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Artificial Intelligence in the Circular Economy in Finland

Exploring Future Scenarios

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Master's thesis

in Futures Studies

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Student's statement regarding the use of Artificial Intelligence (AI) for preparing and/or writing this thesis:

☐ **I have not used any AI-based tools.**

☒ **I have used AI-based tools**. Their use is documented in the Appendix. The AI tools were used in a way that complies with academic integrity guidelines.

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Abstract

The circular economy (CE) has gained popularity in sustainability studies for reducing waste and improving resource efficiency while also serving as a basis for transitioning towards sustainability. Artificial Intelligence (AI), on the other hand, has been recognized as a means of enhancing practices related to the circular economy by analyzing the available data and automating various processes, conducting predictive maintenance, managing waste more effectively and tracking materials. While there have been attempts to analyze the relationship between Artificial Intelligence and the circular economy, there is still limited future-oriented research on how this relationship may develop over time, especially in the Finnish context.

This thesis proposes an exploration of the alternative futures of using Artificial Intelligence in Finland's circular economy systems by 2035. Specifically, the following research questions are formulated: what alternative future scenarios can be developed for the use of artificial intelligence in circular economy systems in Finland up to 2035, and what implications these scenarios may have for circular economy stakeholders in Finland.

The research employs the qualitative desk-based futures approach. This research is based on the literature review and environmental scanning followed by building the four scenarios with the help of the futures table. The main drivers behind the scenarios were identified using the STEEP framework including social, technological, economical, environmental and political aspects. Based on the selected factors, four different scenarios were built.

The research shows that in order to achieve the desired futures of utilizing Artificial Intelligence in circular economy systems, it is essential not only to make sure that new technologies are developed but also on wider conditions such as digital skills, public awareness, stakeholder collaboration, investment, data-sharing systems, and policy support.

Keywords: Artificial Intelligence (AI), Circular Economy (CE), Finland, futures studies, scenario building, sustainability transition, digitalization, resource efficiency, strategic foresight

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1 INTRODUCTION

1.1 Topic of the Study

The concept of circular economy (CE) appears to become an important concept in the scientific and policy discourse on sustainability (Kirchherr et al., 2017; European Commission, 2020). Contrary to the traditional approach focused on "taking, making, and disposing" products, CE tries to maximize the use of products and materials as much as possible by means of reuse, repair, remanufacture, recycling, etc. (Tudor et al., 2020). It is important to note that, along with such shifts, there emerged connections between CE and digitalization as a major feature of contemporary systems in general (Lehtimäki et al., 2023).

This connection provides a notable view when it comes to the important roles of the artificial intelligence (AI) in the CE. Early works suggest that AI could be instrumental in promoting resource efficiency, supporting better product sorting and recycling, improving logistical operations, helping in predictive maintenance activities, and enhancing transparency in material flows (Lopes de Sousa Jabbour et al., 2018; Govindan, 2023; Snoun et al., 2025). Most recently, AI has been described as one of the key factors facilitating the transition into a CE in production ecosystems via waste valorisation, transparent supply chains, sustainable design, and optimized manufacturing (de Lucas López et al., 2026). At the same time, according to the available literature, the potential of AI requires a number of additional factors, such as good-quality data, sufficient digital literacy, access to finance, policy support, and others (Ormazabal et al., 2018; Madanaguli et al., 2024; de Lucas López et al., 2026).

Finnish context can be considered quite representative regarding the chosen topic. First, it should be mentioned that Finland has always been known to be ahead of other countries in terms of its policies on CE transition, which can be explained, at least partly, by being the first country in Europe that published its national CE roadmap (Sitra, 2016). Since then, the Finnish CE policy framework became enriched with new roadmaps and sustainable growth strategies (Sitra, 2019). Besides, the Finnish government has developed policies related to digitalization, carbon neutrality, and sustainability as a whole (European Commission, 2020; EEA, 2024). All things considered, Finland seems to serve as an interesting national example when exploring the future of AI in CE.

It should be stated that, despite all of the mentioned changes, there has been no particular progress in terms of exploring the future of AI application for circular economies. As one can see, most of the publications in this area were concentrated on practical issues, technologies, or case studies rather than future pathways (Bressanelli et al., 2018; Lopes de Sousa Jabbour et al., 2018; Madanaguli et al., 2024). The latest review articles mention that the existing studies are relatively fragmented and that more integrated exploration is required to achieve comprehensive results (de Lucas López et al., 2026). Hence, this research problem can be considered highly suitable for conducting futures studies. A futures perspective makes it possible to explore uncertainty, examine multiple plausible developments, and consider how technological, economic, social, and policy factors may interact over time instead of assuming one linear path of change (van Dorsser et al., 2020).

1.2 Research Questions

This thesis aims at analyzing how AI technology will impact CE systems in Finland towards 2035. The future-oriented approach to this research topic is justified since the interrelation between AI and the CE is still unpredictable, dynamic, and determined by multiple factors. In particular, the scenario planning technique is especially useful in the research of the relationship between technological developments and their implementation in the economic system since it makes it possible to explore different futures instead of forecasting only one path of development (Amer et al., 2013; Dator, 2019). It is especially important for studies related to the relevant topics, as technological changes interact with policies, business practices, consumers, and the environment through time (Bauwens et al., 2020; Basile et al., 2024).

The following research questions are explored in this thesis:

RQ1: What alternative future scenarios can be developed for the use of AI in CE systems in Finland by 2035?

RQ2: What are the implications of these scenarios for CE stakeholders in Finland?

From an academic perspective, these questions are important because researchers should pay more attention to the long-term development of the interaction between AI and the CE systems. This topic should be investigated considering its national specifics because Finland has made circular transition among the primary priorities of its economic development. At the same time, from a practical point of view, decision-makers and other stakeholders should be aware of the benefits and prerequisites of implementing AI in CE systems.

1.3 Scope of the Study

This thesis is a qualitative desk-based futures study. It addresses the role of AI in the Finnish context of the CE up to 2035. In other words, instead of attempting a concrete prediction, the study will identify multiple possible futures using the method of scenario building, which is a common approach in futures studies when uncertainty is high and long-term development depends on many interacting drivers (Amer et al., 2013; Kuosa, 2021).

First, the scope of the thesis is geographically limited to Finland, as this makes it possible to relate the findings to Finland's policy framework on the CE, Finland's goals in sustainable development and digitalization (Sitra, 2016; Sitra, 2019). Second, the scope is limited to AI as it is applied to the CE system. In other words, the study is interested in practical applications, including waste management, material tracking, resource optimization, digital product information, and circular business models rather than on technical AI development itself. Third, the time horizon is towards 2035, as this period is relatively long enough and therefore allows considering structural change while being sufficiently close to be relevant for decision-making.

There are some limitations of the thesis from a methodology perspective, using only literature reviews, environmental scanning, and scenarios rather than conducting interviews, surveys, or creating models based on quantitative research. The aim of this thesis is not to provide tested outcomes but rather interpretative and exploratory visions of futures scenarios.

1.4 Structure of the Thesis

The six chapters of this thesis outline the steps taken during the research process. Chapter 1 provides a comprehensive overview of the study. Firstly, the topic is introduced, followed by the statement of relevance, research questions, scope definition, and description of the whole thesis structure.

In Chapter 2, the relevant literature is reviewed. Starting from the definition of the CE, its fundamental characteristics are mentioned. Afterwards, AI and digitalization in CE systems are discussed. Furthermore, this chapter focuses on the Finnish CE, highlighting the key opportunities offered by AI in the Finnish context, but also identifying important limitations and challenges related to its application.

In Chapter 3, the underlying theoretical concepts are elaborated. First of all, scenario thinking as a tool for sustainability research is presented, alongside an explanation for the importance of futures-oriented approaches when dealing with emerging phenomena and uncertainties. Moreover, the integrated framework applied in order to examine relationships between AI, CE systems, and socio-technical change is presented.

Chapter 4 is dedicated to the research methodology. Here, the structure of the desk-based qualitative research on future developments is described, as well as the methods of data collection and analysis, which include an environmental scanning and identification of the key driving forces. Furthermore, the futures table and the procedure of creating scenarios for 2035 are explained.

The findings are provided in Chapter 5. Here, the futures table is described, alongside four alternative scenario narratives of future development – Smart Circular, Collaborative Transition, Gradual Uptake, and Strained System. All four scenarios present different possibilities for the role of AI in CE systems in Finland in 2035.

Lastly, Chapter 6 concludes the thesis. After interpretation of the results through the perspective of research questions, their implications and recommendations for relevant stakeholders are discussed. Also, the limitations of the study and areas of possible future research are outlined.

2 OVERVIEW OF CIRCULAR ECONOMY AND DIGITAL TRANSITION

This chapter reviews the main concepts that inform the foundation of the study. It therefore covers the principles of the CE, the role of AI, and digitalization in supporting circular systems, their recent developments, and the development progress of the CE in the Finnish context. This review develops a conceptual basis for understanding how AI can shape Finland's circular transition by 2035.

2.1 What is Circular Economy?

Minimizing waste and maximizing the value of materials are critical elements in our society today. CE is an economic system focused on the minimal production of wastes along with the maximum valuation of materials by their continuous cycling (Kirchherr et al., 2017). Researchers commonly compare CE to the dominant linear economic model- "take, make, dispose"-that relies on a high volume of resource extraction alongside with decreasing material recovery (Geissdoerfer et al., 2017). In contrast, CE aims at maintaining materials, products, and components at their highest value during a given timeframe. Reuse, repair, remanufacturing, recycling, and recovery become the core loops that make CE different from linear systems (Ellen MacArthur Foundation, 2019).

There are several conceptualizations of CE in the literature. Some scholars focus on technical cycles, such as remanufacturing systems, while others highlight the social and institutional arrangements that would underpin circularity (Kirchherr et al., 2023; Murray et al., 2017). Yet, CE definitions commonly highlight how environmental sustainability should be combined with economic competitiveness. For instance, the European Union (2020) presents CE as part of its long-term strategy related to climate, including resource efficiency, innovation, and environmental protection. One of the crucial features of CE is its dependency on information flows because materials cannot stay in circulation if data related to their composition, condition, location, and value are not available (Walden et al. 2021). This has made the rising interest in digitalization, including AI, Internet of Things (IoT), smart sensors, and digital product passports, as enabling technologies for circular transitions (Bressanelli et al., 2020). Therefore, CE cannot be just a model of waste management but entails systemic transformation with cooperation in industries, government agencies, and consumers (Varsha et al., 2025). This wider framing also meets Finland’s nation-wide approaches, where the transition is framed within the context of a society in transition and not a one-sector reform (Sitra, 2016).

Table 1: Various Circular Economy definitions

Definition	Source
CE is understood as an economic system that aims to minimize waste by reducing, reusing, recycling, and recovering materials across production, distribution, and consumption.	Jesus et al. (2023)
It is a regenerative system that reduces the amount of input, waste, emissions, and losses of energy by suspending, stopping, and reducing cycles of materials and energy.	Geissdoerfer et al. (2017)
It is an industrial system that is designed to be restorative and regenerative by keeping products, parts, and materials in their highest and best form and value.	Ellen MacArthur Foundation (2019)
It is an economic system that uses fewer resources, produces less waste, and emits fewer pollutants by closing the loops of materials and linking economic activities to the environment.	Murray et al. (2017)
It is a manufacturing and consumption framework that covers practices such as sharing, leasing, reuse, repair, refurbishment, and recycling of available resources and goods throughout the duration of their useful life.	European Union (2020)
It is an economic system where materials remain in circulation for as long as they may be used while limiting the development of waste and the requirement for new resources.	Sitra (2016)

2.2 Artificial intelligence and Digitalization in Circular Economy

Digitalization is identified as a significant enabler in transitioning from “traditional” CE practices to more data-driven and a smarter CE (Walden, Steinbrecher, & Marinkovic, 2021; Govindan, 2023). This is because digitalization enables to collect, store, and share of product and process information throughout the life cycle of the product in the CE (Walden et al., 2021). Recent research indicates the traditional CE can remain limited if decision-makers have not real-time information or traceability within value chains (Govindan, 2023; Walden et al., 2021). To address this problem, academics describe the “smart circular economy” as using digital technology to monitor, optimize, and learn through circular activities as well as linking a CE strategy with sustainability agendas such as the SDGs (Govindan, 2023). AI is part of this digital transformation because it has the capabilities to deal with large datasets, extract patterns, and enable decisions at the big-picture level, which cannot be done manually (Snoun et al., 2025). It has been related to technologies such as machine learning and natural language processing in the CE because it has the ability to optimize forecasting, sorting, planning, and monitoring in circular systems (Snoun et al., 2025).

