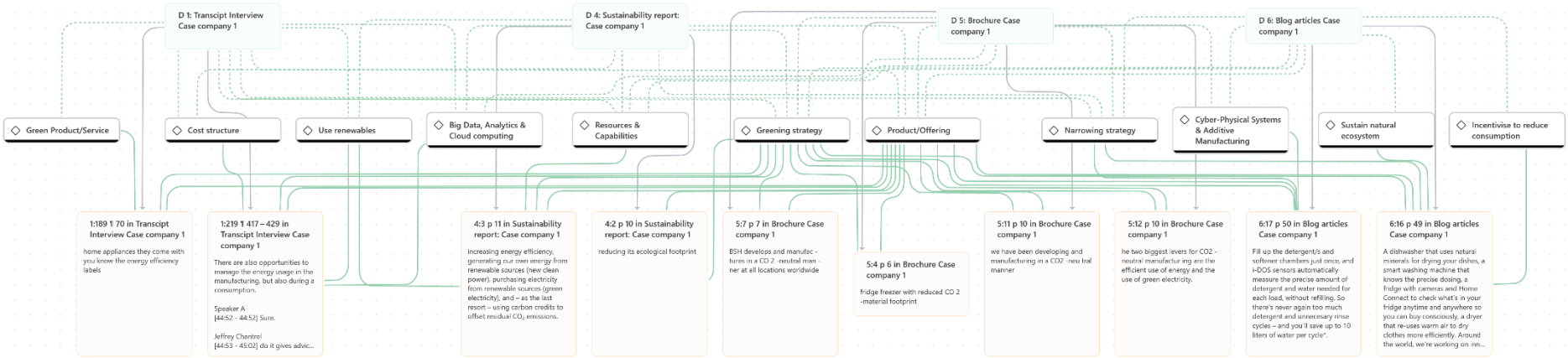


Figure 11: Product/Offering - Greening strategy - Case company 1

Appendix D

Circular Strategies	Circular Practices	Enabling Technologies (Industry 4.0)	Circular Business Model Elements									
			Value Proposition			Value Creation & Delivery				Value Capture		
			Product/Service	Customer	Customer Relationships	Key Activities	Key Partners	Resources & Capabilities	Channels	Cost structure	Revenue Streams
Greening **Sustain & Regreen**	- Use renewables (logistics, production) - Sustain natural ecosystems - Power products with renewables - Green-based partnerships	- Data collection for energy efficiency - Connectivity with partners - Energy management and optimisation - System (energy, ecosystem) modelling - Scenario testing (weather conditions, energy loads)	Energy consumption optimisation in manufacturing. Products have low environmental footprint and are energy efficient Using renewable energy in own processes.	Dutch customers more receptive towards sustainable offering.	Supplier assessment for collaboration with partners based on a sustainability index	Educate customers to use only green products and not greenwashed products. Assist customers about energy efficiency actions through app.	Emission reduction with logistic partners.	Supplier assessment software to promote sustainable value chain. Build-up renewables capacity by buying and producing.	Stakeholder engagement on sustainability and circularity topics.	Economic benefits from energy efficiency	Reputational benefits for sustainability practices.
Narrowing **Reduce & Localize**	- Reduce materials usage - Substitute with innovative materials - Balance supply and demand - Service vs. Product - Incentivise to reduce consumption - Localise supply chain	- Data collection for service monitoring - Connectivity for supply and demand monitoring - Data analysis for consumption pattern recognition and reduction - Prediction algorithms for supply and demand - Life-cycle expectancy prediction - Conceptual service development and user education - Scenario testing for product development with alternative or less materials	Product offering is based on the minimum possible material consumption. Product packaging is designed to use as less possible packaging material. Substitute materials from the EU's REACH candidate list for other materials if technically feasible. Product uses cyber-physical systems and AI to reduce or optimise consumption.		Localisation of reselling used appliances			Algorithms that help selecting recyclable and regulation compliant materials.		Manufacturing cost reduction due to efficient resource utilisation.	
Cycling **Reversing & Reuse**	- Reuse/Resell - Recycle - Redistribute - Take-back system / Reverse logistics - Incentivise to return - Cascade/Repurpose - Recover elements/materials/parts - Industrial Symbiosis	- Resources tracking and condition monitoring - Connectivity with customers for products return - Data transparency and verifiability - Secure resources trading among stakeholders - Material/product condition prediction - Consumption patterns analysis for reselling and efficient redistribution - Automation for optimised resources recovery - Efficient resources collection and shorting	Products made of recycled materials. Products are designed for recyclability. Product packaging is designed to use recycled packaging material. Using AI in sustainable product development.		Parts and material trade among industries to cover material needs without additional resource input to the system.	Collecting end-of-life products. Recycle end-of-life products. Local redistributors for reselling used products. Access end-of-life products and retrieve useful resources from waste. Reassure that recycled or second-life products have good quality and can serve the intended functionalities and purpose.	WEEE partners for reverse logistics, resource circulation and product collection. Trading-based collaborations	Product traceability with IoT Closing materials and products loops.	Channels for recycle information flows with retailers. Software platform for collaboration with partners.	Higher cost for recycled materials.	Non-financial benefits, reputational benefits from working with semi-charity organisations for reselling used products.

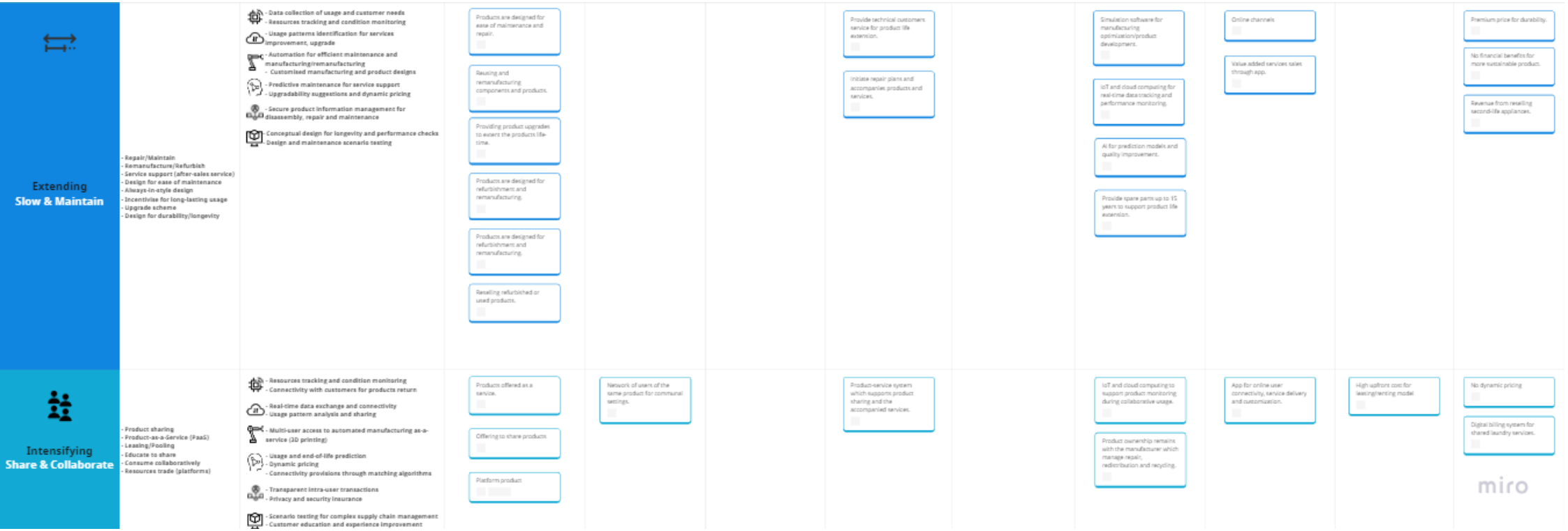


Figure 12: Current CE-I4.0T Nexus Framework Case company 1

Circular Strategies	Circular Practices	Enabling Technologies (Industry 4.0)	Circular Business Model Elements								
			Value Proposition			Value Creation & Delivery				Value Capture	
			Product/Service	Customer	Customer Relationships	Key Activities	Key Partners	Resources & Capabilities	Channels	Cost structure	Revenue Streams
Greening **Sustain & Regreen**	- Use renewables (logistics, production) - Sustain natural ecosystems - Power products with renewables - Green-based partnerships	- Data collection for energy efficiency - Connectivity with partners - Energy management and optimisation - System (energy, ecosystem) modelling - Scenario testing (weather conditions, energy loads)	Processes with Zero targets. Energy efficiency. Appliances are designed to have a low environmental footprint, with energy efficiency, water efficiency and CO2 emission.					Make creative partnerships which embrace green energy, enabled by connected appliances and data sharing. Using environmentally friendly packaging from recycled materials.			
Narrowing **Reduce & Localize**	- Reduce materials usage - Substitute with innovative materials - Balance supply and demand - Service vs. Product - Incentivise to reduce consumption - Localise supply chain	- Data collection for service monitoring - Connectivity for supply and demand monitoring - Data analysis for consumption pattern recognition and reduction - Prediction algorithms for supply and demand - Life-cycle expectancy prediction - Conceptual service development and user education - Scenario testing for product development with alternative or less materials						Predictive models which assist in customer satisfaction, service offerings and demand prediction.			
Cycling **Reversing & Reuse**	- Reuse/Resell - Recycle - Redistribute - Take-back system / Reverse logistics - Incentivise to return - Cascade/Repurpose - Recover elements/materials/parts - Industrial Symbiosis	- Resources tracking and condition monitoring - Connectivity with customers for products return - Data transparency and verifiability - Secure resources trading among stakeholders - Material/product condition prediction - Consumption patterns analysis for reselling and efficient redistribution - Automation for optimised resources recovery - Efficient resources collection and shorting			Collaboration technologies to efficiently manage information and product flows with partners.	Reassure that refurbished products have good quality by refurbish the products just as new. End-of-life strategies when other re-routes are non-beneficial.	Reverse logistics partners which are purposed for product return and resource circulation. Cooperation with facilitators and redistributors for product collection, inspection and direct selling. Recycle and reverse logistics partners which ensure transparency and traceability.	Take-back systems after end of contract or termination. IoT to support traceability.		Resell refurbished appliances.
Extending **Slow & Maintain**	- Repair/Maintain - Remanufacture/Refurbish - Service support (after-sales service) - Design for ease of maintenance - Always-in-style design - Incentivise for long-lasting usage - Upgrade scheme - Design for durability/longevity	- Data collection of usage and customer needs - Resources tracking and condition monitoring - Usage patterns identification for services improvement, upgrade - Automation for efficient maintenance and manufacturing/remanufacturing - Customised manufacturing and product designs - Predictive maintenance for service support - Upgradability suggestions and dynamic pricing - Secure product information management for disassembly, repair and maintenance - Conceptual design for longevity and performance checks Design and maintenance scenario testing	Appliances are designed for durability. Design for ease of maintenance and repair Offer just as new refurbished appliances. Appliance upgrade or service upgrade offers. Design connected appliances.			Provide upgrade plan to gain commitment. Initiate repair plan and predicted maintenance with IoT, data analytics.	Ecosystem collaboration which will support repair, refurbish activities and recycling.	Offer product upgrades or service upgrades to incentive customers using the product longer. IoT to support real-time data transfer and performance monitoring. IoT, data analytics and predictive models exploitation to ensure product life extension.		

