Bridging the Gap between Circular Economy and Sustainability

A Methodology to support circular economy strategies in companies

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Lund University Centre for Sustainability Studies

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Abstract

Circular Economy (CE) is seen as a potential solution to sustainability challenges (eg. global warming), but companies lack guidance in adopting these strategies. The study addresses the need for a unified methodology to assess and prioritize CE strategies at the organizational level. The research integrates social dimensions (social CE indicators and Organizational Life Cycle Sustainability Assessment (O-LCSA)) into an existing four-stage methodology of Alejandrino et al. (2022) and presents a new methodology based on CE indicators and Organizational Life Cycle Sustainability Assessment (O-LCSA). The proposed methodology is tested in a case study, revealing trade-offs and synergies between circularity and sustainability performance. Despite the reveled limitations, the methodology provides an evidence-based framework to improve production systems and consumption patterns. Further research and testing are needed to refine and enhance the methodology, in particular Stage 4.

Keywords: Organizational Life Cycle Sustainability Assessment (O-LCSA), Circular Economy (CE), CE strategies, methodology, sustainability, single-use industry

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Abbreviations

CE	Circular Economy
EU	Europian Union
EUR	Euro
GHG	Greenhouse gas
GWP	Global Warming Potential
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCSA	Life Cycle Sustainability Assessment
O-LCA	Organizational Life Cycle Assessment
O-LCC	Organizational Life Cycle Costing
O-LCSA	Organizational Life Cycle Sustainability Assessment
SC0	Baseline scenario
SC1	Alternative scenario
SDG	Sustainable Development Goal
S-LCA	Social Life Cycle Assessment
SO-LCA	Social Organizational Life Cycle Assessment
SOLCA 1	Social indicator: "Presence of a formal policy concerning health and safety"
SOLCA 2	Social indicator: "Number/percentage of injuries or fatal accidents in the organization"
SOLCA 3	Social indicator: "Number of hours effectively worked by employees"
UN	United Nations

1 Introduction

The world is facing challenges such as biodiversity loss, social inequality, global warming, resource depletion, etc. One of the causes of these challenges is the current systems of consumption and production (UN, 2015a). Addressing these interlinked challenges and their causes is a key purpose of the United Nations (UN) 2030 sustainable agenda (Wang et al., 2019). Sustainability is often seen from the perspective of triple-bottom-line (economy, environment, and society) (Elkington, 1998), and sustainable development is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987). According to Seiffert & Loch (2005), sustainable development is essential for humankind's survival. To stimulate and lead sustainable development the targets and guides for different actions are set on the international level (for example the Paris Agreement (UN, 2015b) and Sustainable Development Goals (UN, 2015a)). To meet those goals, various stakeholders, such as organizations, scientists, and governments, are trying to incorporate sustainable consumption and production practices on the strategic level (Wang et al., 2019). The strategic level requires stakeholders to set specific targets that will contribute to reaching the overarching goals.

The private sector was encouraged to commit enhancement of environmental accountability and to develop cleaner, resource-efficient technologies for a life-cycle economy during the UN Global Ministerial Environment Forum in Malmö in 2000 (Peña et al., 2021). The UN (2012) acknowledges the significance of adopting a life cycle approach and implementing resource-efficient policies, while society as a whole must increase its efforts to accelerate the shift toward sustainability (Peña et al., 2021).

In this context, Circular Economy (CE) is considered to be a new production and consumption paradigm that can become a solution to existing challenges (Geissdoerfer et al., 2017). The CE aim is to “accomplish sustainable development, which implies creating environmental quality, economic prosperity, and social equity, to the benefit of current and future generations'' (Kirchherr et al., 2017, pp. 224–225). According to Kirchherr et al. (2017), the CE has as many pathways as there are researchers and practitioners. It leaves open the space for the wide interpretation from the perspective of both circularity and sustainability impacts.

Different actors, such as academia, governments, NGOs, and businesses, are looking for ways to support the transition toward CE (Kristensen & Mosgaard, 2020). One of the aspects that received attention is the relationship between sustainability and CE (Geissdoerfer et al., 2017; Schroeder et al., 2019). Despite the different understandings of this relationship among various scholars, Geissdoerfer et al. (2017) identified that there are 3 different relationships between CE and sustainability: 1) CE as a condition of sustainability; 2) as mutually advantageous, and 3) as compensatory. The main discussion is the ways to include three sustainability dimensions into CE, as now CE is mostly perceived as a system that brings economic and environmental benefits (Kristensen & Mosgaard, 2020). According to Kristensen & Mosgaard (2020), CE lacks a social dimension in its conceptualization. However, the potential social value of circular solutions can go beyond job creation and bring a broader value for stakeholders (Kristensen & Remmen, 2019; Pla-Julián & Guevara, 2019).