A practical and visible area of AI-CE integration is waste management. This is because cities and firms seek to optimize the collection, processing, and disposal of waste to create a closed cycle system (Štreimikienė et al., 2026). Smarter urban waste management combines the use of IoT sensors like real-time information and AI like forecasting and optimization to increase the efficacy of municipal services (Devi et al., 2025). From the perspective of a CE, the implementation of such technology increases the recycling rate of materials while preventing the misuse of potential resources through the landfilling of trash or mixed refuse (Snoun et al., 2025; Devi et al., 2025). But aside from waste, digitalization is also discussed to improve information exchange and accountability for circular activities in organizations. For instance, research studies about integrated reporting indicate that companies increasingly disclosing the connection between AI activity and a CE strategy and emphasize a better linkage to environmental factors (Nazir et al., 2025). This is important because the circular transition is not only a technological change, but it must be highlighted through proper reporting and clearer connections between operational changes and sustainability outcomes (Nazir et al., 2025).

The other significant digitalization trend for the CE is the Digital Product Passport (DPP) (Walden et al., 2021). The DPPs are described as "data structures that contain essential product information; such as materials, parts, reparability, and take-disposal guidance along the entire product value chain and product lifespan, which can facilitate the product's reuse, repair, and recyclability (Walden et al., 2021). In this view, DPPs are not only "databases," but potential infrastructure for enabling traceability and shared action among many actors in the value chain (Walden et al., 2021). Digitalization and AI are linked to the CE through business models and reporting (Lehtimäki et al, 2023). The CE requires transformation in the manner in which businesses create and extract value where Chabowski et al. (2025) argue that changes are also needed in how a business creates and captures value. A recent study that focuses on the topic of Circular Business Model Innovation reveal that companies are able to redesign products, provide services in place of product sales, and enter into collaborations worldwide as the CE expands throughout the globe (Chabowski et al., 2025). Digitalization can support these changes by enabling platforms, monitoring product use, and managing reverse logistics more efficiently (Govindan, 2023; Chabowski et al., 2025). Additionally, the concepts of AI and the CE are becoming more clarified through the reporting by corporations

(Nazir et al., 2025). The Integrated reporting may report on activities related to the CE or AI initiatives, but the literature indicates that organizations are not consistent in their reporting on these two topics. The view of this thesis on this matter is that the signals from the reports are significant because they provide the actual level of mainstream of AI-CE integration initiatives (Nazir et al., 2025).

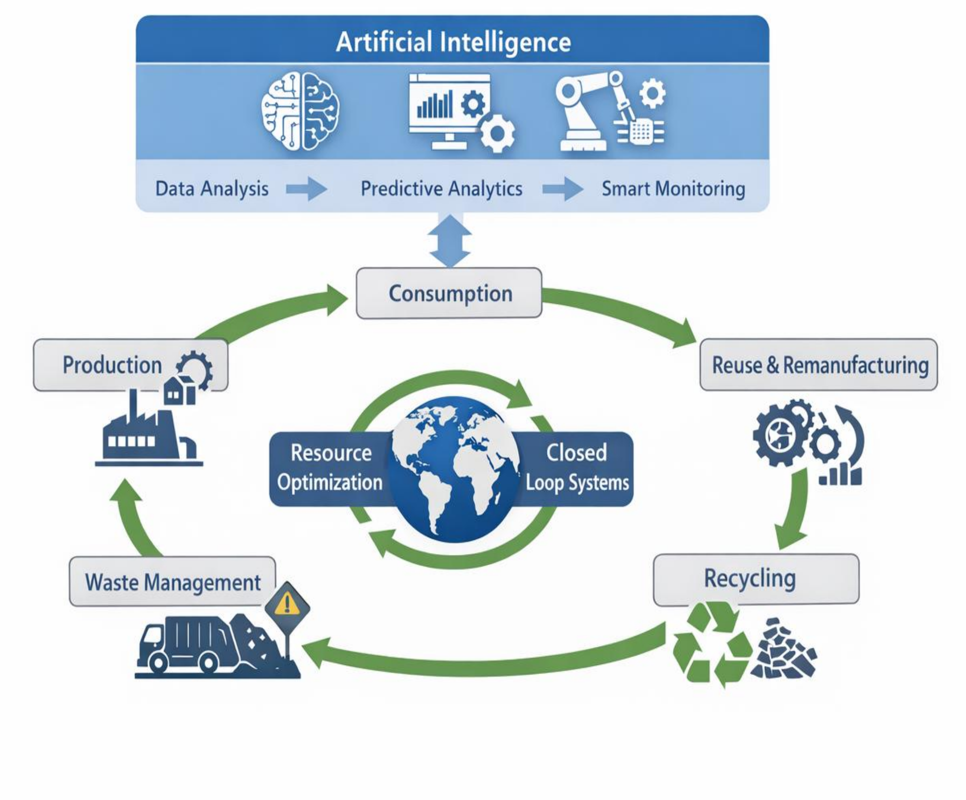

Figure 1: Integration of AI across CE processes (author's own illustration, informed by Bressanelli et al., 2018; Govindan, 2023).

In summary, digitalization is transforming the CE into a smart CE, where information in real time, smarter systems, and digital coordination are improving CE practices (Govindan, 2023; Snoun, 2025). AI emerges as a tool that helps in improved management of waste and resources, though its effectiveness will depend on data, its integration, the ease of its implementation, and its adoption by society. (Snoun, 2025). Smart waste management in cities and product passports demonstrate the significance of information flows in the terms of the CE (Devi et al., 2025; Walden et al., 2021). Furthermore, innovation within the field of circular business models and processes of system innovation play a crucial role in determining whether society will achieve widespread use of AI-enabled circular solutions or merely pilot programs (Jakobsen et al., 2021; Chabowski et al., 2025). This review places the role of AI and digitalization at the forefront in the paths that Finland will take to accelerate the CE outcomes to 2035.

2.3 Circular Economy in Finland

Finland serves as a leading example of the CE concept and implementation in scholarly and practical literature (Sitra, 2016; European Commission, 2020). The CE represents an essential element of the national sustainability strategy of Finland, aiming to separate economic growth by using too many natural resources and damaging the environment (Geissdoerfer et al., 2017). The existing supportive public policies of the government make Finland an appropriate location to analyze the influence of the latest digital technologies in the form of AI applications on the future development of the CE (EEA, 2024).

One important actor in CE activities in Finland is the Finnish Innovation Fund Sitra. They are responsible for navigating the CE policy and the CE vision for the country (Sita, 2016). Finland became an early pioneer by introducing a national roadmap for the circular economy, *Leading the Cycle: Finnish Road Map to a Circular Economy 2016–2025*, which defines CE as a wide economic transformation instead of the only management of waste (Sita, 2016). According to this roadmap, CE focuses on keeping the value of products, goods, and assets for as long as feasible redesign, reuse, remanufacturing, and recycling (Sitra, 2016; Lehtimäki et al, 2023).

According to the Finnish roadmap for a CE, significant changes are needed in various sectors such as manufacturing, building, food, and transportation (Sitra, 2016).This broad perspective is supported by an academic literature review, which states that a transition to a CE requires changes in how we produce, conduct business, and consume (Kirchherr et al., 2017). Consequently, the Finnish roadmap views a transition to a CE as a broad socio-technical transition rather than a sequence of environmental transitions (Sitra, 2016). The plan for the CE in Finland was revised in "The Critical Move – Finland’s Road Map to a CE 2.0." provided by Sitra. This document builds on past goals and addresses new challenges associated with sustainability (Sitra, 2019). It places considerable emphasis on the role of innovation ecosystems and data in facilitating the CE (Sitra, 2019). This aligns with academic theory and research on the role of information and communication technologies in facilitating the process (Bressanelli et al., 2018). In addition, studies on digitalization in the CE suggest that data platforms, sensors, or analyses can enhance transparency or the efficient use of resources throughout a product's entire life cycle (Bressanelli et al., 2018). In industries, newer digital technologies based on Industry 4.0 concepts, such as AI, can support CE-related technologies like predictive maintenance or the sorting and management of material flows (Lopes de Sousa Jabbour et al., 2018). These technological opportunities are well-suited to the Finnish digital infrastructure featured in CE strategic planning documents (Sitra, 2019).

On a Europe-wide level, Finnish CE targets align with Europe's CE Action Plan. The plan provides a vision for a sustainable CE in Europe by 2050 (European Commission, 2020). The European framework emphasizes that digital technology can support a CE in terms of access to data and more (European Commission, 2020). Alignment with these targets makes it more probable that AI solution use will become a part of circular economies in Finland (Sitra, 2019). However, despite these favourable conditions, both policy documents and academic studies suggest that the long-term implications of AI for Finland's CE remain underexplored (Bressanelli et al., 2018; Lopes de Sousa Jabbour et al., 2018). The vast majority of research focuses on analyzing the impact of digital technology in the short term, and there are few studies analyzing the influence of AI on the development routes for the CE, for example, in a mid- or long-term perspective (Kirchherr et al., 2017).

In total, the literature indicates that there is a strong policy foundation and clear strategy to mobilize the CE in the Finnish case, which acts as an encouragement to proceed with the CE (Sitra, 2016; Sitra, 2019). Moreover, it emphasizes the existing research gap concerning the future role of AI on the transformative CE systems within the national context (Bressanelli et al., 2018; Lopes de Sousa Jabbour et al., 2018). In this regard, this gap can only be covered by employing concepts that represent futures instead of the current situations, such as the use of scenario and strategic foresight (European Commission, 2020).

2.4 Opportunities of Artificial Intelligence in the Circular Economy

AI has been discussed many times in different studies, where it has been considered a very useful tool for making the operations of the CE more efficient, meaning that everything will run more smoothly (Bressanelli et al., 2018). CE systems have a lot of data regarding the production, usage, reuse, and even disposal of materials, and so AI can be very useful for handling such large amounts of data, which can be very complicated (Lopes de Sousa Jabbour et al., 2018). AI, by helping to make data-based decisions, can make the operations of the CE more logical (Madanaguli et al., 2024).

One of the major opportunities for AI in the CE involves efficiency in resource utilization which can be achieved through optimization and prediction (Lopes de Sousa Jabbour et al., 2018). For instance, machine learning can examine past and present information to spot inefficiency in resource utilization and propose solutions to eliminate the inefficiency (Khedr & S, 2024). In circular production, AI-based predictive maintenance can predict equipment breakdowns and extend the product and infrastructure lifespan which lowering the need for new resources and minimizes waste (Lopes de

Sousa Jabbour et al., 2018). These capabilities align with the main concept of maximizing value within the system for as long as possible (Kirchherr et al., 2017).

Another major opportunity for AI in the CE involves waste management and recycling which are the core of the CE strategies (Olawade et al., 2024). In recent studies, it was demonstrated that AI-based robots and computer vision can improve the identification, separation, and sorting of reusable and recyclable materials (Kshirsagar et al., 2022). This ensures better quality recycled materials for utilization in the production process (Bressanelli et al., 2018). As a result, AI-supported waste management technologies can contribute to closing material loops more effectively compared to conventional systems (Lakhouit, 2025).

Another major concept in the CE involves transparency and traceability (European Commission, 2020). This concept involves using AI-based systems by processing data from sensors, databases, and digital product passports to trace products and materials through their life cycles (European Commission, 2020), which can ensure better reuse and remanufacturing of products since it provides information regarding the product and materials utilized in the product (Bressanelli et al., 2018). This information reduces uncertainty and promotes trust in products and materials (Kirchherr et al., 2017). From a business perspective, AI has the potential to facilitate new business models that are based on the CE (Khan et al., 2025). For example, AI analytics have the potential to monitor product usage patterns, predict demand, and design services and that emphasize access and performance rather than ownership (Lopes de Sousa Jabbour et al., 2018). Such business models are in line with the CE principles in that they increase product usage rates and reduce material throughput (Kirchherr et al., 2017). Furthermore, AI can help companies assess circular performance and measure environmental impacts more accurately, supporting sustainability reporting and decision-making (European Commission, 2020).

In addition, AI has the potential to facilitate the governance and monitoring of public policies in the CE (European Commission, 2020). For example, AI has the potential to help policymakers assess the effectiveness of CE and identify the areas where interventions are needed (Lopes de Sousa Jabbour et al., 2018). This capacity is particularly relevant for countries such as Finland, where the overall system changes in the CE policies aim to achieve system-level change and requires continuous monitoring and adaptation (Sitra, 2019). Overall, according to research, AI has numerous opportunities to improve the efficiency and transparency of circular systems (Raut et al., 2025). However, these opportunities depend on supportive institutional and technological conditions (Bressanelli et al., 2018).