Figure 13: Current CE-I4.0T Nexus Framework Case company 2

Circular Strategies	Circular Practices	Enabling Technologies (Industry 4.0)	Circular Business Model Elements								
			Value Proposition			Value Creation & Delivery				Value Capture	
			Product/Service	Customer	Customer Relationships	Key Activities	Key Partners	Resources & Capabilities	Channels	Cost structure	Revenue Streams
Greening **Sustain & Regreen**	- Use renewables (logistics, production) - Sustain natural ecosystems - Power products with renewables - Green-based partnerships	- Data collection for energy efficiency - Connectivity with partners - Energy management and optimisation - System (energy, ecosystem) modelling - Scenario testing (weather conditions, energy loads)	Appliances are designed to reduce energy consumption and waste with AI. Use renewable energy for own processes.	Eco-conscious customers for energy consumption of the appliances.		Create awareness about green actions for energy consumption and incentive customer through the app. Educate customers how to consume less energy with the appliances online and in the experience centres. Optimised logistics to reduce CO2 pollution.	Partnering for environmentally friendly recycling of materials along the entire waste management chain. Local waste management partners, for shorter environmentally friendly waste chain		Sustainable insights promotion for energy consumption through the app.	Savings because of localised and optimised logistics.	
Narrowing **Reduce & Localize**	- Reduce materials usage - Substitute with innovative materials - Balance supply and demand - Service vs. Product - Incentivise to reduce consumption - Localise supply chain	- Data collection for service monitoring - Connectivity for supply and demand monitoring - Data analysis for consumption pattern recognition and reduction - Prediction algorithms for supply and demand - Life-cycle expectancy prediction - Conceptual service development and user education - Scenario testing for product development with alternative or less materials	Appliances are designed to reduce consumables and energy consumption. Using AI, ML and cyber-physical systems. Products made of innovative materials to reduce material consumption or increase recyclability Products offered are build based on the minimum possible material consumption. Product packaging is designed to use as less possible packaging material.		Ensure reduced product consumption through optimized consumables offering.	Consumables are offered as a service with the aim to reduce consumption as much as possible		Big data, Cloud computing and simulation software for product resource consumption optimalization, recyclability and durability. Smart inventory management for consumables and ordering through app. visualization software with simulation software to reduce resource utilization.			Revenue stream from optimised consumables.
Cycling **Reversing & Reuse**	- Reuse/Resell - Recycle - Redistribute - Take-back system / Reverse logistics - Incentivise to return - Cascade/Repurpose - Recover elements/materials/parts - Industrial Symbiosis	- Resources tracking and condition monitoring - Connectivity with customers for products return - Data transparency and verifiability - Secure resources trading among stakeholders - Material/product condition prediction - Consumption patterns analysis for reselling and efficient redistribution - Automation for optimised resources recovery - Efficient resources collection and shorting	Offer refurbished appliances Appliances made of recycled plastics and steel Design for recyclability by selecting recyclable materials.		Facilitating third recycling parties with information about hazardous substances and components online.	Reassure that reselling appliances meet quality requirements and energy efficiency performance. Incentivise and educate customers to return products for reuse and redistribution in the right way.	Collaboration with recyled material suppliers Partner with waste management companies to collect and properly dispose of waste equipment. Partner with retailers for used appliances collection and recycling.	Recycle end-of-life appliances Big data, Cloud computing and simulation software for product resource consumption optimalization, recyclability and durability. Further disposal via return system. Take-back system of old appliance when new one is purchased.	Data flow for material/product properties from and to suppliers and reverse logistics providers. Engage with customers to communicate the recycling value.	Invest in more expensive recycled materials	Revenue from Reselling used/refurbished appliances

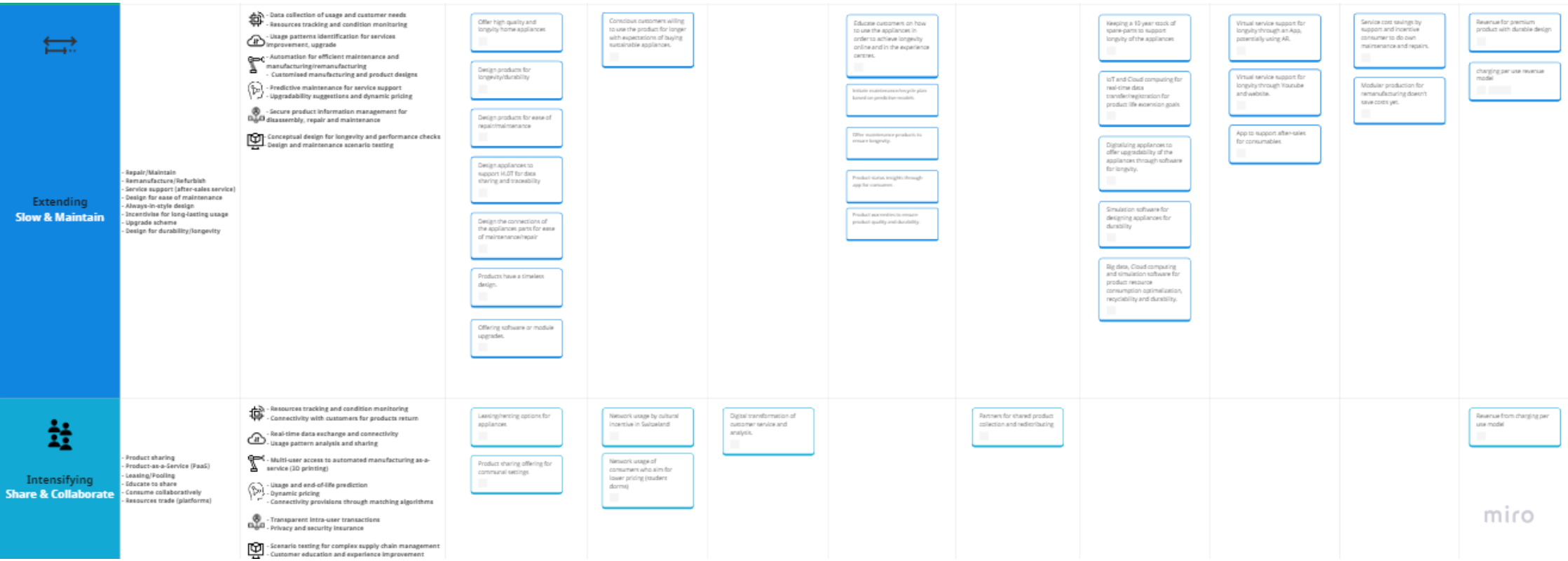


Figure 14: Current CE-I4.0T Nexus Framework

Appendix E

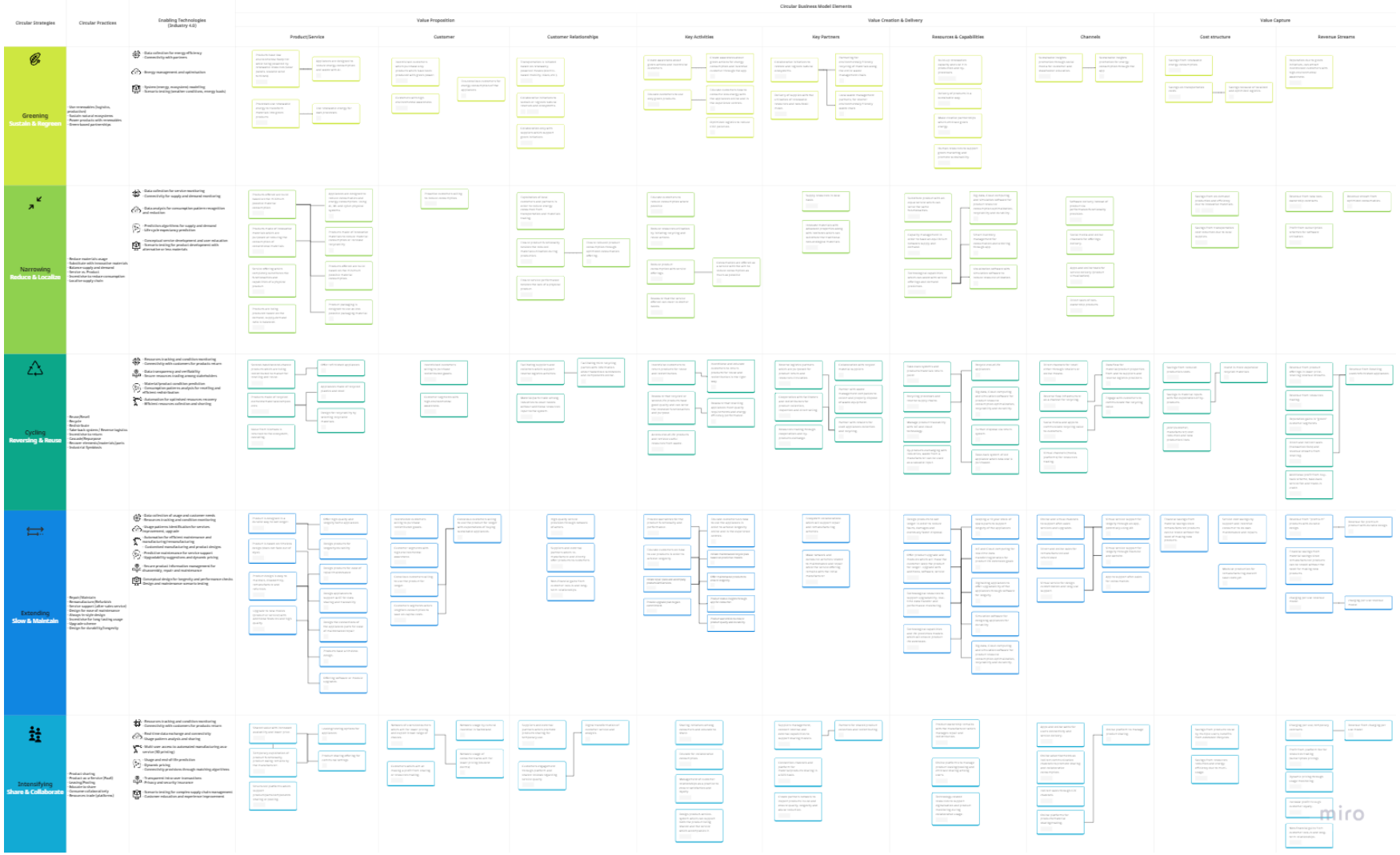


Figure 15: CE-I4.0T Nexus Framework Case company 1

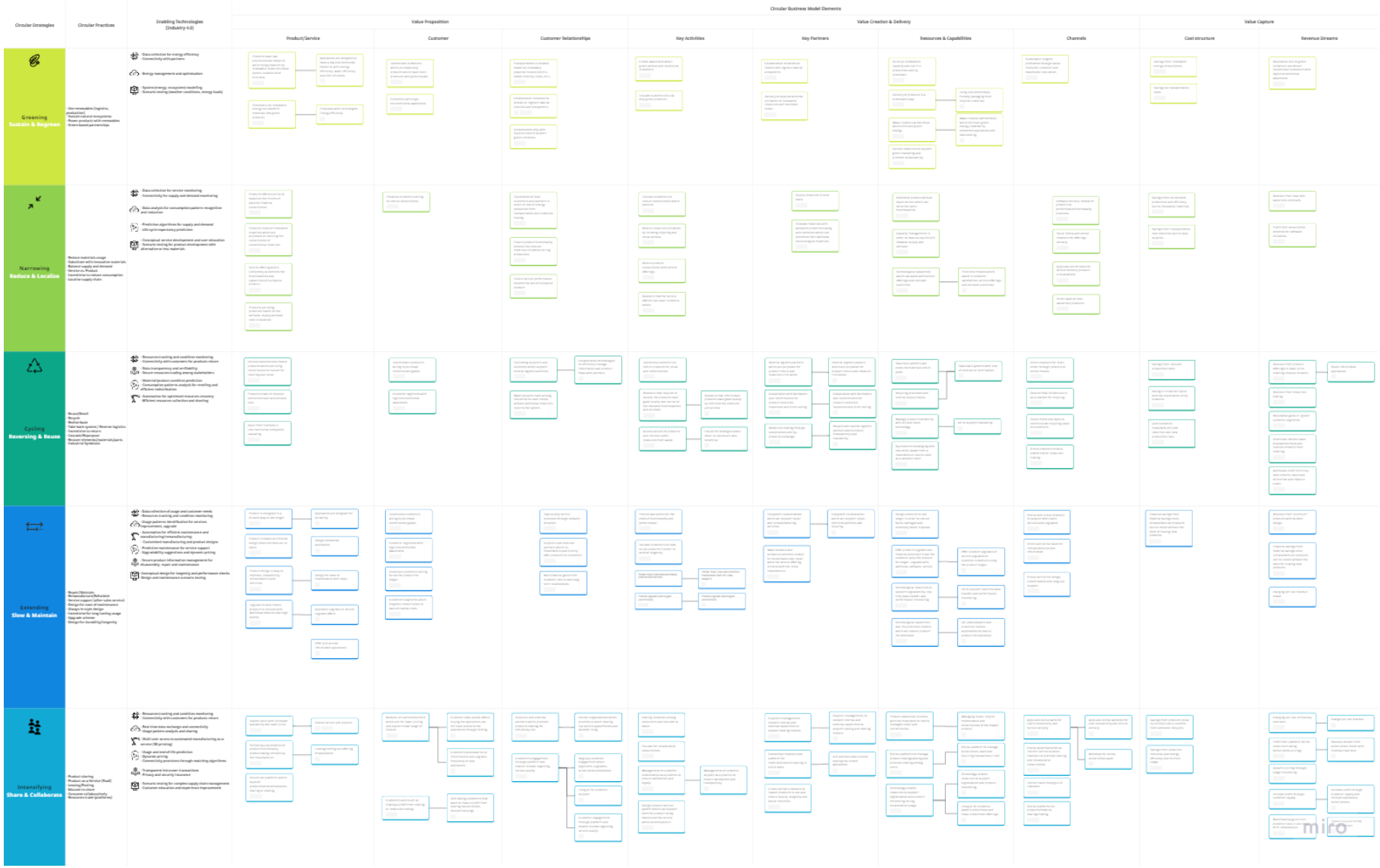


Figure 16: CE-I4.0T Nexus Framework Case company 2

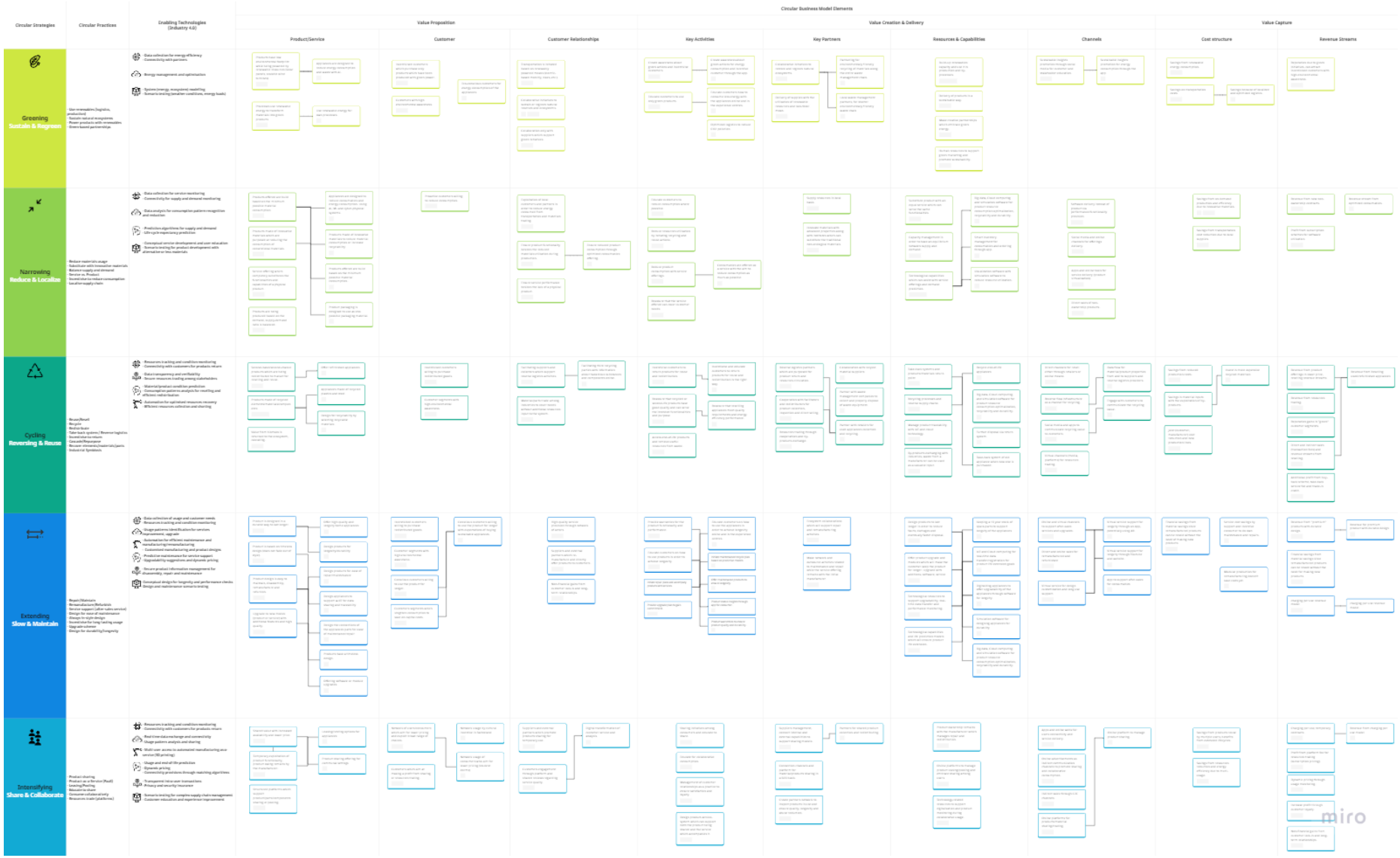
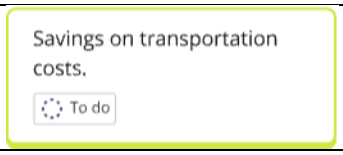
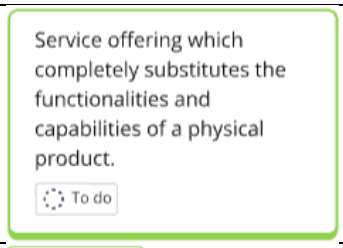
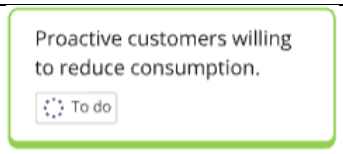
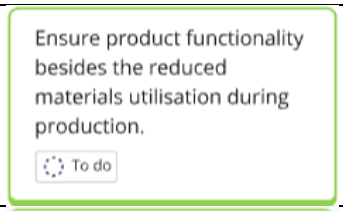
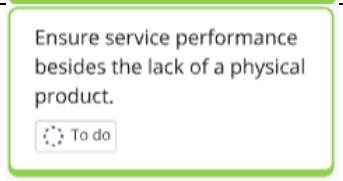
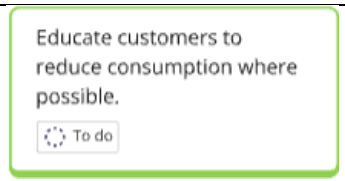


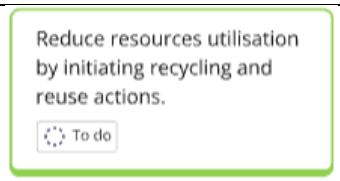
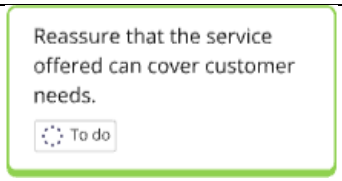
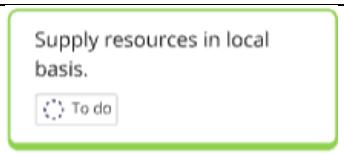
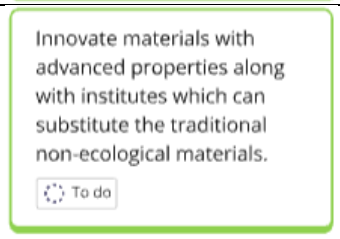
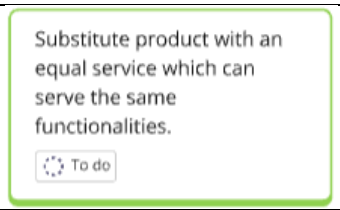
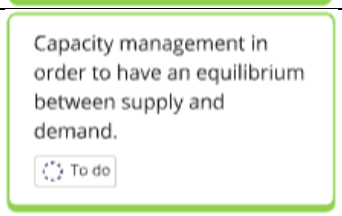
Figure 17: CE-I4.0T Nexus Framework Case company 3

Appendix F

Table 23: GAP analysis Case company 1

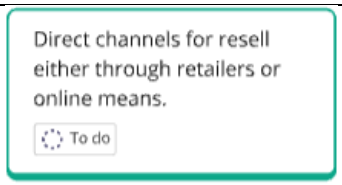
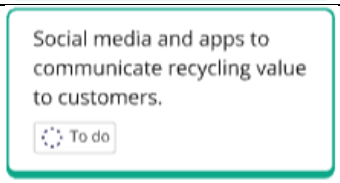
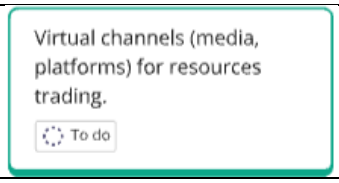
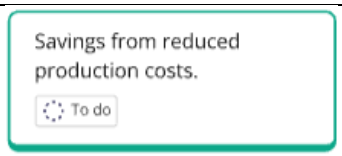
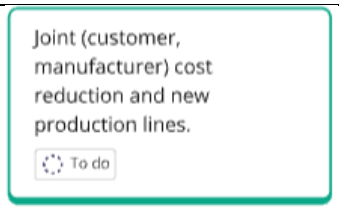
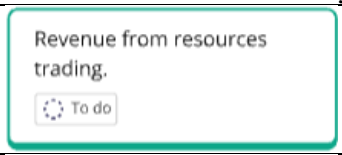
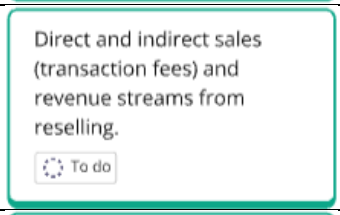
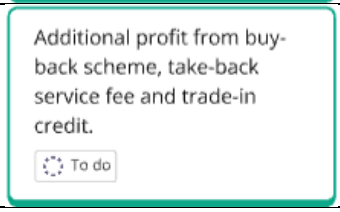
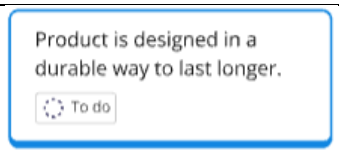
Nr.	Practices	Comments
	Greening strategy – Customer	
1.	Incentivised customers which purchase only products which have been produced with green power. To do	Not mentioned in the data, However the opposite is mentioned in quotation Interview case company 1: 1:174: "So everyone would say they care about sustainability. But if you ask if they're willing to pay more for sustainable products, the answer is at the moment a rather resounding no."
	Greening strategy – Customer Relationships	
2.	Transportation is initiated based on renewably powered means (electric-based mobility, bikes, etc.). To do	Not mentioned in the data. Mentioned in the data is that the case company is focussed on reducing the CO2 pollutions and optimizes transportation efficiency. The case company is selling physical products. Future improvements could be: 1. using electric or hydrogen-powered means of transportation. 2. Another strategy could be to localize supply chains. Smaller factories closer to the client. Feedback: We are piloting certain solutions according to local conditions. With e-bike delivery and electrical service buses. Also used to perform repairs at the customer place.
3.	Collaborative initiatives to sustain or regreen natural reserves and ecosystems. To do	Not mentioned in the data. Future improvements could be: 1. Investments in regreen initiatives.
	Greening strategy – Key Partners	
4.	Delivery of supplies with the utilisation of renewable resources and non-fossil mean. To do	Not mentioned in the data. Mentioned in the data is that the case company is focussed on reducing the CO2 pollutions and optimizes transportation efficiency. The case company is selling physical products. Future improvements could be: 1. using electric or hydrogen-powered means of transportation.
	Greening strategy – Resources & Capabilities	
5.	Delivery of products in a sustainable way. To do	Not mentioned in the data. Mentioned in the data is that the case company is focussed on reducing the CO2 pollutions and optimizes transportation efficiency. The case company is selling physical products. Future improvements could be: 1. using electric or hydrogen-powered means of transportation. Another point related to this practices is to reduce packaging material and substitute packaging material with recyclable materials. This practice is implemented at the case company.
6.	Human resources to support green marketing and promote sustainability. To do	Not directly mentioned in the data. Future improvements: 1. Part of the marketing team focus on green marketing and sustainability. Feedback:

		We do have colleagues working on sustainability and green marketing topics, but not full time. The goal is to integrate sustainability in their day to day work instead of a separate organization.
Greening strategy – Cost structure		
7.		Not directly mentioned in the data. Future improvements: 1. Combine transportation needs with local partners in order to only transport fully loaded trucks. 2. Localize the supply chain
Narrowing strategy – Product/Service		
8.		Not mentioned in the data. The case company manufactures and sells household appliances. The functions these physical products fulfil are difficult to offer through software.
9.		The company's products are developed with technology to reduce consumable consumption. The practice from the default framework refers to the pull principle. Where products are manufactured according to the demand. This is not mentioned in the data. Future improvements: 1. Use predictive models to predict demand and manufacture accordingly. 2. Reconfigure manufacturing process for flexible product manufacturing. For efficient order-based manufacturing.
Narrowing strategy – Customer		
10.		Not mentioned in the data. Feedback: We are observing developing trends among the younger generation (Millennials and Gen Z)
Narrowing strategy – Customer relationships		
11.		Not mentioned in the data. Future improvements: 1. Comprehensive life-cycle testing. 2. Product lifetime warranties 3. Product monitoring during use phase.
12.		Not mentioned in the data. As stated before the case company's products are hard to substitute with a service only model.
Narrowing strategy – Key activities		
13.		Not mentioned in the data. However, the case company has implemented technologies into the products to reduce consumption. This must be a topic inside the company. Future improvements: 1. Educate customers how to correctly use the implemented technology. 2. Educate customers on the benefits of using the implemented consumption reduction features.