2.5 Challenges and Limitations of Artificial Intelligence in the Circular Economy

Despite the opportunities, academic literature also highlights several challenges and limitations of the usage of AI in the CE, which may hinder its progress (Kirchherr et al., 2017). The main challenge to the application of AI in the CE lies in the availability and the quality of data which are essential for the reliability of AI system functions (Bressanelli et al., 2018). CE systems often involve fragmented supply chains and numerous stakeholders, resulting s in poor quality and inconsistent data (European Commission, 2020). Poor quality and inconsistent data may result in biased results from the application of AI, which may limit its contribution to the CE (Lopes de Sousa Jabbour et al., 2018).

Another challenge to the application of AI in the CE lies in the lack of standardization and compatibility of systems (European Commission, 2020). CE involves different sectors and organizational boundaries, and this requires standardization and shared data standards (Bressanelli et al., 2018). without such standards, AI may only be applied at the company level and may fail to benefit the larger supply chain, and this may limit its contribution to the CE (Kirchherr et al., 2017). This limitation reduces contribution of AI to support broader circular transitions rather than efficiency gains (Lopes de Sousa Jabbour et al., 2018).

Economic and organizational factors can also pose barriers to the use of AI in CE systems (Lopes de Sousa Jabbour et al., 2018). For instance, the implementation of AI might require significant investments, skills, and organizational changes, which might not be feasible for small and medium-sized organizations to implement (Bressanelli et al., 2018). Therefore, the benefits of AI-based circular solutions might accrue to large organizations that can afford the implementation of AI (Kirchherr et al., 2017). This might create inequalities among CE actors (European Commission, 2020).

Ethical and social issues pose additional problems in the application of AI in CE systems (European Commission, 2020). For instance, it may be difficult for users and policymakers to understand the decision-making process or how outcomes are generated by an AI system (Kirchherr et al., 2017). This may lead to a lack of trust in the decision-making of an AI system. In addition, some people may worry about the impact of an AI system on employment. This issue should be taken into account in a fair transition to a CE system (Lopes de Sousa Jabbour et al., 2018). From a broader sustainability perspective, some studies have warned against over reliance on technology in addressing CE issues. For instance, an AI system may improve efficiency in the CE system (Kirchherr et al., 2017). However, this efficiency may not automatically lead to reduced resource consumption if people continue to consume resources in the same way (European Commission, 2020). This issue indicates the danger of over-reliance on an AI system in addressing sustainability issues without taking into account other factors, such as the social, cultural, and institutional aspects of society (Bressanelli et al., 2018).

Lastly, some studies have noted a lack of long-term and future-oriented research on the application of an AI system in CE systems. Most of the studies have been done on the current applications or short-term impacts, providing limited insight into how AI may shape CE systems over longer time horizons (Kirchherr et al., 2017). This indicates limited understanding of the long-term effects of an AI system in CE systems which reinforces the need for strategic foresight and scenario-based approaches.

3 THEORETICAL FOUNDATIONS

This chapter discusses the theoretical framework of the study. It includes a discussion of scenario thinking in the CE, as well as an outline of frameworks for integrating AI technologies into CE activities. The section covers the theoretical lens used in the study.

3.1 Scenario Thinking in Sustainability and Circular Economy

Imagining the future is crucial in many aspects of life because it helps people plan for various outcomes in their lives. However, the unpredictability and interconnectedness of issues in the modern world make it difficult to identify a clear vision of the future (Ogollah, 2023). Images of the future are a theoretical notion that is frequently used to organize mental representations that people have regarding the situation of the future (Neuhaus, 2022). While these visions may not come true because the future does not exist at the moment, Rubin (2013) argues that they assist people navigate and cope with life's obstacles. When confronted with complex difficulties, it is unavoidable to develop future scenarios.

The use of scenario thinking is a common technique used by futures studies and sustainability studies. This technique helps people to think about the future when there are ambiguities (Bauwens et al., 2020). This technique helps people to see several possibilities that may be available in the future (Birgen et al., 2024). This is also important when considering the CE because there are ambiguities regarding how technology, the environment, the economy, and society interact (Llorente-González et al., 2025). The CE is considered to be a long-term fundamental shift in the ways that we produce, use, and governance structures (Basile et al., 2024). This shift takes a long time, and there are ambiguities regarding this shift. Therefore, this shift can be analysed by using scenario thinking (Calisto Friant et al., 2025). Scenario approaches help researchers to analyse the effects of the use of new technologies before they are available (Birgen et al., 2024).

There are various research works that have applied the concept of scenario thinking to examine the CE transitions. For instance, Bauwens et al. (2020) developed a framework of scenarios that examine the various CE futures in line with two main areas of uncertainty: how technology will be developed and how centralized the government will be. According to the authors, there are four possible CE futures that can be realized in line with the development of technology and the centralized nature of the government.

Another research work that examined the CE futures is that of Calisto Friant et al. (2025), which examined four CE futures for 2050 in line with the social and economic impacts of CE transitions. According to the authors, there is a possibility for CE futures to be either very sustainable and fair or scenarios where CE does not address social inequality. This is a clear indication that CE transitions are not only technology changes but also social changes. Scenario thinking can also be used to assist in decision-making and planning in CE systems (Greer et al., 2023). Scenario thinking can be used to create different possible futures to better understand possible risks, chances, and uncertainties associated with CE systems (Birgen et al., 2024). Scenario thinking can be very important in new technologies such as AI because the possible effects are uncertain and difficult to forecast (Llorente-González et al., 2025).

In Finland, scenario studies have already been conducted to analyse possible futures in different sectors, including the bio-economy and CE (Kunttu et al., 2022). Scenario studies in Finland show that global trends, new technology, and international policies are very important in shaping possible futures in the CE in Finland (Kunttu et al., 2022). Therefore, scenario thinking can be very important in this study in analysing possible futures in the CE in Finland with regard to AI. Scenario thinking can provide a better framework for this study because we can analyse possible futures in AI in CE systems instead of what is going on currently (Bauwens et al., 2020). Using scenario thinking in this study can provide possible paths, risks, and chances in AI in the CE in Finland by 2035.

3.2 Integrated Framework: Artificial Intelligence and Circular Economy

The CE is a large system that includes production, consumption, waste disposal, and resource recovery. It requires human and social actors like governments, industries, and individuals to collaborate with one another. Moreover, it requires technology that helps save resources and reduce waste (Basile et al., 2024). Because it is a complex system, many researchers refer to it a socio-technical system in which new technology, policies, and human behaviour interact with one another to create circular systems (Korhonen et al., 2018; Marjamaa & Mäkelä, 2022; Greer et al., 2023).

Recently, AI technology has been recognized as an important technology that can assist CE practices (Bressanelli et al., 2018). AI can assist in data analysis, increasing the efficiency of production processes, maintaining items before they deteriorate, and sorting and recycling waste (Lopes de Sousa Jabbour et al., 2018). Therefore, AI can contribute to increasing resource efficiency, minimizing waste, and developing CE business models. So, AI is considered an important technology to accelerate the transition from a linear to a CE (Lopes de Sousa Jabbour et al., 2018). The relationship between AI and the CE can be understood through system-based concepts that show relationships among technology, economic systems, and environmental systems. For instance, Ahmad et al. (2025) proposed a conceptual framework to demonstrate relationships among CE practices, AI technology, economic factors, and industrial decarbonization. The conceptual model proposed that CE practices can directly contribute to mitigating industrial carbon emissions. Moreover, AI technology can directly contribute to mitigating industrial carbon emissions. Furthermore, AI can enhance the relationship between circular practices and industrial decarbonization (Ahmad et al., 2025). The conceptual model is presented in Figure 2.

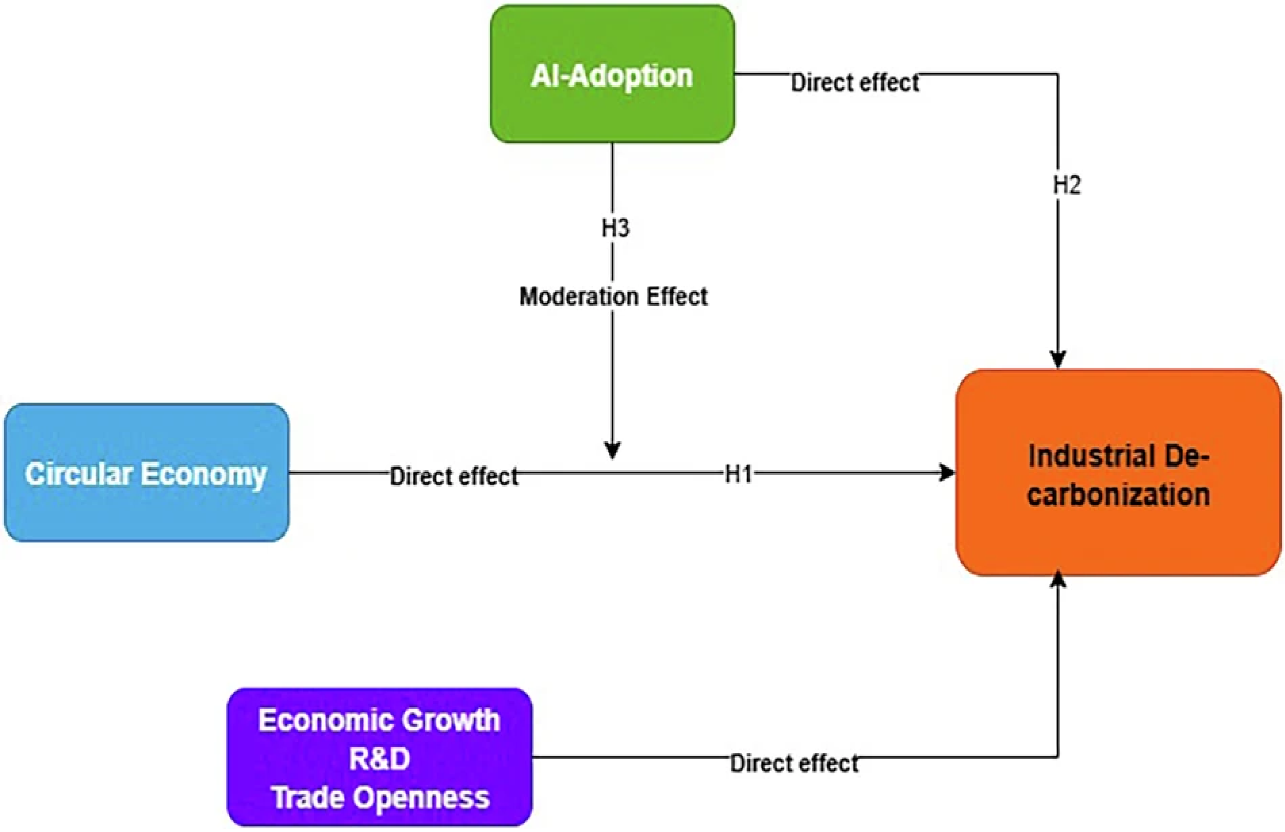

Figure 2: Conceptual Framework (Ahmad et al., 2025, p. 4)

This framework indicates that the CE and AI are not separate entities. These two are connected systems that influence sustainability outcomes. Apart from technology, other elements that influence CE shifts include economic and policy elements (Basile et al., 2024). These elements include investments in research, development, innovation, and trade openness. These elements influence the speed at which CE technologies, as well as AI technologies, are adopted within industry settings (Ahmad et al., 2025). Therefore, CE shifts are influenced by various elements, which need to be viewed as a system. These elements need to be viewed as a system.

To support decision-making within CE systems, researchers have developed various frameworks. These frameworks include the Circular Decision-Making Tree (Greer et al., 2023). This tool is shown in Figure 3. This tool enables decision-makers to compare various CE options. These options include reuse, recycling, remanufacturing, as well as reduction. This tool indicates that decision-making within a CE involves various options. These options need to be weighed to influence sustainability outcomes.