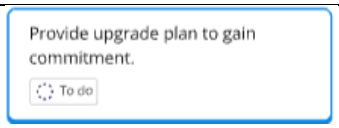
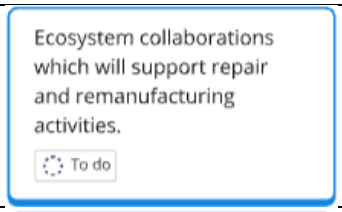
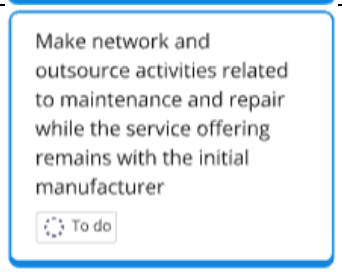
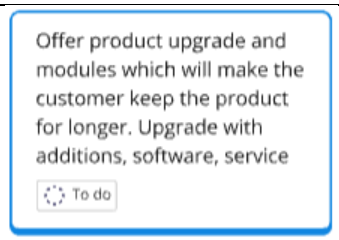
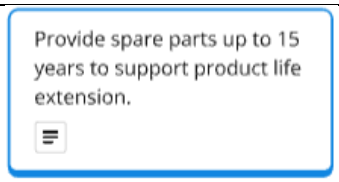
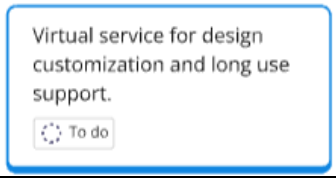
14.		In the data quotes are shown for recycle and reuse actions. However, the data doesn't mention reduce resources utilization because of these actions. Future improvements: 1. Reprocess recycled materials to make new products. 2. Remanufacture old appliances to new products. Feedback: We are under the of scope of WEEE regulation and thus have extended producer responsibility to ensure electronic waste is properly taken care of. We have internal recycled content and product recyclability targets.
15.		The company's products are developed with technology to reduce consumable consumption. The practice from the default framework refers to the pull principle. Where products are manufactured according to the demand. This is not mentioned in the data. Future improvements: 1. Use predictive models to predict demand and manufacture accordingly. 2. Reconfigure manufacturing process for flexible product manufacturing. For efficient order-based manufacturing.
16.		Not mentioned in the data. As stated before the case company's products are hard to substitute with a service only model. However, if interpreted as reassure that the secondary service offered can cover customer needs. The following future improvements can be made: 1. Customer requirements survey 2. Customer satisfaction analysis
Narrowing strategy – Key Partners		
17.		Not mentioned in the data. Future improvements: 1. Source materials in local surroundings of the factories
18.		The case company does substitute non-ecological materials where technical feasible. However, partnering with institutes to develop innovative materials specifically to substitute the non-ecological materials is not mentioned in the data. Future improvement: 1. Partner with institutions to innovate new ecological and recyclable materials which can substitute the current non-ecological materials.
Narrowing strategy – Resources & Capabilities		
19.		Not mentioned in the data. As stated before the case company's products are hard to substitute with a service only model.
20.		The company's products are developed with technology to reduce consumable consumption. The practice from the default framework refers to the pull principle. Where products are manufactured according to the demand. This is not mentioned in the data. Future improvements: 1. Use predictive models to predict demand and manufacture accordingly. 2. Reconfigure manufacturing process for flexible product manufacturing. For efficient order-based manufacturing.

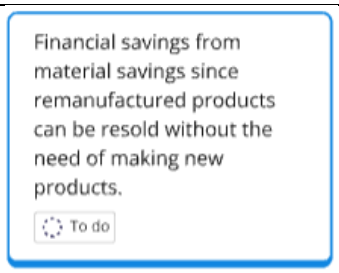
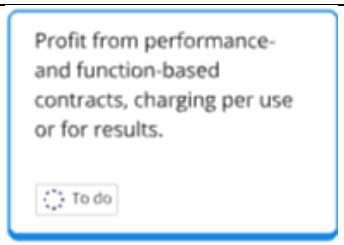
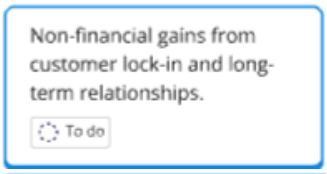
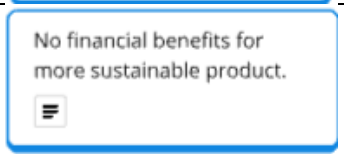
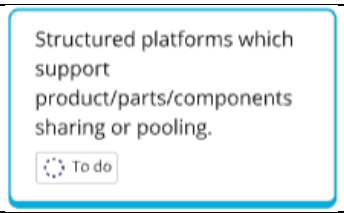
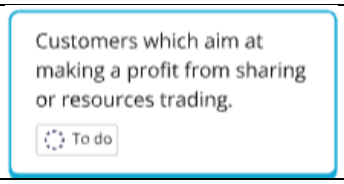
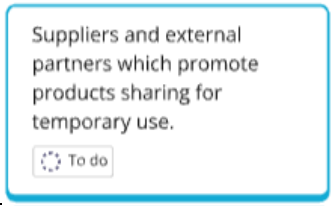
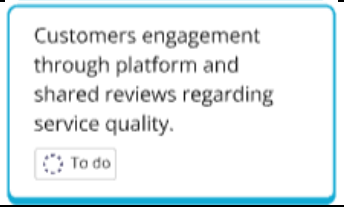
21.	Technological capabilities which can assist with service offerings and demand prediction. To do	Connected appliances with software and real-time data transfer for life-time status and consumable consumption which can be exploited for demand prediction and manufacturing accordingly.
22.	Algorithms that help selecting recyclable and regulation compliant materials.	This practices stems from the data and was not part of the default framework. However, this practices shows how technology can help companies to effectively comply to regulations while improving their product designs for recyclability.
Narrowing strategy – Channels		
23.	Software delivery instead of product via performance/functionality provision. To do	Not mentioned in the data. The company could provide software updates for the appliances to extend the product life time and/or reduce consumption of energy, water and consumables. If the appliances are connected the software can be updated remotely.
24.	Social media and online channels for offerings delivery. To do	The case company delivers a physical product which cannot be delivered online.
Narrowing strategy – Cost structure		
25.	Savings from on demand production and efficiency due to innovative materials. Done Manufacturing cost reduction due to efficient resource utilization.	Mentioned in the data is the fact that manufacturing cost are reduced when less material is used. However, this practices is also relating to demand production and innovative materials. These practices are not mentioned in the data. Future improvements: 1. Demand-based manufacturing 2. Innovate new ecological and recyclable materials
26.	Savings from transportation cost reduction due to local supplies. To do	Local supplies are not mentioned in the data. Future improvements: 1. Source supplies locally.
Narrowing strategy - Revenue streams		
27.	Revenue from new non-ownership contracts. To do	Probably this practice is in place, because the case company is offering shared and renting/leasing offerings. However, it is not specifically mentioned in the data.
28.	Profit from subscription schemes for software utilisation. To do	Not mentioned in the data. Future improvements: 1. Energy efficiency insights and prediction features in the app can be monetized through subscription scheme. 2. Predictive maintenance insights feature in the app can be monetized through subscription scheme.
Cycling strategy – Product/Service		
29.	Second-hand/second-chance products which are being redistributed to market for reselling and reuse. To do	Second-hand/second-chance products are given to semi-charity organizations. However, from the data it is not clear if these appliances are resold by the case company or donated. Future improvements: 1. Develop a second-chance appliances marketplace to sell used products.

30.	Value from biomass is returned to the ecosystem, cascading. To do	This practice is not mentioned in the data. Future improvements: 1. Cascading manufacturing waste and end-of-life product waste. 2. Using manufacturing waste and end-of-life product waste as in input to the manufacturing process. 3. Sell waste to other companies for which this waste could be a manufacturing input.
31.	Product packaging is designed to use recycled packaging material.	This practice stems from the data and was not a default practice. However, a great improvement for the framework.
32.	Using AI in sustainable product development.	This practice stems from the data and was not a default practice.
	Cycling strategy – Customer	
33.	Incentivised customers willing to purchase redistributed goods. To do	Not mentioned in the data. However, this can be implied by the fact that used products are redistributed through the semi-charity partner organizations.
34.	Customer segments with high environmental awareness. To do	Not mentioned in the data, However the opposite is mentioned in quotation Interview case company 1: 1:174: "So everyone would say they care about sustainability. But if you ask if they're willing to pay more for sustainable products, the answer is at the moment a rather resounding no."
	Cycling strategy – Customer Relationships	
35.	Facilitating suppliers and collectors which support reverse logistics activities. To do	Not mentioned in the data. Future improvements: 1. Implementing digital product passport.
	Cycling strategy – Key Activities	
36.	Incentivise customers to return products for reuse and redistribution. To do	Not mentioned in the data. Future improvements: 1. Buy-back schemes 2. Repair offering
	Cycling strategy – Key Partners	
37.	Cooperation with facilitators and redistributors for product collection, inspection and direct selling. To do	In the data WEEE partners are mentioned for reverse logistics, resource circulation and product collection. However, partners for collection, inspection and reselling are not mentioned. 1. Cooperate with partners for collection, inspection, repair and reselling.
38.	Resources trading through cooperatives and by-products exchange. To do	Not mentioned in the data. Future improvements: 1. Resource trading instead of land-fill.

Cycling strategy – Channels		
39.		Not mentioned in the data. Future improvements: 1. Setting up channels for reselling. 2. Online marketplace with remote quality control through connected devices with remote diagnostics.
40.		Not mentioned in the data. Interviewee explains that the case company is careful with sustainability marketing because of greenwashing. Future improvements: 1. Use social media to incentivise customers for recycling.
41.		Not mentioned in the data. Future improvements: 1. Provide services for product/part/material collection.
Cycling strategy – Cost structure		
42.		Not mentioned in the data. Future improvements: 1. Optimized resource utility. Less material is used which will reduce production cost. 2. Reuse manufacturing waste or sell it on the market.
43.		Instead of savings from recycled material, the interviewee mentioned that recycled material is in most cases more expensive then virgin raw material.
44.		Not mentioned in the data. Future improvements: 1. Product delivery in parts and easy to assemble by the customer. 2. Part manufacturing instead of product manufacturing.
Cycling strategy – Revenue streams		
45.		Not mentioned in the data. Future improvements: 1. Manufacturing waste material trading. 2. End-of-life materials trading.
46.		Not mentioned in the data.
47.		Not mentioned in the data. Future improvements: 1. Buy-back scheme appliances and resell them for more. 2. Free take-back service for old appliances, for remanufacture, refurbish or resource trading. 3. Giving trade-in credit which can be spend on consumables or product discounts.
Extension strategy – Product/Service		
48.		Feedback: *Case company's name* is extending the availability of its spare parts for most of its large appliances such as washing machines, dishwashers and stoves from 10 to 15 years. Spare parts for small appliances,

		including fully automatic coffee machines or vacuum cleaners, will also be offered for longer, with *Case company's name* extending their availability from 7 to 10 years for most models. This refers to all functionally relevant and storable parts for appliances produced after 1 January 2023. The move underscores *Case company's name*'s commitment to quality and durability.
49.	Product is based on timeless design (does not fade out of style). To do	Not particular mentioned in the data. Future improvements: 1. Develop timeless designs and avoid hypes and trends. 2. Design quickly obsolete parts for ease of replacement.
Extension strategy – Customer		
50.	Incentivized customers willing to purchase redistributed goods. To do	Not particular mentioned in the data.
51.	Customer segments with high environmental awareness. To do	Not particular mentioned in the data.
52.	Conscious customers willing to use the product for longer. To do	Not particular mentioned in the data.
53.	Customers segments which lengthen consumption to save on capital costs. To do	Not particular mentioned in the data.
Extension strategy – Customer Relationships		
54.	High quality service provision through network of actors. To do	Not particular mentioned in the data. Future improvements: 1. Online training platform for retailers, delivery partners, used product collectors. 2. Digital maintenance support (potentially with AR).
55.	Suppliers and external partners which re-manufacture and directly offer products to customers. To do	Not mentioned in the data. Future improvements: 1. Source partners for remanufacturing and reselling. 2. Remote quality control through connected devices with remote diagnostics. 3. Digital product passport which provides partner organizations with all the data about a particular product to remanufacture, maintain and resell it.
56.	Non-financial gains from customer lock-in and long-term relationships. To do	Not mentioned in the data. Future improvements: 1. Data gathering for product or service improvements or testing new offerings.
Extension strategy – Key Activities		

57.		Not mentioned in the data. Future improvements: 1. Inform customers about a new version of the product they already have and give them a loyalty bonus. 2. Provide updates for the offering when in use by the customer.
Extension strategy – Key Partners		
58.		Not mentioned in the data. Future improvements: 1. Source partners for remanufacturing and reselling.
59.		Not mentioned in the data. Future improvements: 1. Work with local maintenance and repair specialists to create shorter supply chains and save the investment into an own maintenance and repair department which could be very costly.
Extension strategy – Resources & Capabilities		
60.		Not mentioned in the data. Might already be in place. Future improvements: 1. Make sure products are designed modularly with the aim to be able to change parts or software in the future to improve the performance of the product and help the customer to have the product as long as possible. 2. Provide software or hardware upgrades when new features are developed or new products will be lanced.
61.		This practice was not part of the default framework, but worth mentioning. Keeping spare parts for a long time is an big investment in providing a service for product extension. Feedback: *Case company's name* is extending the availability of its spare parts for most of its large appliances such as washing machines, dishwashers and stoves from 10 to 15 years. Spare parts for small appliances, including fully automatic coffee machines or vacuum cleaners, will also be offered for longer, with *Case company's name* extending their availability from 7 to 10 years for most models. This refers to all functionally relevant and storable parts for appliances produced after 1 January 2023. The move underscores *Case company's name*'s commitment to quality and durability.
Extension strategy – Channels		
62.		Not mentioned in the data. Company could offer virtual maintenance, repair or upgrade service through the app or website.
Extension strategy – Cost structure		

63.		Statements about this practice are not mentioned in the data.
Extension strategy – Revenue streams		
64.		Not mentioned in the data. But likely function-based contracts with charging per use is in place. In the data is mentioned a digital billing system for shared laundry services. It is possible that this billing system is based on a charging per use model. However, this is not certain.
65.		Not mentioned. What is mentioned as a non-financial gain is the benefit of attracting many new talents and student who are sustainability conscious and will work at the case company.
66.		This practice is not a part of the default framework. Interestingly the interviewee mentioned that customers claim that the sustainability of a product is important for them. However, it turns out that most customers are not willing to pay a premium for more sustainable products
Intensifying strategy – Product/Service		
67.		Not mentioned in the data. Future improvements: 1. Platform to find, reserve and pay for the service of the products available and accessible to share.
Intensifying strategy – Customer		
68.		This practice is not mentioned in the data. Future improvements: 1. Support customers who want to provide the product of the case company as a shared product.
Intensifying strategy – Customer Relationships		
69.		This practice is not particularly mentioned in the data.
70.		This practice is not particularly mentioned in the data. The case company offers already a connectivity app. Through this app customers engagement could be increased. The app can ask customers for their feedback after a service delivery or product delivery. Surveys can be provided through the app. This data can be used to optimize the service and product offering.
Intensifying strategy – Key Activities		

71.	Sharing initiatives among consumers and educate to share. To do	The case company has processes in place to provide sharing services. However, I cannot derive from the data particular sharing initiatives or how the case company educates to share. Marketing could aim to educate customers to share. With communicating the benefits for sharing the products or show how to possibly share.
72.	Educate for collaborative consumption. To do	The case company has processes in place to provide sharing services. However, I cannot derive from the data particular how the case company educates for collaborative consumption. Feedback: *Case company's subsidiary* aims to making communal washing and drying attractive for everyone involved.
73.	Management of customer relationships as a practice to ensure satisfaction and loyalty. To do	Not particularly mentioned in the data.
Intensifying strategy – Key Partners		
74.	Suppliers management, connect internal and external capabilities to support sharing models. To do	This practice is not particularly mentioned in the data.
75.	Connection channels and platform for material/products sharing in a B2B basis. To do	This practice is not particularly mentioned in the data. Could be a feature of the supplier platform?
76.	Create partners network to inspect products in use and ensure quality, longevity and abuse reduction. To do	This practice is not particularly mentioned in the data. In use product inspection could also be partly done remotely with remote diagnostics. Periodically physical inspections are also important. With device connectivity and predictive models the software can automate periodically inspection planning with location of each product. An automated email or signal can be send to the local inspection partner to plan for the inspection in a certain time frame.
Intensifying strategy – Resources & Capabilities		
77.	Online platforms to manage product leasing/pooling and embrace sharing among users. To do	This practice is not particularly mentioned in the data.
Intensifying strategy – Channels		
78.	Online advertisements as indirect communication channels to promote sharing and collaborative consumption. To do	This practice is not particularly mentioned in the data.

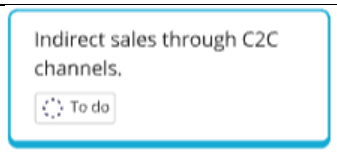
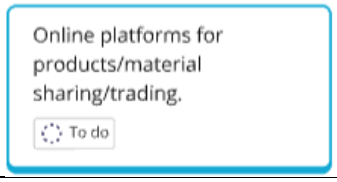
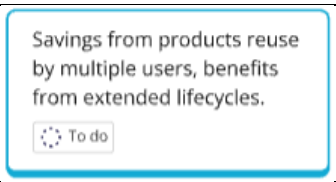
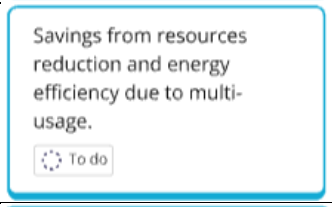
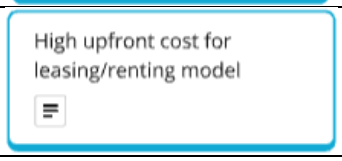
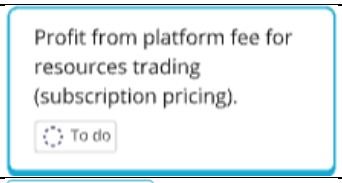
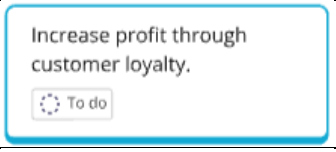
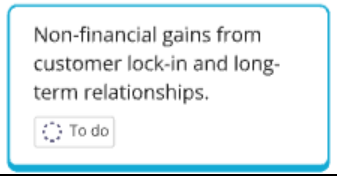
79.		This practice is not particularly mentioned in the data. The case company could provide a product marketplace where customers can sell or rent out their new or used products. The case company can benefit from the data and provides the quality or can offer the services the products need and customers cannot provide to each other.
80.		This practice is not particularly mentioned in the data.
Intensifying strategy – Cost structure		
81.		This practice is not particularly mentioned in the data. As WEEE partner keeping product as long as possible in use could be beneficial because collecting, recycling or cascading old appliances is expensive?
82.		This is probably true, however not particularly mentioned in the data. Feedback: The case company offers a green collection fridge which helps reduce carbon emissions.
83.		This practices is not part of the default framework. However worthwhile mentioned. A downside of the leasing/renting business model are the high upfront investments. This was also mentioned by the interviewee. This is why it is included in this framework.
Intensifying strategy – Revenue streams		
84.		This is not mentioned in the data.
85.		In the data it was mentioned that dynamic pricing is not involved. This could be an option for the charge per use services that when energy prices are low for example the price for a service on that particular moment is also lower. Dynamic pricing for example could also mean that customers receive discounts per use to more frequently they use the services.
86.		This is not mentioned in the data. However, in a sharing business model it becomes more and more beneficial is multiple subscriptions are offered to the same customer. Delivery, services and returns are more efficient.
87.		Satisfied and loyal customers generate mouth to mouth marketing. Satisfied an loyal customers are more open to share information and help optimizing the case company products and services.

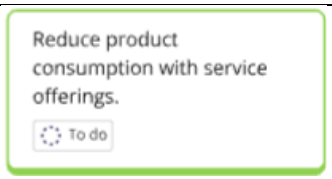
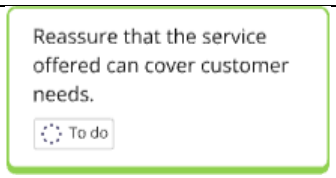
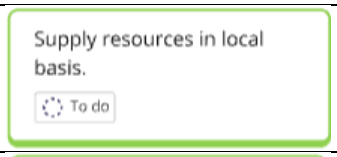
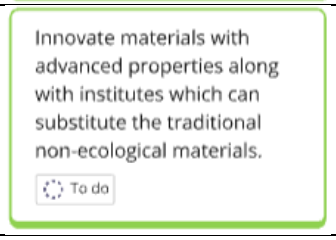
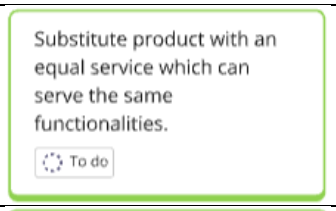
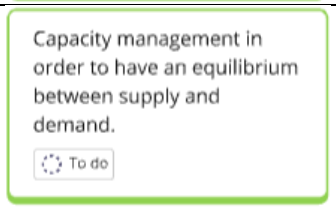
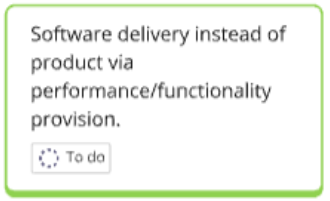
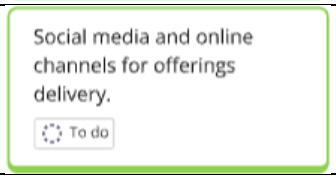
Table 24: GAP analysis Case company 2

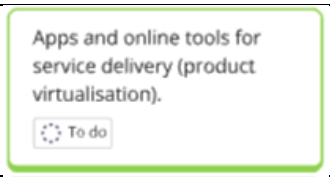
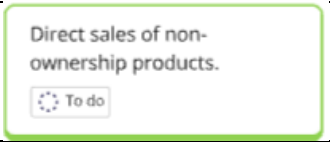
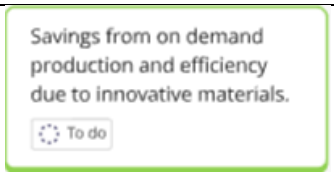
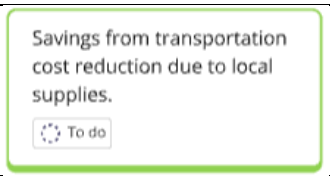
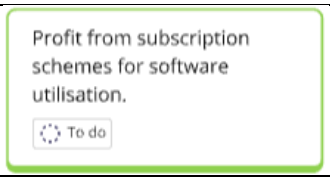
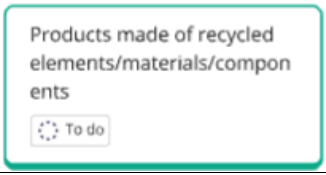
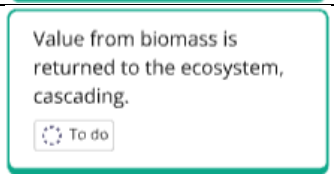
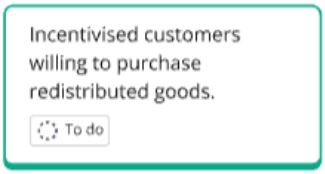
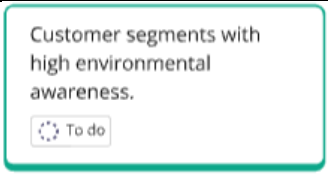
Nr.	Practices	Comments
Greening strategy – Customer		

1.	Incentivised customers which purchase only products which have been produced with green power. To do	Not mentioned in the data.
2.	Customers with high environmental awareness. To do	Not mentioned in the data.
Greening strategy – Customer Relationships		
3.	Transportation is initiated based on renewably powered means (electric-based mobility, bikes, etc.). To do	Not mentioned in the data. The case company is selling physical products. Future improvements could be: 1. using electric or hydrogen-powered means of transportation. 2. Another strategy could be to localize supply chains. Smaller factories closer to the client.
4.	Collaborative initiatives to sustain or regreen natural reserves and ecosystems. To do	Not mentioned in the data. Future improvements could be: 1. Investments in regreen initiatives.
5.	Collaboration only with suppliers which support green initiatives. To do	Not mentioned in the data.
Greening strategy – Key Activities		
6.	Create awareness about green actions and incentivise customers To do	Not mentioned in the data. If not already in place the case company could through marketing and incentivising customers to lease appliances instead of buying and advice customers to use the appliances in an eco-friendly way.
7.	Educate customers to use only green products. To do	Not mentioned in the data.
Greening strategy – Key Partners		
8.	Collaborative initiatives to restore and regreen natural ecosystems. To do	Not mentioned in the data.
9.	Delivery of supplies with the utilisation of renewable resources and non-fossil mean. To do	Not mentioned in the data. The case company is selling physical products. Future improvements could be: 1. using electric or hydrogen-powered means of transportation.
Greening strategy – Resources & Capabilities		

10.	Build-up renewables capacity and use it in production and by-processes. To do	Not mentioned in the data. The case company is selling physical products. Future improvements could be: 1. using electric or hydrogen-powered means of transportation. 2. Another point related to this practices is to reduce packaging material and substitute packaging material with recyclable materials. This practice is implemented at the case company.
11.	Human resources to support green marketing and promote sustainability. To do	Not directly mentioned in the data, but might be in place. Future improvements: 1. Part of the marketing team focus on green marketing and sustainability.
	Greening strategy – Channels	
12.	Sustainable insights promotion through social media for customer and stakeholder education. To do	Not mentioned in the data. Case company 2 could use their social media platforms to give insights of how to use the products in the most sustainable way. Tips about maintenance for a longer product lifetime could also be given.
	Greening strategy – Cost structure	
13.	Savings from renewable energy consumption. To do	Not mentioned in the data. Savings in renewable energy consumption could result from energy efficient appliances for the customer. On the other side, savings from renewable energy consumption is relate to the energy usage of the case company itself.
14.	Savings on transportation costs. To do	Not directly mentioned in the data. Future improvements: 1. Combine transportation needs with local partners in order to only transport fully loaded trucks. 2. Localize the supply chain
	Greening strategy – Revenue streams	
15.	Reputation due to green initiatives, can attract incentivised customers with high environmental awareness. To do	Not mentioned in the data. In the data is mentioned that customers of case company 2 are customers who want to be more flexible with their home appliances and for example upgrade to a newer appliance more frequently. For other customers buying high-end appliances is not affordable and therefore they rent the appliances. Incentivised customers with high environmental awareness from case company 2 can be attracted due to case company 2's offering of leasing and that they refurbished used appliances to extent their product life cycle with reducing the input of virgin raw materials into the economic system.
	Narrowing strategy – Product/Service	
16.	Products offered are build based on the minimum possible material consumption To do	Not mentioned in the data. Case company 2 is dependent on a manufacturer. However, it might be possible to co-design new appliances based on minimum possible material consumption.
17.	Products made of innovative materials which are purposed at reducing the consumption of conventional materials. To do	Not mentioned in the data. Case company 2 is dependent on a manufacturer. However, it might be possible to co-design new appliances based on using innovative eco-friendly materials.