This integrated approach is consistent with Finnish research on the CE. Indeed, Marjamaa & Mäkelä (2022) argue that a transition to a CE will require major changes in many areas: rules, technology, businesses, and daily life. This integrated approach confirms that AI needs to be considered as part of a broader system of circular change, rather than a new phenomenon. Moreover, an integrated approach helps to understand why the role of AI in a CE in the future remains an open question. Indeed, AI may play a role in accelerating circular change if investment, institutions, data availability, and trust are strong. Conversely, if investment, institutions, data availability, and trust are weak, AI may play a limited role. This integrated approach is particularly relevant when studying the future possibilities. Indeed, an integrated approach helps to identify key elements which may shape the future: technology, institutions, economic systems, and sustainability. Overall, an integrated approach was used in this study to analyze the role of AI in a CE. This integrated approach relies on three main elements. Firstly, a CE is a complex system. This complexity cannot be reduced to a simple solution or a single policy intervention (Korhonen et al., 2018). Secondly, AI is an enabling technology. This technology may have a positive impact on a CE. However, its impact depends on wider institutional conditions (Bressanelli et al.). Thirdly, the relationship between AI and a CE is a future-oriented issue. This relationship remains uncertain which justifies a scenario approach (Marjamaa & Mäkelä, 2022).

4 METHODOLOGY

The methodological techniques employed in the research are covered in this chapter. Before going into detail on the justification for the data collection and analysis methods, it includes an outline of the research design. Overall, the research was carried out using a systematic approach (Ogollah, 2023).

4.1 Research design

The research design used in this thesis is qualitative, and a desk-based futures research approach was used. This research employed a qualitative research approach since its main purpose was to explore and understand the possible role of AI in the CE in the future. This research was not intended to test any statistical relationship or measure any variables quantitatively. Instead, it was meant to be purely exploratory and future-oriented (Ogollah, 2023). This makes qualitative futures research methods suitable for use in this research. The research process started with a conceptualization phase, which involved conducting a literature review on CE, AI, digitalization, and futures studies. It provided valuable in delineating the existing research landscape, identifying core concepts, and pinpointing deficiencies concerning the application of AI within CE systems, with a primary focus on Finland. After identifying a gap in research, the next phase involved designing the research process and establishing appropriate methods of undertaking data collection. Since this was a desk-based research, the main data sources were academic articles, policy documents, organizational reports, and industry publications. This research has been conducted through a structured process that includes conceptualization, research design, qualitative analysis, and interpretation. First, the problem and research questions were defined based on the literature review. Secondly, appropriate futures research methods were selected. Thirdly, environmental scanning and qualitative analysis were conducted to identify key trends, signals, and driving forces of change. Fourthly, the findings were interpreted through scenario development and discussion of possible future outcomes. Figure 3 describes the research design process that has been used in this study (Ogollah, 2023).

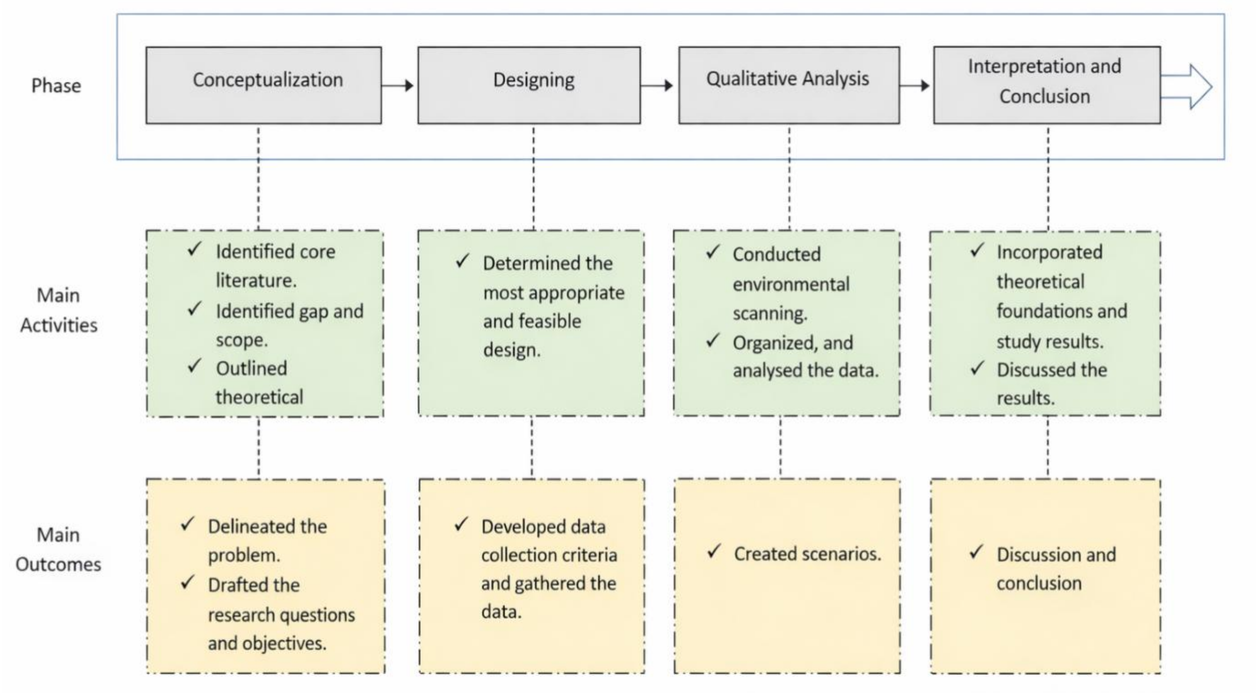

Figure 3: The Research Design (Ogollah, 2023, p. 26)

4.2 Scenario Development Process

Scenario building is one of the techniques frequently used in futures studies. It helps researchers to look at and compare various possible futures. Scenarios are not guesses at what will occur. Scenarios are not guesses at what will occur; they are clear descriptions of various possible developments in the future, based on current trends, uncertainties, and driving forces. Scenarios are helpful to researchers and others to comprehend complicated systems and prepare for various possible outcomes (Amer et al., 2013; Derbyshire & Wright, 2017).

The idea of scenarios originated to investigate future uncertainties and changes. Kahn and Wiener (1967) treated scenarios as a set of imagined future events to investigate possible developments and their consequences. Scenario planning is now commonly used in business, public policy, and research as a technique to support decision-making in uncertain circumstances (Chermack et al., 2001; Amer et al., 2013). Scenarios are helpful because they enable us to look at several possible futures, not just one predicted outcome. The point of scenarios is not to predict the future, but to explore various possible futures and see how our decisions today may influence what happens tomorrow (Dator, 2019). Scenario thinking is helpful to people and organizations to imagine their possibilities for the future and comprehend how their current decisions influence their future (Richter et al., 2023). There are a variety of approaches to building scenarios. Some researchers use a set of frameworks such as

Dator's four futures: growth, collapse, discipline, and transformation. Other researchers use flexible approaches depending on their studies (Inayatullah, 1998; Vallet et al., 2020). In this thesis, scenarios are built based on the futures table method, which is a structured approach to building scenarios. This approach emphasizes a set of key driving forces and their possible development in the future (Kuosa, 2021).

The building of scenarios through the futures table method is made up of several steps: First, the research agenda and scope are defined. Second, the main driving forces that may influence the future are identified. Third, different possible future states of these driving forces are determined. Fourth, scenario paths are selected by combining different future states. Finally, scenario narratives are developed to describe each possible future in a structured way (Tapio et al., 2013; Kuosa, 2021).

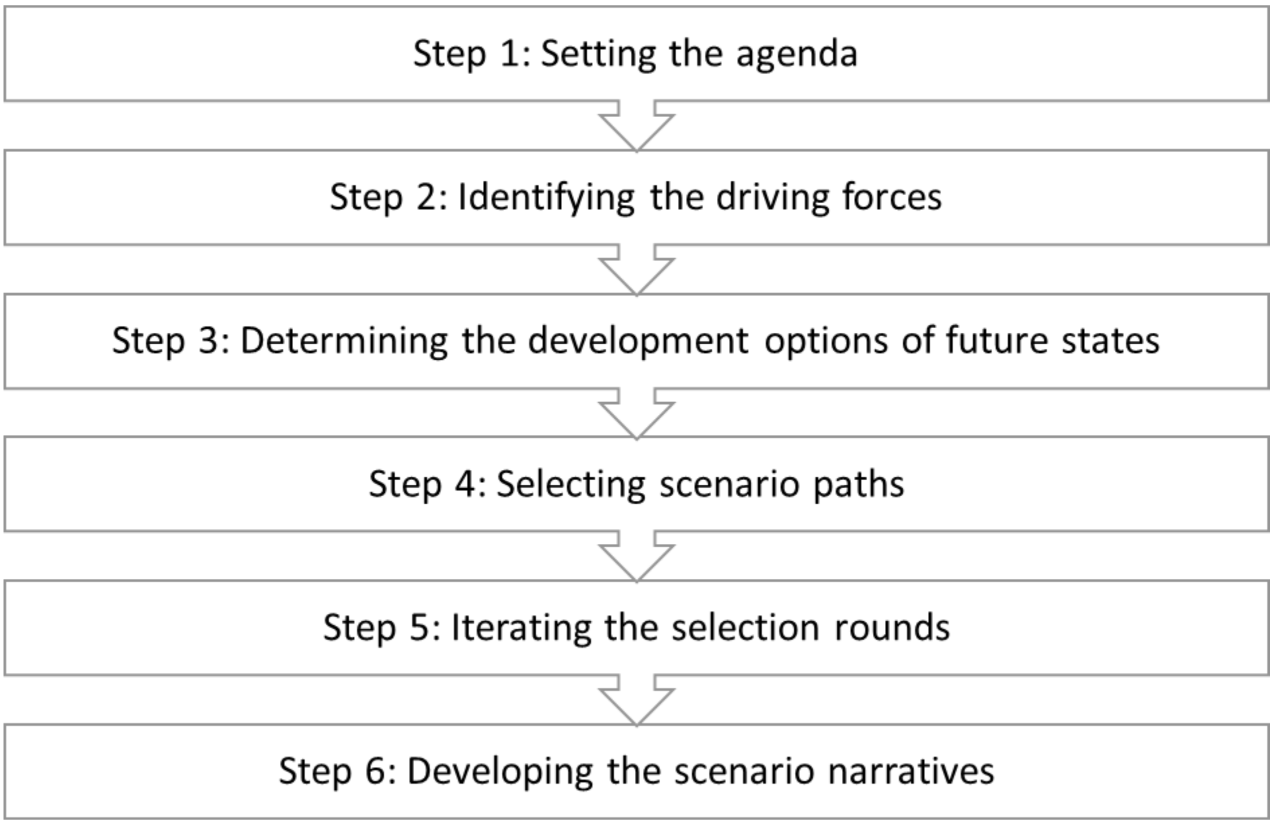

Figure 4: The Scenario Building Process Using Futures Table (Ogollah, 2023, p. 29)

4.3 Data Collection

Environmental scanning was the primary data collection methodology employed in this research. Environmental scanning is considered a significant methodology in futures research. Futures research often involves collecting information regarding future developments, trends, signals, and potential sources of change (Harris & Brooker, 2025). Environmental scanning can be conducted either as a precursor to understanding the subject matter in general or as a primary means of data collection in futures research (Glenn & Gordon, 2009). In this research, environmental scanning has been adopted as the primary data collection methodology because the research aims to explore possible future results in the case of AI in the CE in Finland by the year 2035.

A web-based form of environmental scanning was adopted in this research. This methodology was considered appropriate for this research because it allowed the researcher to collect recent and relevant information from academic, policy, and institutional sources regarding the CE, AI, sustainability transitions, and policy developments in Finland and Europe (Amer et al., 2013; Ogollah, 2023). Environmental scanning was considered a significant data collection methodology in this research because it would help identify signals and trends, which would later be considered in the scenario-building methodology adopted in this research (Kuosa, 2021).

Environmental scanning may generate a significant amount of information, and hence, purposive selection criteria were adopted to avoid information overload and to keep the research manageable (Ogollah, 2023). The materials collected in this research included academic literature, policy documents, and information from websites. Academic literature was collected primarily from Google Scholar and other online academic databases. The search terms were identified based on the research topic and the initial conceptualization of the research. Initially, the search terms included combinations of keywords such as "AI" AND "CE," "AI" AND "CE" AND "Finland," "digitalization" AND "CE," "urban CE" AND "AI," "AI" AND "resource efficiency," "waste management," "recycling," etc.

Following this initial search, any duplicate materials were removed, and the materials were filtered manually by reading their titles, abstracts, and executive summaries. At this point, it was essential to focus on materials that had relevance to the research questions and provided further understanding of how AI relates to CE systems. Materials that focused on very technical aspects of AI, such as algorithm design or computer engineering, without any clear relation to CE, sustainability, or socio-technical change, were excluded from further consideration. Materials with no clear relevance to Finland or Europe were also utilized, but in a limited capacity.