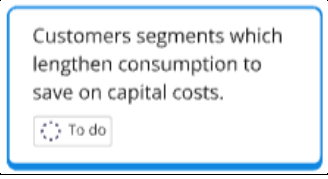
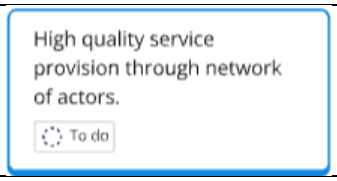
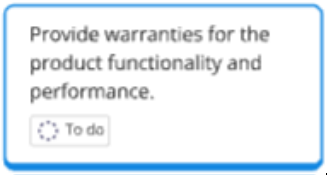
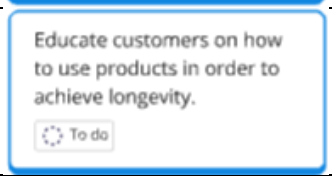
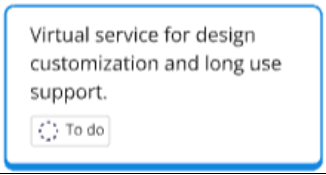
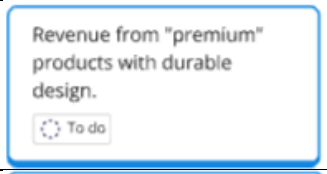
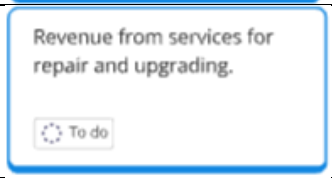
18.	Service offering which completely substitutes the functionalities and capabilities of a physical product. To do	Not mentioned in the data. The case company leases out household appliances. The functions these physical products fulfil are difficult to offer through software.
19.	Products are being produced based on the demand, supply-demand ratio is balanced. To do	Not mentioned in the data. Case company 2 is dependent on a manufacturer. The practice from the default framework refers to the pull principle. Where products are manufactured according to the demand. This is not mentioned in the data. Future improvements: 1. Use predictive models to predict demand and buying appliances accordingly. 2. Share demand predictions with the manufacturer for efficient order-based manufacturing.
Narrowing strategy – Customer		
20.	Proactive customers willing to reduce consumption. To do	Not mentioned in the data.
Narrowing strategy – Customer relationships		
21.	Exploitation of local customers and partners in order to reduce energy consumed from transportation and materials trading. To do	Not mentioned in the data. Case company 2 leases out home appliances to customers. A potential improvement could be to collect end-of-contract appliances at a local partner who does the inspection and refurbishment. Case company 2 could subsequently find new customers for the refurbished appliances near to the refurbish partner. Data analytics and algorithms can support in optimizing local supply chain and delivery.
22.	Ensure product functionality besides the reduced materials utilisation during production. To do	Not mentioned in the data. Future improvements: 1. Comprehensive life-cycle testing. 2. Product lifetime warranties 3. Product monitoring during use phase.
23.	Ensure service performance besides the lack of a physical product. To do	Not mentioned in the data. As stated before the case company's products are hard to substitute with a service only model.
Narrowing strategy – Key activities		
24.	Educate customers to reduce consumption where possible. To do	Not mentioned in the data. However, the case company leases out appliances with technologies into the products to reduce consumption. Future improvements: 1. Educate customers how to correctly use the implemented technology. 2. Educate customers on the benefits of using the implemented consumption reduction features.
25.	Reduce resources utilisation by initiating recycling and reuse actions. To do	The data doesn't mention reduce resources utilization. Future improvements: 1. Return recycled materials to the manufacturer. 2. Remanufacture old appliances to new products.

26.		The company's products are developed with technology to reduce consumable consumption. The practice from the default framework refers to the pull principle. Where products are manufactured according to the demand. This is not mentioned in the data. Future improvements: 1. Use predictive models to predict demand and buying appliances accordingly. 2. Share demand predictions with the manufacturer for efficient order-based manufacturing.
27.		Not mentioned in the data. As stated before the case company's products are hard to substitute with a service only model. However, if interpreted as reassure that the secondary service offered can cover customer needs. The following future improvements can be made: 1. Customer needs survey 2. Customer satisfaction analysis These practices are implemented by case company 2 and mentioned in quotation; 2:27
Narrowing strategy – Key Partners		
28.		Not mentioned in the data. Case company 2 doesn't manufacturer the appliances itself. Future improvements: 1. Work together with the manufacturer to support local resource sourcing.
29.		Case company 2 doesn't manufacture the products. However, they can co-design and develop the products. Future improvement: 1. Partner with manufacturer and institutions to innovate new ecological and recyclable materials which can substitute the current non-ecological materials.
Narrowing strategy – Resources & Capabilities		
30.		Not mentioned in the data. As stated before the case company's products are hard to substitute with a service only model.
31.		The practice from the default framework refers to the pull principle. Where products are manufactured according to the demand. This is not mentioned in the data. Future improvements: 1. Use predictive models to predict demand and buying appliances accordingly. 2. Share demand predictions with the manufacturer for efficient order-based manufacturing.
Narrowing strategy – Channels		
32.		Not mentioned in the data. The company could provide software updates for the appliances to extend the product life time and/or reduce consumption of energy, water and consumables. If the appliances are connected the software can be updated remotely. Software cannot replace the functionalities of the physical product.
33.		The case company delivers a physical product which cannot be delivered online.

34.		Not mentioned in the data. Future improvements: 1. App to manage contracts and control the connected appliances. 2. Online tool to simulate energy consumption of intended subscription products.
35.		Not mentioned in the data, but likely that this is in place. 1. App to manage subscription contracts
Narrowing strategy – Cost structure		
36.		This practices is also relating to demand production and innovative materials. These practices are not mentioned in the data. Future improvements: 1. Demand-based procurement 2. Innovate new ecological and recyclable materials in partnership with manufacturer.
37.		Local supplies are not mentioned in the data. Future improvements: 1. Source supplies locally.
Narrowing strategy - Revenue streams		
38.		Not mentioned in the data. However the offering includes services, maintenance and repair. Future improvements: 1. Energy efficiency insights and prediction features in the app can be monetized through subscription scheme.
Cycling strategy – Product/Service		
39.		Packaging is made with recycled material. In the data is not mentioned that the products are also made of recycled material.
40.		This practice is not mentioned in the data. Future improvements: 1. Cascading manufacturing waste and end-of-life product waste. 2. Using manufacturing waste and end-of-life product waste as in input to the manufacturing process. 3. Sell waste to other companies for which this waste could be a manufacturing input.
Cycling strategy – Customer		
41.		Not mentioned in the data. However, this can be implied by the fact that used products are refurbished and redistributed.
42.		Not mentioned in the data.
Cycling strategy – Customer Relationships		

43.	Material/parts trade among industries to cover needs without additional resources input to the system. To do	This practice is not mentioned in the data. Future improvements: 1. Sell waste to other companies for which this waste could be a manufacturing input.
Cycling strategy – Key Activities		
44.	Incentivise customers to return products for reuse and redistribution. To do	Not mentioned in the data. But likely that case company 2 tries to incentivise customers to use refurbished appliances. Return is included in the subscription at the end of the contract or at termination of the contract as the appliances are owned by case company 2.
Cycling strategy – Resources & Capabilities		
45.	By-products exchanging with industries, waste from a manufacturer can be used as a valuable input. To do	This practice is not mentioned in the data. Future improvements: 1. Sell waste to other companies for which this waste could be a manufacturing input.
Cycling strategy – Channels		
46.	Reverse flow infrastructure as a channel for recycling. To do	Not mentioned in the data. However, an reserve infrastructure must be in place at case company 2 because they need to return end-of-contract appliances. If there is a reverse infrastructure for recycling in place is unsure yet.
47.	Social media and apps to communicate recycling value to customers. To do	Not mentioned in the data. Future improvements: 1. Use social media to incentivise customers for recycling.
48.	Virtual channels (media, platforms) for resources trading. To do	Not mentioned in the data.
Cycling strategy – Cost structure		
49.	Savings from reduced production costs. To do	Not mentioned in the data. Case company 2 doesn't manufacture the appliances.
50.	Savings in material inputs with the exploitation of by-products. To do	Not mentioned in the data. Case company 2 doesn't manufacture the appliances.
51.	Joint (customer, manufacturer) cost reduction and new production lines. To do	Not mentioned in the data. Future improvements: 1. Provide repair instructions for customers to repair their appliances themselves.
Cycling strategy – Revenue streams		

52.	Revenue from resources trading. To do	Not mentioned in the data.
53.	Reputation gains in "green" customer segments. To do	Not mentioned in the data.
54.	Direct and indirect sales (transaction fees) and revenue streams from reselling. To do	Not mentioned in the data. Case company 2 leases out appliances they remain ownership.
55.	Additional profit from buy-back scheme, take-back service fee and trade-in credit. To do	Not mentioned in the data. Future improvements: 1. Giving trade-in credit which can be spend on consumables or extra subscription discounts.
Extension strategy – Product/Service		
56.	Product is based on timeless design (does not fade out of style). To do	Not particular mentioned in the data. Future improvements: 1. Co-develop timeless designs and avoid hypes and trends. 2. Co-design quickly obsolete parts for ease of replacement.
57.	Design connected appliances.	This practice is not part of the default framework. However, it is an important practice to support other extension practices, like predictive maintenance and product performance tracking.
58.	Offer just as new refurbished appliances.	This practice is not part of the default framework. However, it is an important practice to mention in the light of the extension strategy.
Extension strategy – Customer		
59.	Incentivized customers willing to purchase redistributed goods. To do	Not particular mentioned in the data, but likely as case company 2 offers subscriptions on refurbished products.
60.	Customer segments with high environmental awareness. To do	Not particular mentioned in the data.
61.	Conscious customers willing to use the product for longer. To do	Not particular mentioned in the data. Probably the opposite. Mentioned in the data is that some customers take a subscription to frequently renew their appliances.

62.		Not particular mentioned in the data.
Extension strategy – Customer Relationships		
63.		Not particular mentioned in the data. Future improvements: 1. Online training platform for service partners, delivery partners, used product collectors. 2. Digital maintenance support (potentially with AR).
Extension strategy – Key Activities		
64.		Not mentioned in the data. Case company 2 offers a care-free subscription which could potentially be referred to as warranty.
65.		Not mentioned in the data.
Extension strategy – Channels		
66.		Not mentioned in the data. Future improvements: 1. Company could offer virtual maintenance, repair or upgrade service through the app or website. 2. Modular product design and customer personalize end product by selecting and combining certain product modules.
Extension strategy – Cost structure		
67.		Statements about this practice are not mentioned in the data.
Extension strategy – Revenue streams		
68.		Not mentioned in the data. Case company 2 offers a subscription model. However, contract buy-outs are mentioned. Effectively, the customer is then buying a premium product as case company 2 does offers durable premium products.
69.		Reservice and repair revenue is included in the subscription offering.

70.	Profit from performance- and function-based contracts, charging per use or for results. To do	Not mentioned in the data. But likely function-based contracts with charging per use is in place as case company 2 is offering products in shared communal settings.
Intensifying strategy – Product/Service		
71.	Structured platforms which support product/parts/components sharing or pooling. To do	Not mentioned in the data, but is very likely present at case company 2. Future improvements: 1. Platform to find, reserve and pay for the service of the products available and accessible to share.
Intensifying strategy – Key Activities		
72.	Sharing initiatives among consumers and educate to share. To do	The case company has processes in place to provide sharing services. However, I cannot derive from the data particular sharing initiatives or how the case company educates to share. Marketing could aim to educate customers to share. With communicating the benefits for sharing the products or show how to possibly share.
73.	Educate for collaborative consumption. To do	The case company has processes in place to provide sharing services. However, I cannot derive from the data particular how the case company educates for collaborative consumption.
74.	Design product-service-system which can support both the product being shared and the service which accompanies it. To do	From the data we cannot derive if a PSS is in place and how it is working.
Intensifying strategy – Channels		
75.	Online advertisements as indirect communication channels to promote sharing and collaborative consumption. To do	Case company 2 use online advertisements however from the data we cannot derive that promoting sharing is being particularly advertised with.
76.	Indirect sales through C2C channels. To do	This practice is not particularly mentioned in the data. The case company could provide a product marketplace where customers can sell their new or used products if they have bought-out the subscription contract. The case company can benefit from the data and provides the quality or can offer the services the products need and customers cannot provide to each other.
78.	Online platforms for products/material sharing/trading. To do	This practice is not particularly mentioned in the data.
Intensifying strategy – Cost structure		

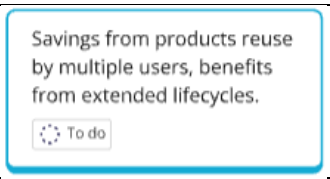
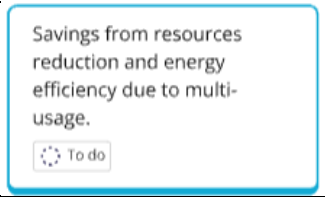
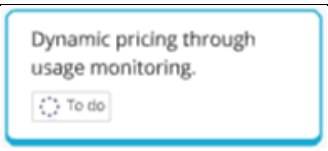
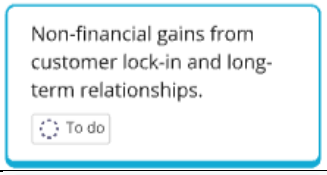
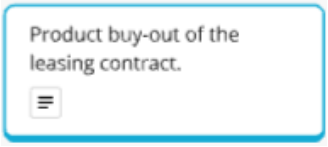
79.		Case company 2 reuses products and let their appliances be shared. Cost savings from these practices are not mentioned in the data.
80.		This is probably true, however not particularly mentioned in the data.
Intensifying strategy – Revenue streams		
81.		This practice is not mentioned in the data however, this could be an option for the charge per use services that when energy prices are low for example the price for a service on that particular moment is also lower. Dynamic pricing for example could also mean that customers receive discounts per use the more frequently they use the services.
82.		Satisfied and loyal customers generate mouth to mouth marketing. Satisfied an loyal customers are more open to share information and help optimizing the case company products and services.
83.		This practice is not part of the default framework. However, it is an extra revenue stream for case company 2. Customers have to possibility to buy-out their subscription and become owner of the previous leased appliances.

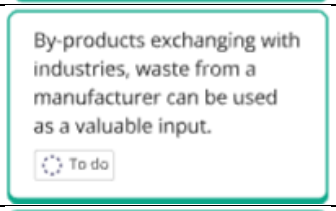
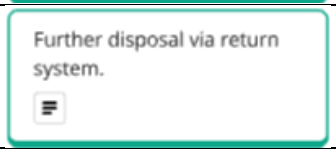
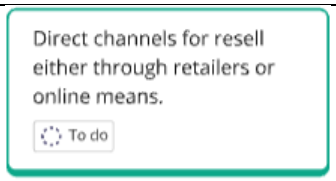
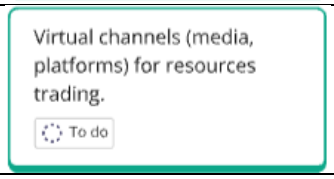
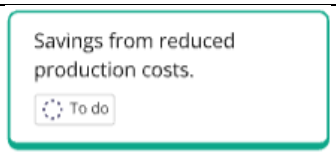
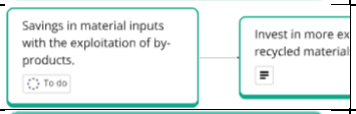
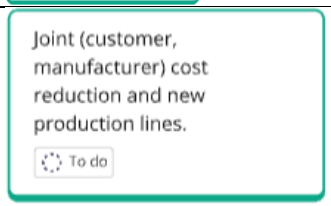
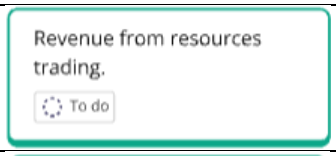
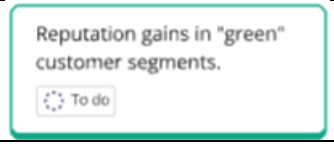
Table 25: GAP analysis Case company 3

Nr.	Practices	Comments
	Greening strategy – Customer	
1.	Incentivised customers which purchase only products which have been produced with green power. To do	Not mentioned in the data.
	Greening strategy – Customer Relationships	
2.	Transportation is initiated based on renewably powered means (electric-based mobility, bikes, etc.). To do	Not mentioned in the data. Mentioned in the data is that the case company is focussed on reducing the CO2 pollutions and optimizes transportation efficiency. The case company is selling physical products. Future improvements could be: 1. using electric or hydrogen-powered means of transportation. 2. Another strategy could be to localize supply chains. Smaller factories closer to the client.
3.	Collaboration only with suppliers which support green initiatives. To do	Not mentioned in the data.
	Greening strategy – Activities	
4.	Optimized logistics to reduce CO2 pollution.	This practice is not part of the default framework. Case company 3 is focussing on optimizing their logistics in order to reduce CO2 pollution.
	Greening strategy – Key Partners	
5.	Delivery of supplies with the utilisation of renewable resources and non-fossil mean. To do	Not mentioned in the data. Mentioned in the data is that the case company is focussed on reducing the CO2 pollutions and optimizes transportation efficiency. The case company is selling physical products. Future improvements could be: 1. using electric or hydrogen-powered means of transportation.
	Greening strategy – Resources & Capabilities	
6.	Delivery of products in a sustainable way. To do	Not mentioned in the data. Mentioned in the data is that the case company is focussed on reducing the CO2 pollutions and optimizes transportation efficiency. The case company is selling physical products. Future improvements could be: 1. using electric or hydrogen-powered means of transportation. Another point related to this practices is to reduce packaging material and substitute packaging material with recyclable materials. This practice is implemented at the case company.
7.	Human resources to support green marketing and promote sustainability. To do	Not directly mentioned in the data. Future improvements: 1. Part of the marketing team focus on green marketing and sustainability.
	Greening strategy – Cost structure	
8.	Savings from renewable energy consumption. To do	Not directly mentioned in the data. In the data from case company 3 practices to optimize renewable energy consumption are mentioned, but not if this saves costs.

Greening strategy – Revenue streams		
9.	Reputation due to green initiatives, can attract incentivised customers with high environmental awareness. To do	Not mentioned in the data that case company 3 is generating more revenue due to a green reputation. Mentioned in the data is that customers of case company 3 buy their appliances, because of high quality, hygiene, durability more then because of environmental awareness.
Narrowing strategy – Product/Service		
10.	Service offering which completely substitutes the functionalities and capabilities of a physical product. To do	Not mentioned in the data. The case company manufactures and sells household appliances. The functions these physical products fulfil are difficult to offer through software.
11.	Products are being produced based on the demand, supply-demand ratio is balanced. To do	Not mentioned in the data. Future improvements: 1. Use predictive algorithms, customer data and product monitoring to predict demand and manufacture accordingly
Narrowing strategy – Customer		
12.	Proactive customers willing to reduce consumption. To do	Not mentioned in the data.
Narrowing strategy – Customer relationships		
13.	Ensure service performance besides the lack of a physical product. To do	Not mentioned in the data. As stated before the case company's products are hard to substitute with a service only model. Feedback: This is indeed hard to achieve as in order to cool products or wash laundry you need physical products. However, the case company is testing service offerings instead of product offerings with shared usage and subscription offerings.
Narrowing strategy – Key activities		
14.	Educate customers to reduce consumption where possible. To do	Not mentioned in the data. However, the case company has implemented technologies into the products to reduce consumption. This must be a topic inside the company. Future improvements: 1. Educate customers how to correctly use the implemented technology. 2. Educate customers on the benefits of using the implemented consumption reduction features.
15.	Reassure that the service offered can cover customer needs. To do	Not mentioned in the data. As stated before the case company's products are hard to substitute with a service only model. However, if interpreted as reassure that the secondary service offered can cover customer needs. The following future improvements can be made: 1. Customer needs survey 2. Customer satisfaction analysis
Narrowing strategy – Key Partners		

16.	Innovate materials with advanced properties along with institutes which can substitute the traditional non-ecological materials. To do	The case company does substitute non-ecological materials where technical feasible. However, partnering with institutes to develop innovative materials specifically to substitute the non-ecological materials is not mentioned in the data. Future improvement: 1. Partner with institutions to innovate new ecological and recyclable materials which can substitute the current non-ecological materials.
Narrowing strategy – Resources & Capabilities		
17.	Substitute product with an equal service which can serve the same functionalities. To do	Not mentioned in the data. As stated before the case company's products are hard to substitute with a service only model.
18.	Capacity management in order to have an equilibrium between supply and demand. To do	The company's products are developed with technology to reduce consumable consumption. The practice from the default framework refers to the pull principle. Where products are manufactured according to the demand. This is not mentioned in the data. Future improvements: 1. Use predictive models to predict demand and manufacture accordingly. 2. Reconfigure manufacturing process for flexible product manufacturing. For efficient order-based manufacturing.
Narrowing strategy – Channels		
19.	Software delivery instead of product via performance/functionality provision. To do	Not mentioned in the data. The company could provide software updates for the appliances to extend the product life time and/or reduce consumption of energy, water and consumables. If the appliances are connected the software can be updated remotely.
20.	Social media and online channels for offerings delivery. To do	The case company delivers a physical product which cannot be delivered online.
21.	Apps and online tools for service delivery (product virtualisation). To do	In the data it is mentioned that case company 3 has an app for product connectivity. In the data is not mentioned if this app provides service deliveries.
22.	Direct sales of non-ownership products. To do	In the data it is mentioned that case company 3 has an app for product connectivity. In the data is not mentioned if this app provides subscription sales.
Narrowing strategy – Cost structure		
23.	Savings from on demand production and efficiency due to innovative materials. To do	Case company 3 is applying innovative materials. However it is not mentioned that the case company manufactures based on the demand and if this is saving costs.
24.	Savings from transportation cost reduction due to local supplies. To do	Case company 3 sources supplies locally. It is not mentioned that this saves costs.

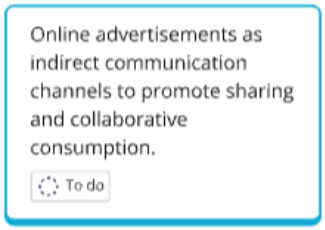
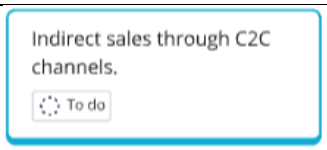
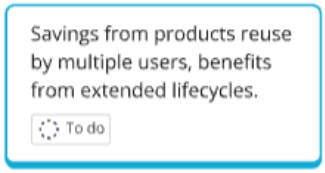
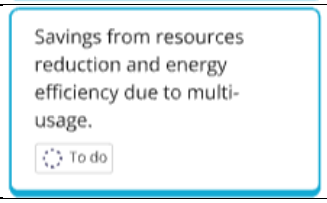
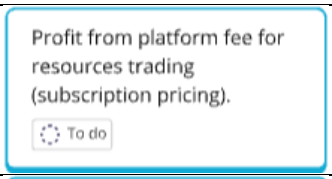
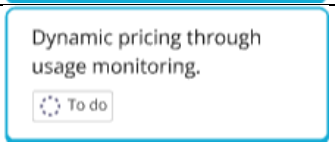
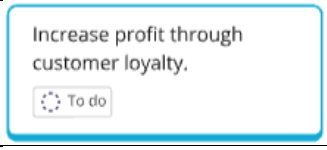
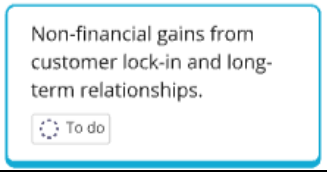
Narrowing strategy - Revenue streams		
25.	Profit from subscription schemes for software utilisation. To do	Not mentioned in the data. Future improvements: 1. Energy efficiency insights and prediction features in the app can be monetized through subscription scheme. (feature already in place) 2. Predictive maintenance insights feature in the app can be monetized through subscription scheme. (feature already in place)
26.	Revenue stream from optimized consumables.	This practice is not a part of the default framework. However optimized consumables generates revenue for case company 3 and it contributes to resource reduction and sustainability.
Cycling strategy – Product/Service		
27.	Value from biomass is returned to the ecosystem, cascading. To do	This practice is not mentioned in the data. Future improvements: 1. Cascading manufacturing waste and end-of-life product waste. 2. Using manufacturing waste and end-of-life product waste as in input to the manufacturing process. 3. Sell waste to other companies for which this waste could be a manufacturing input.
Cycling strategy – Customer		
28.	Incentivised customers willing to purchase redistributed goods. To do	Not mentioned in the data. However, this can be implied by the fact that used products are redistributed.
29.	Customer segments with high environmental awareness. To do	Not mentioned in the data, However what is mentioned in quotation Interview case company 3: 3:24 is that the case company is not convinced customers are really buying their appliances for sustainability reasons. More because of the quality and hygiene and energy cost savings.
Cycling strategy – Customer Relationships		
30.	Material/parts trade among industries to cover needs without additional resources input to the system. To do	Not mentioned in the data. Feedback: End-of-life products are collected through partners and recycled through partners as they have specialize business processes for this and the manufacturer at this moment doesn't which make recycling and reusing the resources from EoL products inefficient, costly and difficult.
Cycling strategy – Key Activities		
31.	Access end-of-life products and retrieve useful resources from waste. To do	Not mentioned in the data. Case company 3 has access to end-of-life product through their return initiatives, but it is not clear if the case company retrieves useful resources from these appliances or from waste.
Cycling strategy – Key Partners		
32.	Resources trading through cooperatives and by-products exchange. To do	Not mentioned in the data. Future improvements: 1. Sell not useful returned parts to partners for whom it can be a valuable input stream.