The second type of literature was non-academic and consisted of materials found on the internet, such as policy materials, reports from various organizations, strategies, and materials from various institutions. Given that this thesis is heavily based on Finland, there was a great focus on materials from Finland and Europe in general. This included reports and policy materials from the European Commission, Sitra, the Finnish Ministry of Environment, the European Environment Agency (EEA), and other such organizations working on various aspects of CE, sustainability, and innovation in general. This type of literatures was included because it is very important in understanding different policy directions, trends, and possibilities in relation to the move towards a CE.

In this phase, the credibility of the sources was determined based on their relevance, authority, time, and institutional background. Official publications, policy roadmaps, and reports from recognized research or government organizations were considered a priority. In addition, certain online materials were examined using AI to assist the researcher in recognizing patterns, emerging signals, and weak signals on AI in CE systems. AI was used as a supporting tool, not to substitute the researcher's role. The data collection process was a combination of academic and non-academic materials form a comprehensive and relevant database for horizon scanning. This was a crucial step, especially since the topic of AI in CE is still developing and not only academic literature but also policy and institutional reports discuss it.

4.4 Analytical Process

Framing the Analysis

A systematic analysis was conducted to scope out and build the future scenarios. This was done by following the futures table and scenario development framework, which was discussed earlier in the methods chapter. The first step in building the scenarios was to define the main issue and set the plan. The main issue of this thesis was to build a picture of what the future role of AI will be in a CE in Finland.

The main issue was derived from the main goal of this thesis, which was to explore different possible future scenarios and options of AI in CE systems. Scenario planning can be particularly valuable when researchers and people involved in decision-making try to think about long-term developments (Cordova-Pozo & Rouwette, 2023). This thinking includes considering what current trends and uncertainties might mean for the future (Amer et al., 2013). One of the key considerations when building a scenario is to set a time frame (Cordova-Pozo & Rouwette, 2023). In this thesis, the time horizon is set to the year 2035. This was chosen because it takes a long time to move towards a CE and to build AI technologies. On the other hand, the horizon should not be too far into the future, otherwise the scenarios become unrealistic and too speculative (Brier, 2005). AI and other technologies grow rapidly, but it takes a long time to integrate technologies into a big system like a CE due to factors such as social, economic, and infrastructural (Amiri et al., 2024). Therefore, it is a good and realistic time to look into the future and see how AI and the CE might turn out. The geographic focus for this study is on Finland, because of its position as a forerunner in CE policy and innovation, and there are already several national strategies in place to move towards a CE. The aim of this scenario building process is to explore various possible futures for the use of AI in Finland's CE up to 2035.

Driving Forces

The second part of the analysis was about what might drive future use and development of AI in CE systems in Finland. In scenario building, driving forces are the main forces at play, which define what is going to happen next (Tapio et al., 2013, p. 27; Kuosa, 2021, p. 3). Driving forces are typically identified from environmental scanning and from reading literature. They are grouped into categories, which helps in building scenarios. In this research, driving forces were identified by using AI-supported environmental scanning of academic articles, policy papers, industry reports, and national strategy papers about CE and AI in Finland and the European Union (Habibi et al., 2025). The STEEP method was applied for grouping the driving forces into five categories: social, technological, economic, environmental, and political. The STEEP method is widely applied in futures research for organizing future data, which is complex in nature, and for scenario building (Amer et al., 2013; Tapio et al., 2013). All these driving forces were identified and used to select the most impactful and uncertain ones for scenario development. The initial set of identified driving forces is presented in Table 2.

Table 2: Initial Set of Driving Forces

Social Drivers
• Increasing public awareness of sustainability and CE practices in Finland. • Growing need for digital skills and AI-related competencies in the workforce. • Public acceptance and trust in AI and data-driven systems. • Collaboration between stakeholders. • Changing consumer behavior towards sharing economy, reuse, and sustainable products. • Organizational readiness and willingness of companies to adopt AI-driven circular solutions.
Technological Drivers
• Development of AI and machine learning technologies. • Integration of AI with Internet of Things (IoT) and smart systems. • Use of digital twins for product lifecycle and material tracking. • Data availability and data-sharing platforms for CE systems. • Development of smart waste management and recycling technologies. • Automation and predictive maintenance systems for resource efficiency.
Economic Drivers
• Resource productivity and efficiency targets in Finland. • Development of circular business models. • Investment in green and digital transition projects. • Competitiveness of Finnish companies in CE markets. • Cost savings through efficient resource and material management. • Growth of CE markets and sustainable innovation.
Environmental Drivers
• Finland's carbon neutrality targets. • Waste reduction and recycling targets. • Material scarcity and resource efficiency challenges. • Climate change and environmental sustainability pressures. • Energy efficiency and renewable energy transition. • Environmental regulations related to waste and emissions.
Political Drivers
• EU CE Action Plan. • Finland's national CE roadmap and policies. • EU AI Act and digital regulations. • Government funding and incentives for green and digital transition. • Data governance and data-sharing regulations. • National and EU sustainability strategies and program

Selected Driving Forces

In order to effectively develop scenarios, the initially identified driving forces were narrowed down to those most relevant to the development of the futures of AI in Finland's CE. This was based on an environmental scan of academic journals and industry publications.

Firstly, social aspects have a major influence on how AI evolves in CE systems, especially with respect to digital skills, public acceptance, and collaboration among stakeholders (OECD, 2025). The development of CE systems with AI requires a workforce with high digital skills; therefore, a lack of digital skills may impede the development of AI systems in CE systems (OECD, 2025). Public acceptance and trust in AI also influence whether organizations and society are willing to adopt AI-based CE systems (Rusko, 2024). Furthermore, collaboration among government, companies, universities, and other stakeholders is also crucial for the development of CE systems (Business Finland, 2024).

The role of technological factors is also significant in defining the future of AI in the CE, as AI technologies are known for their significant contribution to data-based decision-making, automation, and optimization of resource usage (Rusko, 2024). Technologies such as AI-based waste management, digital twins, and resource management systems are also expected to improve their efficiency in CE systems (Wilts et al., 2021; Tanskanen et al., 2025). AI requires a lot of data to function; therefore, data availability is also important for developing AI-based CE systems (AI 4.0 Programme, 2022). This is because data availability is also essential for developing the digital infrastructure for using AI in CE systems (OECD, 2025).

Economic factors make important contribution to the development and the use of AI in CE systems, especially with regard to investment, circular business models, and productivity (EEA, 2024). Therefore, developing and using AI requires financial engagement from both government and business actors (Farshadfar et al., 2024). In addition, circular business models such as product-as-a-service, sharing platforms, and remanufacturing play a crucial role in the development and use of AI in CE systems (EEA, 2024). Research indicates that CE systems such as AI-based waste sorting machines are economically beneficial due to their ability to reduce costs (Farshadfar et al., 2025).

Environmental factors are also have a vital role in determining the future of AI in the CE. The issue of climate change, the growing pressure from limited resources and rising waste generation are factors that call for the development of efficient systems (EEA, 2024). The move by Finland to be carbon neutral and the CE strategy also increases the need for innovative solutions that make better use of resources while lowering environmental harm (Statistics Finland, 2024). AI can make an important contribution in addressing the environmental issue by increasing the efficiency of the movement of materials, the process of recycling, and the cutting emissions across industrial and urban settings (Wilts et al., 2021).

Lastly, it is important to understand that political factors play a crucial role in shaping the future development of AI in CE systems, as government policies, regulations, and strategies can either promote or hinder the development of AI-based CE systems (OECD, 2025). The framework of policies at the European Union level and national levels is of critical value in providing funding, regulation, and strategic direction for CE and digitalization initiatives (EEA, 2024). Therefore, political aspects, including government support, are viewed as critical driving forces for defining the future of AI in Finland's CE systems (Rusko, 2024).

In general, it is important to understand that these chosen driving forces are of critical value in defining the future of AI in Finland's CE systems. The chosen driving forces were applied in developing the futures table and defining alternative scenarios for the year 2035 (Tapio et al., 2013; Kuosa, 2021).

Defining Future Development Paths

The next step in the scenario building process was to determine the different possible paths of development for the various driving forces that had been selected. These paths of development are the alternatives, the different directions that the different driving forces could take by the year 2035. In the field of futures research, these alternatives are important because they enable us to comprehend the different ways in which the different developments may come together to produce different possible futures (Tapio et al., 2013; Kuosa, 2021). Therefore, different sets of future development options were created for every driving force that had been selected, and these are presented in the form of a futures table. The future development options define how each of the driving forces might develop over time, for example, whether the development of technology would be slow, moderate, or fast, or whether government support would be weak, moderate, or strong. The development options must be mutually exclusive and logically consistent so that they can be combined into different scenario paths (Tapio et al., 2013). The purpose of defining alternative paths is to create a framework for exploring different possible futures for applying AI in CE systems in Finland, which might occur towards 2035 (Kuosa, 2021). The completed futures table with the development options is presented in Appendix 1.

Scenario Construction and Narrative Development

The next step involved combining the different development options to create alternative scenarios of the future scenarios. In scenario planning, there are various techniques available to assist in choosing scenario paths. These techniques include scenario archetypes, theory, and/or intuitive logic (Amer et al., 2013). An intuitive logic technique was used to construct the scenarios by combining different possible futures of selected driving forces.

The process of scenario development involved selecting one of the key drivers and combine their possible futures with those of other drivers. This process was repeated several times to produce different combinations of possible futures. Each of these combinations produced a different scenario. The developed scenarios were also reviewed for their internal consistency, logical plausibility, and differentiation from each other, which is an important aspect of scenario development (Kuosa, 2021; Amer et al., 2013).

The scenario paths were then used to write narratives for each scenario to describe how the future might unfold. This describes how AI would develop in CE systems, what role policy and investments would play, and how environmental factors would be involved. It also describes how stakeholders would be affected in Finland by 2035. The scenario narratives are discussed in Chapter 5.

5 FINDINGS

This chapter introduces the scenario narratives developed for this research. Four alternative futures for the use of AI in the CE of Finland were developed until 2035, based on the future states presented in Table 2. The table of the futures results from combining the selected driving forces with the possible paths of the driving forces. The future states were based on the results of the literature review, horizon scanning, and policy objectives for AI and the CE in Finland. The scenarios combine different future states into a consistent and believable whole. The rationale for the scenarios follows the familiar patterns of the archetypes of growth, transformation, steady development, and strained development (Amer et al., 2013; Dator, 2019; Kuosa, 2021; Tapio et al., 2013).

Table 3: Scenario Paths for AI in Circular Economy

Driver	**Variable**	**Smart Circular**	**Collaborative Transition**	**Gradual Uptake**	**Strained System**
Social	Public awareness of CE	Widespread awareness	High public engagement	Moderate awareness	Limited awareness
	Digital skills	Highly skilled workforce	Skills improving through collaboration	Moderate skill levels	Skills shortage
	Stakeholder collaboration	Technology-led collaboration	Strong multi-actor collaboration	Some cooperation	Fragmented stakeholders
Technological	AI adoption in CE	Widespread AI adoption	AI used in key sectors	Gradual adoption	Slow adoption
	Data sharing platforms	Open data platforms	Shared data ecosystems	Limited data sharing	Closed data systems

Driver	Variable	Smart Circular	Collaborative Transition	Gradual Uptake	Strained System
	Smart waste technologies	Advanced automation	Moderately advanced	Basic improvements	Limited technology
	Digital twins	Widely used	Used in major cities	Pilot projects	Rarely used
Economic	Investment in AI & CE	High investment	Public-private investments	Moderate investment	Low investment
	Circular business models	Fully circular models	Expanding circular models	Hybrid models	Mostly linear economy
	Resource productivity	Very high efficiency	Improving efficiency	Moderate improvement	Low efficiency
Environmental	Carbon neutrality	Achieved	Nearly achieved	Progress but slow	Targets delayed
	Recycling rates	High recycling	Improved recycling	Moderate recycling	Low recycling
	Material scarcity	Well managed	Managed through collaboration	Some shortages	Serious shortages
Political	Policy support	Moderate support	Strong policy support	Moderate regulation	Weak policy support
	Government funding	Innovation funding	Sustainability funding	Limited funding	Minimal funding

5.1 Scenario 1: Smart Circular

In 2035, Finland has been successfully integrated AI into its CE and has become a leader in the innovation of the CE. AI, digital technologies, and other innovations have been skilfully incorporated into the optimization of the CE. The emergence of AI technology has been rapid, and it has been incorporated into various sectors of including waste management, production, and energy. The citizens have a high awareness of the CE and are actively participating in the reuse and recycling of products and the sharing economy. Investments in education have had a remarkable impact on the digital literacy of the workforce and the economy, enabling them to take advantage of AI in the CE. The cooperation between government, industry, academia, and innovation developers, has increased and promoted innovative CE ideas and digital technologies.