Cycling strategy – Resources & Capabilities		
33.		From the data we can retrieve that IoT technology is used, however it is not particularly mentioned that this technology is used for traceability purposes.
34.		Mentioned in the data is that waste is returned and further disposed, however not if by-products from other manufacturers is used as a valuable input for case company 3.
35.		This practice is not part of the default framework. This practices derived from the data shows that the case company has practices in place to return waste and end-of-life product and disposes waste efficiently.
Cycling strategy – Channels		
36.		Not mentioned in the data. Future improvements: 1. Setting up channels for reselling. 2. Online marketplace with remote quality control through connected devices with remote diagnostics.
37.		Not mentioned in the data. Future improvements: 1. Provide services for product/part/material trading.
Cycling strategy – Cost structure		
38.		Not mentioned in the data. Future improvements: 1. Optimized resource utility. Less material is used which will reduce production cost. 2. Reuse manufacturing waste or sell it on the market.
39.		Instead of savings from recycled material, the interviewee mentioned that recycled material is in most cases more expensive then virgin raw material.
40.		Not mentioned in the data. Future improvements: 1. Product delivery in parts and easy to assemble by the customer. 2. Part manufacturing instead of product manufacturing. Feedback: This practice is being tested. However, it is hard to offer a building package and let customer assemble their product themselves as it includes electrical components and this is not legally allowed.
Cycling strategy – Revenue streams		
41.		Not mentioned in the data. Future improvements: 1. Manufacturing waste material trading. 2. End-of-life materials trading.
42.		Not mentioned in the data.

43.	Additional profit from buy-back scheme, take-back service fee and trade-in credit. To do	Not mentioned in the data. Future improvements: 1. Buy-back scheme for appliances and resell them. 2. Free take-back service for old appliances, for remanufacture, refurbish or resource trading. 3. Giving trade-in credit which can be spend on consumables or product discounts.
Extension strategy – Customer		
44.	Incentivized customers willing to purchase redistributed goods. To do	Not particular mentioned in the data.
45.	Customer segments with high environmental awareness. To do	Not particular mentioned in the data.
Extension strategy – Customer Relationships		
47.	Suppliers and external partners which re-manufacture and directly offer products to customers. To do	Not mentioned in the data. Remanufacture and reselling is mentioned in the data, but not clear if external partners are involved. Future improvements: 1. Source partners for remanufacturing and reselling. 2. Remote quality control through connected devices with remote diagnostics. 3. Digital product passport which provides partner organizations with all the data about a particular product to remanufacture, maintain and resell it.
48.	Non-financial gains from customer lock-in and long-term relationships. To do	Not mentioned in the data. Future improvements: 1. Data gathering for product or service improvements or testing new offerings.
Extension strategy – Key Partners		
49.	Ecosystem collaborations which will support repair and remanufacturing activities. To do	Not mentioned in the data. Future improvements: 1. Source partners for remanufacturing and reselling.
50.	Make network and outsource activities related to maintenance and repair while the service offering remains with the initial manufacturer To do	Not mentioned in the data. Future improvements: 1. Work with local maintenance and repair specialists to create shorter supply chains and save the investment into an own maintenance and repair department which could be very costly.
Extension strategy – Resources & Capabilities		
51.	Keeping a 10 year stock of spare-parts to support longvity of the appliances	This practice was not part of the default framework, but worth mentioning. Keeping spare parts for a long time is an big investment in providing a service for product extension.
Extension strategy – Channels		

52.	App to support after-sales for consumables	This practice is not a part of the default framework. However, it shows a channel that is being employed to sell online.
Extension strategy – Cost structure		
53.	Financial savings from material savings since remanufactured products can be resold without the need of making new products. To do	Statements about this practice are not mentioned in the data.
54.	Service cost savings by support and incentive consumer to do own maintenance and repairs.	This practice is not part of the default framework. This practice employed by case company 2 reduces the cost of service providing by helping customers doing their repairs and maintenance themselves. Saving transportation and maintenance employee to visit the customer.
55.	Modular production for remanufacturing doesn't save costs yet.	This practice is not part of the default framework. The interviewee of case company 3 points out that a modular production doesn't necessarily save costs.
Extension strategy – Revenue streams		
56.	Revenue from services for repair and upgrading. To do	Case company 3 is providing services for repair and upgrading, however it is not clear of revenue streams are resulting from these offerings.
57.	Non-financial gains from customer lock-in and long-term relationships. To do	Not mentioned in the data.
Intensifying strategy – Product/Service		
58.	Structured platforms which support product/parts/components sharing or pooling. To do	Not mentioned in the data. Future improvements: 1. Platform to find, reserve and pay for the service of the products available and accessible to share.
Intensifying strategy – Customer		
59.	Customers which aim at making a profit from sharing or resources trading. To do	This practice is not mentioned in the data. Future improvements: 1. Support customers who want to provide the product of the case company as a shared product.
Intensifying strategy – Customer Relationships		
60.	Suppliers and external partners which promote products sharing for temporary use. To do	This practice is not particularly mentioned in the data.

Intensifying strategy – Key Activities		
61.	Sharing initiatives among consumers and educate to share. To do	The case company has processes in place to provide sharing services. However, I cannot derive from the data particular sharing initiatives or how the case company educates to share. Marketing could aim to educate customers to share. With communicating the benefits for sharing the products or show how to possibly share.
62.	Educate for collaborative consumption. To do	The case company has processes in place to provide sharing services. However, I cannot derive from the data particular how the case company educates for collaborative consumption.
63.	Management of customer relationships as a practice to ensure satisfaction and loyalty. To do	Not particularly mentioned in the data.
64.	Design product-service-system which can support both the product being shared and the service which accompanies it. To do	Not mentioned in the data.
Intensifying strategy – Key Partners		
65.	Connection channels and platform for material/products sharing in a B2B basis. To do	This practice is not particularly mentioned in the data.
66.	Create partners network to inspect products in use and ensure quality, longevity and abuse reduction. To do	This practice is not particularly mentioned in the data. During use product inspection could also be partly done remotely with remote diagnostics. Periodically physical inspections are also important. With device connectivity and predictive models the software can automate periodically inspection planning with location of each product. An automated email or signal can be send to the local inspection partner to plan for the inspection in a certain time frame.
Intensifying strategy – Resources & Capabilities		
67.	Online platforms to manage product leasing/pooling and embrace sharing among users. To do	This practice is not particularly mentioned in the data.
68.	Technology-related resources to support digitalisation and product monitoring during collaborative usage. To do	This practice is not particularly mentioned in the data. The connectivity of the appliances could be used for this.
Intensifying strategy – Channels		

69.		This practice is not particularly mentioned in the data.
70.		This practice is not particularly mentioned in the data. The case company could provide a product marketplace where customers can sell or rent out their new or used products. The case company can benefit from the data and provides the quality or can offer the services the products need and customers cannot provide to each other.
Intensifying strategy – Cost structure		
71.		This practice is not particularly mentioned in the data. As WEEE partner keeping product as long as possible in use could be beneficial because collecting, recycling or cascading old appliances is expensive?
72.		This is probably true, however not particularly mentioned in the data.
Intensifying strategy – Revenue streams		
73.		This is not mentioned in the data.
74.		This was not mentioned in the data. This could be an option for the charge per use services that when energy prices are low for example the price for a service on that particular moment is also lower. Dynamic pricing for example could also mean that customers receive discounts per use to more frequently they use the services.
75.		This is not mentioned in the data. However, in a sharing business model it becomes more and more beneficial if multiple subscriptions are offered to the same customer. Delivery, services and returns are more efficient.
76.		Satisfied and loyal customers generate mouth to mouth marketing. Satisfied an loyal customers are more open to share information and help optimizing the case company products and services.

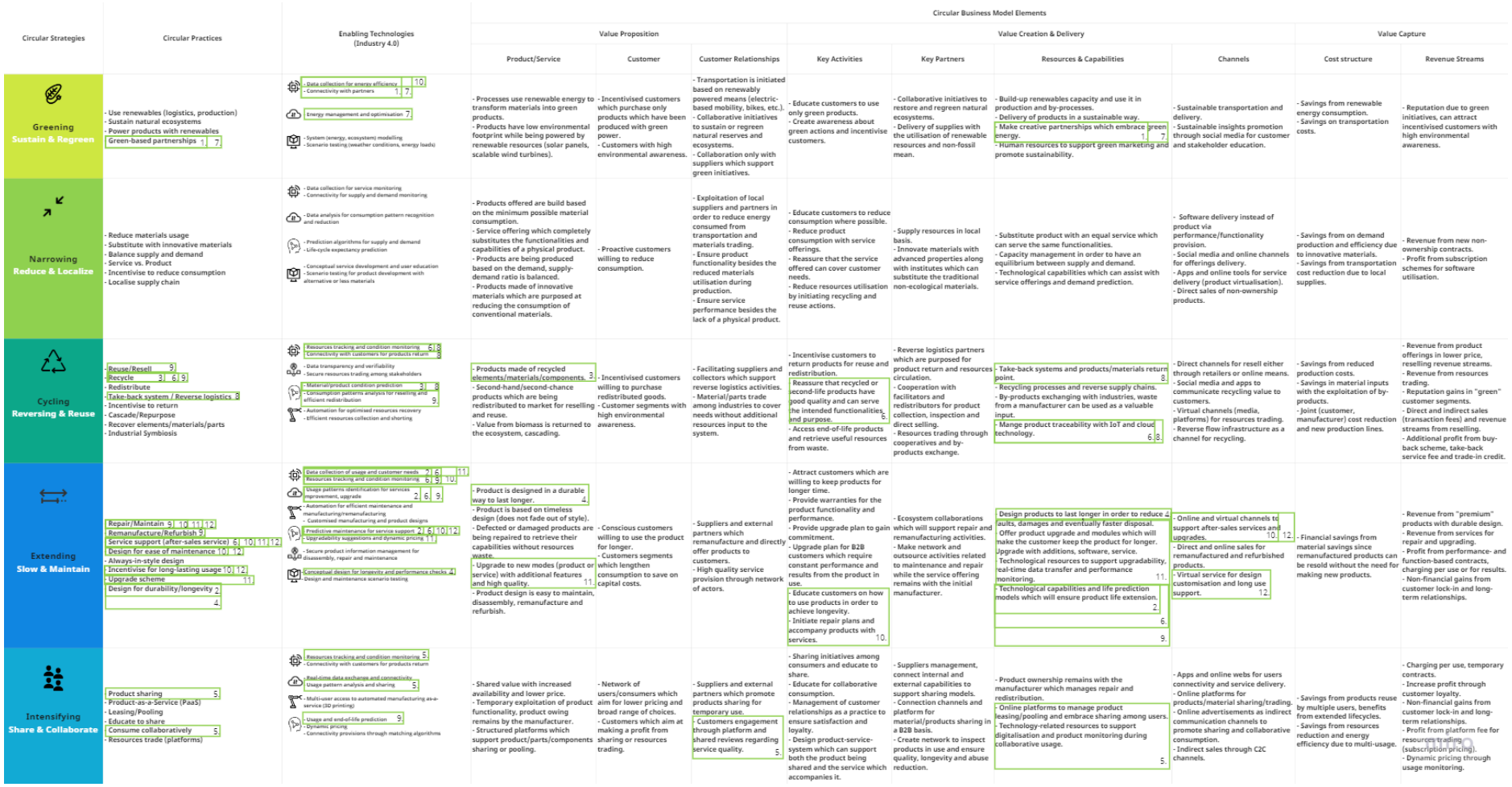


Figure 18: Empirical derived practices from the case companies