In this scenario, public awareness of CE practices is high, and citizens actively engage in CE practices. AI is part of the daily life through digital platforms that assist consumers in making CE choices through the provision of information on product lifespan, repairability, and recyclability. The workforce is highly skilled in using the digital technologies, AI, and data management, facilitating the creation and implementation of CE solutions with AI. The adoption of AI in CE systems is widespread. In this context, AI is the key factor which plays a crucial role in smart waste management systems. In smart waste management systems, sophisticated robotic systems are used for sorting waste materials with high precision using image recognition. Recycling systems are highly automated, resulting in a significant increase in recycling rates and a decrease in waste materials. In addition, digital twins are widely used in cities and industrial networks for simulating materials, energy consumption, and infrastructure performance.

Open data platforms allow data sharing among companies, municipalities, and other stakeholders to collaborate data exchange among diverse actors using technology which allows for the exchange of material data, product information, and logistics data in real time. This also help supply chains to become more transparent and efficient, allowing companies to trace materials used in products throughout their entire lifecycle. Companies can design and implement fully circular business models where products are designed to be reused, repaired, remanufactured, and recycled. In this scenario, considerable and increasing investments in AI and CE technologies drive technological advancements in this field. Both businesses and organizations invest in innovation in this field. Governments also invest in funding innovation, specifically in startups, new technologies and new businesses in circular economies. With all these developments, Finland achieves carbon neutrality in 2035 and has high levels of resource productivity. The country also has high levels of recycling, and material scarcity is managed with efficient tracking and reuse, as well as AI-driven predictive resource management. The CE creates new business opportunities, promotes resource efficiency, and minimizes environmental impact. The Smart Circular scenario shows a future where AI plays a key role in creating a highly efficient and technology-driven CE. With widespread use of AI, data platforms, robust investments, and a highly skilled workforce, Finland is ready to move into a smart and fully CE in 2035.

5.2 Scenario 2: Collaborative Transition

In the year 2035, the move towards a CE in Finland is facilitated by effective collaboration between various entities in the public sector, the private sector, and research institutions. AI is also incorporated in the economy but in selected sectors rather than in the whole economy. The development of the CE is not driven by technology alone but also by governance, collaboration, and shared sustainability agendas.

Public awareness of the CE is also high in this scenario, with citizens participating in various recycling and sharing schemes and engaging in various CE initiatives in their communities. The improvement in digital skills in this scenario is gradual, driven by education and training in the workplace and collaboration between organizations. This gradual improvement in digital skills will also contribute to the development of AI applications, especially in sectors where the benefits of the CE are evident in terms of economic and environmental benefits.

In this scenario, AI is applied in various sectors such as waste management, logistics, and infrastructure, among others. The technology applied in waste management is moderately developed, and digital twins are also applied in various cities to help them optimize their operations and minimize their impacts on the environment, even though AI is not fully developed in the economy. Data sharing is developed through companies, cities, and research organizations through data sharing ecosystems and is used through cooperation between them. However, data governance, data ownership, and data standardization are some of the key challenges which require continuous negotiation and cooperation between these organizations. Economically, this scenario is such that it is creating an environment in which joint investments are being done in AI and CE infrastructure between the public and private sector. There are diverse CE business models being developed, which include repairs, remanufacturing, sharing, and product-service systems. Currently, companies are working in partnership, both individually and collectively, to develop a CE. The role of the government in supporting sustainability funding and CE is also an important factor in developing CE pilot projects. In this scenario, the environment is also being protected. The rate of recycling is improving, and

Finland is getting closer to its carbon neutrality goals. In addition, the problem of scarcity of resources is being solved through cooperation and partnership between various industries and CE networks.

However, despite the success of the strategy, there are some challenges that need to be considered. The development of AI requires significant investment and qualified people. The level of embracing the CE strategy may not be the same in all sectors of the economy. Furthermore, the joint effort may not be easy, as the parties involved may not have the same objectives and targets in mind. Therefore, support from all the parties involved is crucial in ensuring the success of the strategy.

5.3 Scenario 3: Gradual Uptake

By 2035, Finland has managed to incorporate AI and CE concepts, but this has not been a rapid process. Instead, it has been a gradual shift, especially where there are obvious financial benefits. AI, for instance, is used in waste management, logistics, and manufacturing. However, there are still companies that are reluctant to let go of traditional ways of doing business. Additionally, there are no significant differences in consumption patterns from previous decades. Although people are used to recycling and sorting, there are still instances where traditional consumption patterns are dominant. This is because, for most people, traditional consumption patterns are not only convenient but also cheaper. Product-service systems and sharing economy concepts are available but are not yet very popular. As a result, CE concepts are becoming popular but not dominant. The country's workforce possesses sufficient skills for AI, but this may not be the case for all companies. As a result, there are instances where AI may not be adopted as rapidly as expected. Large companies and municipalities are able to utilize AI and big data platforms, but this may not be the case for all companies. In addition, there are cases where companies are prevent to share information, especially where there are obvious risks of losing out to competitors.

Investment levels are low throughout the 2020s and the early part of the 2030s. Some businesses see the CE solutions as a new market opportunity, while others treat them more as a regulatory requirement than a competitive advantage. As a result, many businesses are operating with hybrid models that combine the linear and the circular approaches, including recycling and remanufacturing. Environmental trends are positive, with increasing rates of recycling and gradual increases in the efficiency of resource use but, the levels of material use remain relatively high. Finland is progressing towards carbon neutrality, although the rate of progress is slower than anticipated. Global competition for raw materials occasionally creates supply chain risks, which in turn creates more interest in material recovery and also recycling, although this is not enough to eliminate material dependencies.

This scenario describes a future where the CE develops gradually and not through revolutionary change. AI is seen to be helping the CE where there are obvious benefits, although it is not changing the entire economic system. As a result, there is a slow and Gradual Uptake, with environmental benefits accruing gradually and the full potential of AI in the CE not being realized.

5.4 Scenario 4: Strained System

The Finnish initiative of integrating AI in CE systems until 2035 faced challenges in overcoming economic and organizational challenges. The CE has remained a key priority for the Finnish government. However, the development of these systems has been slow. There has been little improvement in the level of awareness of the CE. There have been no changes in consumer behavior. Recycling systems have been created, however participation rates vary among individuals. The transition to a CE remains an essential policy goal, but implementing large-scale, systemic changes has proven challenging.

The use of AI in CE activities has been a slow process. The investment costs of AI have remained expensive, and there have been shortages of skilled workers and organizational resistance to accepting new technology. While there have been some large-scale experiments in AI, data analytics, and smart technology, most businesses have been unwilling to adopt new technologies. Smart technologies in waste management have made just minimal progress, with few projects including digital twins. Data sharing across businesses remains limited, and corporations have been reticent to share operational data due to concerns about competitiveness, cybersecurity, and unclear data governance policies. This lack of collaboration remains an important barrier to achieving transparency in material flows and creating efficient circular value chains.

In this case, the economy remains unclear, limiting investment in new CE infrastructure and AI technology. Many organizations continue to focus on cost-cutting and increasing short-term productivity, which is not the case with sustainable businesses. CE business concepts are uncommon, while the traditional linear economy remains the primary business model in the economy. As a result, resource productivity progressively grows, recycling rates remain low, and reliance on new raw materials is high. In this context, the global demand for raw materials is causing periodic shortages. Many industries are facing challenges related to the availability of materials, which is subsequently impacting the cost of production. It is becoming increasingly challenging to achieve environmental requirements, and the path to carbon neutrality is losing its way.

Without sufficient policy support and government funding, the process is becoming increasingly complex. Moreover, the level of collaboration among stakeholders is becoming fragmented to achieve the CE. It is becoming increasingly evident that the future will not rely on AI to drive the CE. As a result, the CE stays low, while the linear economy remains strong. Development is visible, but at in a reduced rate. Finland is expected to be behind technologically advanced and circular-based economies. By 2035, it is clear that the CE will still be in transition.

6 DISCUSSION AND CONCLUSION

This study is designed to explore the possible impact of AI on CE systems in Finland towards 2035 through futures studies. Instead of predicting a single possible future, four different scenarios were developed to present different possible futures in which AI can influence CE systems in Finland in response to different changes in social, technological, economic, environmental, and political aspects. Scenarios are "images of possible futures that can be used to reduce uncertainty, stimulate thinking, and explore different routes to a particular destination" (Amer et al., 2013; Dator, 2019; Kuosa, 2021).

The results of the present research suggest that the futures of AI in CE systems cannot be explained by technological development alone. The application of AI could aid in waste management, logistics, predicting machine maintenance needs, product tracking, and handling materials in CE systems. The overall effect of AI in these systems also relies on other factors. These four scenarios also show that different futures can arise from the same national context. In the Smart Circular scenario, AI thoroughly ingrained in CE practices, enabling a highly efficient and innovation-based CE system. In the Collaborative Transition scenario, described that the role of cooperation, governance, and shared sustainability objectives is more important. In the Gradual Uptake scenario, change remains to be incremental and varied, while in the Strained System scenario, investment, support, and relationships between stakeholders are lacking.

In this way, the four scenarios provide an answer to the first research question: that multiple possible alternative futures can be developed for the use of AI in CE systems in Finland by 2035. As the scenarios are not an end in themselves, the next step is to consider what the scenarios imply for the actors involved in the circular transition process in Finland. The focus shifts from describing the scenarios to interpreting the implications of the scenarios for the stakeholders involved in the CE in Finland. In this way, the chapter also deals with the second research question regarding the implications of the scenarios for the stakeholders involved in the CE in Finland.

6.1 Implications of the Scenarios for Stakeholders

Developed scenarios in this study illustrate that the role of AI in the CE in the future will have different implications for different groups of stakeholders. However, regardless of the four scenarios developed in this study, AI is likely to strengthen the CE transition if it is supported by good institutions, enough investment, cooperation between actors, and reliable data systems.

For policymakers, the scenarios demonstrate that; regulation, public funding, and long-term strategies are very important. In the stronger scenarios that developed in this study, government support is seen to strengthen the development of CE systems financially and in terms of cooperation among different stakeholders. This is consistent with the Finnish and European visions of the CE transition, which is seen as a comprehensive transition of the entire system (Sitra, 2016; Sitra, 2019; European Commission, 2020). In the weaker scenarios, government support slows down the development of CE systems. Therefore, public policy is likely to have a significant influence on the role of AI in the CE and whether it is a central or peripheral driver of the CE transition.

For companies and industrial actors, AI offers opportunities which include: predictive maintenance, smart sorting, tracking of materials, reverse logistics, and efficient use of resources. Previous studies suggest that AI and other digital technologies can support CE activities (Bressanelli et al., 2018; Lopes de Sousa Jabbour et al., 2018; Govindan, 2023). However, the scenarios suggest that not all companies and actors can benefit from AI, means that some companies can gain more advantages than others. For instance, in the better futures, companies can combine AI and CE strategies like service-based systems, remanufacturing, and product life extension. In the weaker futures, companies can stick to conventional strategies because the costs of CE strategies and AI technologies can be too high, and the benefits can be too low.

Municipalities are other stakeholders in the CE. This is because many CE activities occur in cities. For instance, urban waste management can be one of the areas in which AI can support CE strategies, and municipalities can use smart urban waste management systems and AI to improve efficiency (Devi et al., 2025). The scenarios in this thesis support the idea that municipalities can use AI and smart systems to support CE strategies. This can be noted in the scenarios, especially in the stronger futures, which means that municipalities can play an important role in Finland's CE journey.

For technology developers and the agents of innovation, these scenarios offer opportunities and limitations. For instance, AI technologies can be more helpful in sorting, monitoring, predicting, and managing data. However, the scenarios indicate that even with improved technologies, the CE can still not move forward. This is because, according to earlier studies, digital innovation can only thrive in tracking, coordinating, and implementing ideas in the entire value chain (Bressanelli et al., 2018; Walden et al., 2021). Therefore, technology developers should not only focus on the performance of technologies but also they need to consider usability, trust, and compatibility with circular systems.

For citizens and consumers, the scenarios indicate that social acceptability plays a major role in the CE. For instance, citizens should be aware and willing to recycle, reuse, and even share. The scenarios indicate that these attitudes determine whether CE practices remain exceptional or become more common. This is consistent with earlier studies on circular economies, which indicate that the CE relies not only on technological and policy innovations but also on changing social habits and consumers' behavior (Kirchherr et al., 2017; Basile et al., 2024). This means that even with AI technologies, the CE can remain slow because consumers' attitudes towards owning, convenience, and short lifecycles of products can remain unchanged.

As a conclusion, AI is not a complete solution to solve the problems in a CE, but rather it is a useful tool in making things more efficient and assisting in better decision-making, but it is not a solution on its own in solving bigger social, economic, and institutional problems. In earlier studies, digital innovation has shown as the best chance of being effective in cases where it can support traceability, coordination, and usability (Bressanelli et al., 2018; Walden et al., 2021). Therefore, technology developers should not only concentrate on performance but also on usability, trustworthiness, and compatibility with circular systems. Overall, the second research question is addressed by demonstrating that the implications of the scenarios vary for different stakeholder groups, although all scenarios have a single overarching lesson in common. The future of AI in Finland's CE will depend on the collaboration of the government, companies, municipalities, innovation actors, and citizens. Strong futures are those in which AI is related to other CE changes, while weak futures are those in which AI remains in isolation from other changes in the system. For Finnish stakeholders, the key question is not whether AI is used, but rather how it is governed, supported, and integrated into CE systems.

6.2 Limitations of the Study

This study has some limitations that should be acknowledged. Firstly, this research was conducted as an individual desk-based futures study. Although this type of research is appropriate for an individual Master's thesis, but it would have been more benefits by involving a number of experts in building scenarios, as this would allow for a broader variety of perspectives on which driving forces to include in a particular scenario, as suggested by Amer et al. (2013) and Vallet et al. (2020).

Secondly, this research relied on secondary data, such as articles, policy papers, and reports were used as sources of information, whereas using primary data would have provided a clearer picture of how Finnish stakeholders see the opportunities and challenges presented by AI in a system of CE.

Thirdly, another limitation is related to the use of AI-assisted horizon scanning in the data collection process. In this study, AI was used only as a supporting tool for identifying patterns, trends, and weak signals, while the interpretation and final analytical decisions remained with the researcher. However, AI-assisted scanning may still carry risks, such as overemphasising highly visible trends while giving less attention to weaker but potentially important developments. This means that researcher judgement remained very important throughout the process, and full neutrality cannot be claimed in futures-oriented research (Richter et al., 2023).

Lastly, AI and, CE policy is constantly changing, which means that some of the assumptions and signs presented in this thesis may change in the future. Therefore, this thesis should not be taken as a prediction of future scenarios, but rather as a tool for building scenarios, which are images of future possibilities based on available information during a particular time (Dator, 2019; Kuosa. 2021)

6.3 Further Research

This thesis indicates several promising lines for further research. An important one is to carry out in-depth research into different sectors, such as waste management, production, construction, logistics, and digital product passports. Although this thesis addressed the topic of AI and the CE on the level of the entire system, sector-based research might help to gain a clearer view of the actual processes and developments related to these phenomena. Another promising field for further research is the application of the method of scenarios. Although the scenarios developed in this thesis were the result of individual work using the desk research method, it is possible to involve different stakeholders, such as policymakers, municipalities, businesses, technology experts, and researchers, in the scenario development process. It is assumed that this would contribute to the development of even more relevant scenarios, especially in the field of the CE, where the processes and developments in the field of technology, institutions, and society are closely intertwined (Amer et al., 2013; Vallet et al., 2020).

Further research is needed to address the overall circumstances in which the CE with the support of AI might take place. Questions related to data sharing, data security, ethics, and trust might become even more important in the future, especially considering the growing role of digital technologies in the activities related to the CE (European Commission, 2020; Roberts et al., 2024). It might be useful to compare the situation in Finland with the situation in other countries to determine what is unique to Finland and what is characteristic of the entire European region. Furthermore, it is possible to pay greater attention to the social consequences in the future to obtain a clearer view of the actual processes and developments related to the CE.

References

Ahmad, S., Wu, X., Rahman, A. U., & Ullah, A. (2025). Unlocking industrial decarbonization: the catalytic role of artificial intelligence in circular economy practices from EU countries. *Humanities & Social Sciences Communications*, *12*(1), Article 1969. https://doi.org/10.1057/s41599-025-06230-8

Amer, M., Daim, T. U., & Jetter, A. (2013). A review of scenario planning. *Futures, 46*, 23–40. https://doi.org/10.1016/j.futures.2012.10.003

Amiri, A. G., Hakimi, M., Rajaee, S. M. K., & Hussaini, M. F. (2024). Artificial intelligence and technological evolution: A comprehensive analysis of modern challenges and future opportunities. *Journal of Social Science Utilizing Technology, 2*(3), 301–316.

Artificial Intelligence 4.0: Finland as a leader in twin transition – Final report of the Artificial Intelligence 4.0 programme. (2022). Ministry of Economic Affairs and Employment of Finland. https://urn.fi/URN:ISBN:978-952-327-918-6

Basile, V., Petacca, N., & Vona, R. (2024). Measuring circularity in life cycle management: A literature review. *Global Journal of Flexible Systems Management, 25*(3), 419–443. https://doi.org/10.1007/s40171-024-00402-2

Bauwens, T., Hekkert, M., & Kirchherr, J. (2020). Circular futures: What will they look like? *Ecological Economics, 175*, 106703. https://doi.org/10.1016/j.ecolecon.2020.106703

Birgen, C., Grytli, T., & Becidan, M. (2024). Scenario analysis tool for estimating future waste composition and amounts toward a circular economy. *Journal of Material Cycles and Waste Management, 26*, 2724–2740. https://doi.org/10.1007/s10163-024-01992-w

Bressanelli, G., Adrodegari, F., Perona, M., & Saccani, N. (2018). Exploring how usage-focused business models enable circular economy through digital technologies. *Sustainability, 10*(3), Article 639. https://doi.org/10.3390/su10030639

Brier, D. J. (2005). Marking the future: A review of time horizons. *Futures, 37*(8), 833–848. https://doi.org/10.1016/j.futures.2005.01.005

Business Finland. (2024). *Circular economy creates competitiveness: 4 enablers for the transition to circular economy*. Business Finland. https://www.businessfinland.fi

Calisto Friant, M., Vermeulen, W. J. V., & Salomone, R. (2025). Degrowth or barbarism? An exploration of four circular futures for 2050. *Frontiers in Sustainability, 6*, Article 1527052. https://doi.org/10.3389/frsus.2025.1527052

Chermack, Thomas & Lynham, Susan & Ruona, W.E.A. (2001). A Review of Scenario Planning Literature. Futures Research Quarterly. 17. 7-31.

Chabowski, B. R., Gabrielsson, P., Hult, G. T. M., et al. (2025). Sustainable international business model innovations for a globalizing CE: A review and synthesis, integrative framework, and opportunities for future research. *Journal of International Business Studies, 56*(3), 383–402. https://doi.org/10.1057/s41267-023-00652-9

Cordova-Pozo, K., & Rouwette, E. A. J. A. (2023). Types of scenario planning and their effectiveness: A review of reviews. *Futures, 149*, 103153. https://doi.org/10.1016/j.futures.2023.103153

Dator, J. (2019). *Jim Dator: A noticer in time: Selected work, 1967–2018* (Vol. 5). Springer International Publishing. https://doi.org/10.1007/978-3-030-17387-6

de Lucas López, A. J., Vera, C. L., & Álvarez Miguel, Á. J. (2026). Artificial intelligence as a catalyst for the circular economy: A mixed-methods analysis of sustainable production ecosystems (2023–2024). *International Entrepreneurship and Management Journal, 22*(2), Article 59. https://doi.org/10.1007/s11365-026-01176-y

Derbyshire, J., & Wright, G. (2017). Augmenting the intuitive logics scenario planning method for a more comprehensive analysis of causation. *International Journal of Forecasting, 33*(1), 254–266. https://doi.org/10.1016/j.ijforecast.2016.01.004

Devi, A., Singh, N., Thandra, N., Gupta, N., Salman, Z. N., & Natarajan, K. (2025). AI and IoT-Enabled Smart Urban Waste Management System for Efficient Collection, Segregation, and Disposal. *E3S Web of Conferences*, *619*, Article 03002. https://doi.org/10.1051/e3sconf/202561903002

Ellen MacArthur Foundation. (2019). *What is the meaning of a circular economy and what are the main principles?* https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

European Commission. (2020). *A new circular economy action plan: For a cleaner and more competitive Europe*. https://ec.europa.eu/newsroom/growth/items/673419/en

European Environment Agency. (2024). *Circular economy country profile: Finland*. European Environment Agency. https://www.eea.europa.eu

European Topic Centre on Circular Economy and Resource Use. (2022). *Circular economy country profile: Finland*. https://www.eionet.europa.eu

Farshadfar, Z., Khajavi, S. H., Mucha, T., & Tanskanen, K. (2025). Machine learning-based automated waste sorting in the construction industry: A comparative competitiveness case study. *Waste Management, 194*, 77–87. https://doi.org/10.1016/j.wasman.2025.01.008

Farshadfar, Z., Mucha, T., & Tanskanen, K. (2024). Leveraging machine learning for advancing circular supply chains: A systematic literature review. *Logistics, 8*(4), Article 108. https://doi.org/10.3390/logistics8040108

Gallasch, G. E., Jordans, J., & Ivanova, K. (2018). Application of field anomaly relaxation to battlefield casualties and treatment: A formal approach to consolidating large morphological spaces. In R. Sarker, H. A. Abbass, S. Dunstall, P. Kilby, R. Davis, & L. Young (Eds.), *Data and decision sciences in action* (pp. 327–341). Springer International Publishing. https://doi.org/10.1007/978-3-319-55914-8_24

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Glenn, J. C., & Gordon, T. J. (2009). Environmental scanning. In J. C. Glenn & T. J. Gordon (Eds.), *Futures research methodology* (Version 3.0). The Millennium Project.

Govindan, K. (2023). How digitalization transforms the traditional circular economy to a smart circular economy for achieving SDGs and net zero. *Transportation Research Part E: Logistics and Transportation Review, 177*, 103147. https://doi.org/10.1016/j.tre.2023.103147

Greer, R., von Wirth, T., & Loorbach, D. (2023). The circular decision-making tree: An operational framework. *Circular Economy and Sustainability, 3*(2), 693–718. https://doi.org/10.1007/s43615-022-00194-6

Habibi, A., Ghavami, M., & Taghipour, K. (2025). *AI coworker: Horizon scanning in foresight*. *Quarterly Journal of Parsmodir Advertising and Marketing, 12*(42), 1–11. https://www.researchgate.net/publication/397668788_AI_Coworker_Horizon_Scanning_in_Foresight

Harris, B., & Brooker, J. (2025). Environmental Scanning: A Look to the Future. *New Directions for Evaluation*, *2025*(185–186), 33–41. https://doi.org/10.1002/ev.20633

Inayatullah, S. (1998). Causal layered analysis: Poststructuralism as a method. *Futures, 30*(8), 815–829. https://doi.org/10.1016/S0016-3287(98)00086-X

Jakobsen, S., Lauvås, T. A., Quatraro, F., Rasmussen, E., & Steinmo, M. (Eds.). (2021). *Research handbook of innovation for a circular economy*. Edward Elgar Publishing. https://doi.org/10.4337/9781800373099\

Jesus, G. M. K., Jugend, D., Paes, L. A. B., Siqueira, R. M., & Leandrin, M. A. (2023). Barriers to the adoption of the circular economy in the Brazilian sugarcane ethanol sector. *Clean Technologies and Environmental Policy, 25*(2), 381–395. https://doi.org/10.1007/s10098-021-02129-5

Kahn, H., & Wiener, A. J. (1967). The next thirty-three years: A framework for speculation. *Daedalus, 96*(3), 705–732. https://www.jstor.org/stable/pdf/20027066.pdf

Khan, MD. A., Rahman, A., Mahmud, F. U., Bishnu, K. K., Ahmed, M., Mridha, M. F., & Aung, Z. (2025). A systematic review of AI-driven business models for advancing Sustainable Development Goals. *Array (New York)*, *28*. https://doi.org/10.1016/j.array.2025.100539

Khedr, A. M., & S, S. R. (2024). Enhancing supply chain management with deep learning and machine learning techniques: A review. *Journal of Open Innovation*, *10*(4). https://doi.org/10.1016/j.joitmc.2024.100379

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling, 127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kirchherr, J., Yang, N.-H. N., Schulze-Spüntrup, F., Heerink, M. J., & Hartley, K. (2023). Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions. *Resources, Conservation and Recycling*, *194*, Article 107001. https://doi.org/10.1016/j.resconrec.2023.107001

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics, 143*, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Kristoffersen, E., Blomsma, F., Mikalef, P., & Li, J. (2020). The smart circular economy: A digital-enabled circular strategies framework for manufacturing companies. *Journal of Business Research, 120*, 241–261. https://doi.org/10.1016/j.jbusres.2020.07.044

Kunttu, J., Wallius, V., Kulvik, M., Leskinen, P., Lintunen, J., Orfanidou, T., & Tuomasjukka, D. (2022). Exploring 2040: Global trends and international policies setting frames for the Finnish wood-based economy. *Sustainability, 14*(16), 9999. https://doi.org/10.3390/su14169999

Kuosa, T. (2021). *Futures table – A powerful scenario planning tool*. Futures Platform. https://www.futuresplatform.com/blog/futures-table-scenario-planning-tool

Lakhouit, A. (2025). Revolutionizing urban solid waste management with AI and IoT: A review of smart solutions for waste collection, sorting, and recycling. *Results in Engineering, 25*, 104018. https://doi.org/10.1016/j.rineng.2025.104018

Lehtimäki, H., Aarikka-Stenroos, L., Jokinen, A., & Jokinen, P. (Eds.). (2023). *The Routledge handbook of catalysts for a sustainable circular economy* (1st ed.). Routledge. https://doi.org/10.4324/9781003267492

Llorente-González, L. J., Alberich, J. P., Genovese, A., & Lowe, B. H. (2025). Towards radical circular economy futures: Addressing social relations of production. *Technological Forecasting and Social Change, 213*, Article 123972. https://doi.org/10.1016/j.techfore.2025.123972

Lopes de Sousa Jabbour, A. B., Jabbour, C. J. C., Godinho Filho, M., & Roubaud, D. (2018). Industry 4.0 and the circular economy: A proposed research agenda and original roadmap for sustainable operations. *Annals of Operations Research, 270*(1–2), 273–286. https://doi.org/10.1007/s10479-018-2772-8

Madanaguli, A., Sjödin, D., Parida, V., & Mikalef, P. (2024). Artificial intelligence capabilities for circular business models: Research synthesis and future agenda. *Technological Forecasting and Social Change, 200*, Article 123189. https://doi.org/10.1016/j.techfore.2023.123189

Marjamaa, M., & Mäkelä, M. (2022). Images of the future for a circular economy: The case of Finland. *Futures, 141*, Article 102985. https://doi.org/10.1016/j.futures.2022.102985

Murray, Alan, et al. "The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context." *Journal of Business Ethics* [Dordrecht], vol. 140, no. 3, February 2017, pp. 369–80, https://doi.org/10.1007/s10551-015-2693-2.

Nazir, S., Doni, F., Capocchi, A., & Sarfraz, A. (2025). Are artificial intelligence and circular economy activities 'run-of-the-mill' in integrated reporting? *Business Strategy and the Environment, 34*(6), 7897–7924. https://doi.org/10.1002/bse.4351

Neuhaus, C. (2022). Images of the Future. In E. Schüll, D. Holtmannspötter, C. Neuhaus, A. Zweck, B. Schulz-Montag, K. Steinmüller, & L. Gerhold (Eds.), *Standards of Futures Research* (pp. 5–12). Springer Fachmedien Wiesbaden GmbH. https://doi.org/10.1007/978-3-658-35806-8_1

OECD. (2025). *Progress in implementing the European Union coordinated plan on artificial intelligence: Finland country note*. https://www.oecd.org

Ogollah, V., Turun kauppakorkeakoulu, Turku School of Economics, Tulevaisuuden tutkimuskeskus, Finland Futures Research Centre, Tulevaisuudentutkimus, & Futures Studies. (2023). *Disaster Management in the Era of Blockchain Technologies: An Exploration with Future Scenarios*. https://urn.fi/URN:NBN:fi-fe2023072691562

Olawade, D. B., Fapohunda, O., Wada, O. Z., Usman, S. O., Ige, A. O., Ajisafe, O., & Oladapo, B. I. (2024). Smart waste management: A paradigm shift enabled by artificial intelligence. *Waste Management Bulletin*, *2*(2), 244–263. https://doi.org/10.1016/j.wmb.2024.05.001

Raut, S., Hossain, N. U. I., Kouhizadeh, M., & Fazio, S. A. (2025). Application of artificial intelligence in circular economy: A critical analysis of the current research. *Sustainable Futures*, *9*, Article 100784. https://doi.org/10.1016/j.sftr.2025.100784

Richter, I., Gabe-Thomas, E., Queirós, A. M., Sheppard, S. R. J., & Pahl, S. (2023). Advancing the potential impact of future scenarios by integrating psychological principles. *Environmental Science & Policy, 140*, 68–79. https://doi.org/10.1016/j.envsci.2022.11.015

Rhyne, R. (1995). Field anomaly relaxation: The arts of usage. *Futures, 27*(6), 657–674. https://doi.org/10.1016/0016-3287(95)00032-R

Rusko, R. (2024). The role of AI in Finnish green economy and especially in circular economy: Challenges and possibilities. In *Reshaping environmental science through machine learning and IoT* (pp. 18–35). IGI Global. https://doi.org/10.4018/979-8-3693-2351-9.ch007

Sitra. (2016). *Leading the cycle: Finnish roadmap to a circular economy 2016–2025*. https://www.sitra.fi

Sitra. (2019). *The critical move – Finland's road map to a circular economy 2.0*. Finnish Innovation Fund Sitra.

Štreimikienė, D. (Ed.). (2026). *Circular economy assessment: Indicators and applications* (1st ed.). CRC Press. https://doi.org/10.1201/9781003728542

Snoun, A., Mufida, M. K., El-Cadi, A. A., & Delot, T. (2025). AI-driven innovations in waste management: Catalyzing the circular economy. *Engineering Proceedings, 97*(1), 12. https://doi.org/10.3390/engproc2025097012

Statistics Finland. (2024). *Circular economy indicators*. Statistics Finland. https://stat.fi/tup/kiertotalous/index_en.html

Suarez-Visbal, L. J., Rosales-Carreón, J., Corona, B., Hoffman, J., & Worrell, E. (2024). Transformative circular futures in the textile and apparel value chain: Guiding policy and business recommendations in the Netherlands, Spain, and India. *Journal of Cleaner Production, 447*, Article 141512. https://doi.org/10.1016/j.jclepro.2024.141512

Tapio, P., Varho, V., & Heino, H. (2013). Renewable energy in the Baltic Sea region 2025. *Journal of East-West Business, 19*(1–2), 47–62. https://doi.org/10.1080/10669868.2013.779544

Tudor, T., & Dutra, C. J. (Eds.). (2020). *The Routledge handbook of waste, resources and the circular economy* (1st ed.). Routledge. https://doi.org/10.4324/9780429346347

Vallet, F., Puchinger, J., Millonig, A., Lamé, G., & Nicolaï, I. (2020). Tangible futures: Combining scenario thinking and personas - A pilot study on urban mobility. *Futures, 117*, 102513. https://doi.org/10.1016/j.futures.2020.102513

van Dorsser, C., Taneja, P., Walker, W., & Marchau, V. (2020). An integrated framework for anticipating the future and dealing with uncertainty in policymaking. *Futures : The Journal of Policy, Planning and Futures Studies*, *124*, Article 102594. https://doi.org/10.1016/j.futures.2020.102594

Varsha, S. S. V., Baig, Z. T., Sikarwar, V. S., Sarmah, A., Leu, S.-Y., Vuppaladadiyam, A. K., & Duan, H. (2025). Towards circular economy via sustainable waste management practices. *Resources, Conservation and Recycling*, *219*, Article 108298. https://doi.org/10.1016/j.resconrec.2025.108298

Walden, J., Steinbrecher, A., & Marinkovic, M. (2021). Digital product passports as enabler of the circular economy. *Chemie Ingenieur Technik, 93*(11), 1717–1727. https://doi.org/10.1002/cite.202100121

Wilts, H., et al. (2021). Artificial intelligence in the sorting of municipal waste as an enabler of the circular economy. *Resources, 10*(4), Article 28. https://doi.org/10.3390/resources10040028

Zhang, A., Tay, H. L., Alvi, M. F., Wang, J. X., & Gong, Y. (2023). Carbon neutrality drivers and implications for firm performance and supply chain management. *Business Strategy and the Environment, 32*(4), 1966–1980. https://doi.org/10.1002/bse.3230

Appendices

Appendix 1: Extended Futures Table Used in Scenario Development

Driver	Variable	Possible Future State 1	Possible Future State 2	Possible Future State 3	Possible Future State 4
Social	Public awareness of CE	Widespread awareness and active circular participation	High public engagement in circular practices	Moderate awareness with selective participation	Limited awareness and weak engagement
	Digital skills	Highly skilled workforce with strong AI capabilities	Skills improving through education and collaboration	Moderate digital skills with uneven distribution	Skills shortage and weak digital readiness
	Stakeholder collaboration	Technology-led collaboration across sectors	Strong multi-actor collaboration	Some cooperation, but limited coordination	Fragmented stakeholders and weak coordination
Technological	AI adoption in CE	Widespread AI adoption across circular systems	AI used in key sectors and cities	Gradual adoption in selected applications	Slow adoption and limited implementation
	Data sharing platforms	Open data platforms and real-time information exchange	Shared data ecosystems across organisations	Limited data sharing between actors	Closed data systems and weak interoperability
	Smart waste technologies	Advanced automation and intelligent sorting	Moderately advanced waste technologies	Basic improvements in sorting and collection	Limited technology and low automation
	Digital twins	Widely used in cities and industries	Used in major cities and selected sectors	Pilot projects and early-stage experimentation	Rarely used outside isolated projects

Driver	Variable	Possible Future State 1	Possible Future State 2	Possible Future State 3	Possible Future State 4
Economic	Investment in AI and CE	High investment from public and private actors	Public-private investments in key areas	Moderate investment with selective uptake	Low investment and cautious market behaviour
	Circular business models	Fully circular models widely adopted	Expanding circular business models	Hybrid models combining circular and linear practices	Mostly linear economy with limited circular uptake
	Resource productivity	Very high efficiency and strong optimisation	Improving efficiency through innovation	Moderate improvement over time	Low efficiency and continued material losses
Environmental	Carbon neutrality	Achieved by 2035	Nearly achieved	Progress continues but slowly	Targets delayed beyond the planned horizon
	Recycling rates	High recycling and strong recovery systems	Improved recycling performance	Moderate recycling with uneven progress	Low recycling and weak material recovery
	Material scarcity	Well managed through recovery and tracking	Managed through collaboration and substitution	Some shortages in selected sectors	Serious shortages and supply risks
Political	Policy support	Moderate but stable support for innovation	Strong policy support for sustainability transition	Moderate regulation with mixed implementation	Weak policy support and limited coordination

Driver	Variable	Possible Future State 1	Possible Future State 2	Possible Future State 3	Possible Future State 4
	Government funding	Innovation funding for AI and CE solutions	Sustainability funding for pilot projects and transition	Limited funding and selective support	Minimal funding and low state involvement

Appendix 2. Documentation of AI Use in the Thesis Process

In the creation of this thesis, I utilized generative artificial intelligence for several support tasks. Below, I detail the tool, its purpose, and the verification measures. I confirm that I have used an AI tool with the necessary care and caution, have fully disclosed its use in accordance with university policy, and take full responsibility for all content presented in this thesis.

Tool: OpenAI ChatGPT, GPT-5

- **Stage of thesis process:** Ideation, limited literature review support, editing, and revision
- **Purpose of use:** In my thesis ChatGPT were used to support me during the initial stages of planning, enhancing readability by language improvements and suggesting possible keywords for literature searches.
    - **Example Prompt:** "Help me improve the wording of this paragraph in academic English."
      "Suggest keywords for searching literature on artificial intelligence and circular economy in Finland."
      "Help me improve the structure of this chapter."

Verification: The results produced by the AI were used only as a suggestion, and each item was manually verified before using them. My own keyword search was compared to the AI-generated one based on academic literature searches from different sources. Edits of language which provided by the AI were carefully checked to maintain the original meaning of the text. No text created by the AI was ever used within the paper; it just guided me while doing my own search and writing process. I retained final control over the text.