The European Commission (2020) and the United Nations (2015a) recognize and address the need to shift to circular strategies through the Circular Economy Action Plan (Action Plan) and Sustainable Development Goal (SDG) 12 (Responsible consumption and production). The European Union in the Action Plan highlights the importance of industrial companies' circularity, which will help to reach climate neutrality and the long-term competitiveness of companies (European Commission, 2020). In order to match the EU's ambition to move towards a CE, companies must adopt CE strategies. It requires guidance and understanding of the impacts that decisions based on strategy will bring. According to (Vinante et al., 2021), there is a lack of comprehensive methodology for choosing CE strategies at the company level.

Different actors are trying to evaluate the current position, future opportunities, and strategies of companies to provide guidelines for circular decision-making. Knowing what and how to evaluate is essential in overcoming the reluctance to embrace circular solutions, particularly in the industrial sector (Zamfir et al., 2017), which has the potential to make and implement decisions quickly and efficiently. One of the common ways for sustainability evaluation is through the understanding of impacts. Commonly actors use technical metrics based on quantitative analysis (eg. life cycle assessment) (Suski et al., 2021). Life cycle assessment (LCA), is a science-based and standardized methodology for evaluating the impacts linked to a product or service's life cycle. LCAs can aid in comprehending the environmental consequences of CE strategies (Peña et al., 2021).

Additionally, in the past 15 years, diverse methodologies of evaluating circularity in itself have emerged, to provide insights into the compliance of actions with commonly accepted CE principles (Vinante et al., 2021). Studies suggest that methodologies are mostly qualitative methods that help create sustainability awareness in companies but are not useful for making decisions in selecting CE strategies (Valls-Val et al., 2022). Therefore, there are research gaps in developing and applying joint CE and sustainability assessments (Lindgreen et al., 2022). There is no published unified methodology that can assess and prioritize CE strategies at the organizational level based on all three aspects of sustainability (Alejandrino et al., 2022). Therefore, it is important to develop such a methodology to guide companies toward circular and sustainable decision-making.

1.1 Research aim

This paper aims to develop a methodology that will help companies to identify CE strategies and prioritize them according to the environmental, social, and economic impacts that their application could produce. Therefore, it is important to answer the following questions:

RQ 1: What is a comprehensive methodology for assessing and prioritizing Circular Economy strategies at the organizational level based on all three aspects of sustainability?

RQ 2: What are the benefits and challenges of the proposed methodology?

RQ 3: To what degree does the proposed methodology help companies with assessing and prioritizing CE strategies?

1.2 Thesis roadmap

The structure of the thesis is as follows. Chapter 2 covers the background of the current literature on life cycle approaches and circularity, with a focus on CE strategies and the relationship between CE and Life cycle approaches. Additionally, the section will introduce the case study for the test of the proposed methodology. Chapter 3 will describe the methods of the research and the data collection. Chapter 4 describes the advancement of the methodology and its testing in the case study. The findings show that there are trade-offs between parameters as well as challenges in conducting the assessment. The results are further discussed in Chapter 5 to draw insights on what are the benefits and challenges of the methodology and to which extent it helps companies with the CE strategies choice. Finally, the thesis ends with a conclusion.

2 Background and introduction to the case study

Companies and organizations are increasingly interested in CE and CE strategies (Peña et al., 2021). However, integration of CE into the company through strategies will require assessment. It will help the companies to choose and prioritize the CE strategies and, therefore, lead them to make more circular and sustainable decisions. While sustainability and efficiency assessments abound (Ness et al., 2007; Peças et al., 2023), the assessment that will evaluate CE sustainability is lacking (Alejandrino et al., 2021). It is important to evaluate CE sustainability, as circular activities are not always more sustainable than linear (Luthin et al., 2023). Luthin et al. (2023) and Peña et al. (2021) stated that to avoid burden-shifting from one area to another (eg. lower CO2 emissions, but increase water consumption) is important to combine CE and life cycle approaches. In this study life cycle approaches are used as a sustainability assessment tool for CE strategy implementation. This chapter describes the life cycle approaches (2.1), the Circular Economy (2.2), and their relationship (2.3) and concludes with a description of the case study (2.4).

2.1 Life Cycle Approaches

Life Cycle Thinking (LCT) is a comprehensive concept that provides support for better integration of sustainability into policy-making. Sala et al. (2021) mention in their literature review that currently this concept is viewed as a general concept that refers to an assessment of products/sectors/projects burdens at all stages of the lifecycle. It is a core of SDG 12 (Responsible consumption and production) that aims to challenge consumption patterns through the influence on the stakeholders (throughout the whole value chain) (UN, 2015c).

Life cycle assessment (LCA) has been a growing area of research with a lot of improvements in inventory and impact assessment (Sala et al., 2013). Over the years, the shift from environmental analysis to a more comprehensive approach was needed. Life Cycle Sustainability Assessment (LCSA) was developed as a response to the critiques of LCA and has become a transdisciplinary framework. LCSA combines in itself LCA, Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) (Sala et al., 2013; UNEP, 2010; Klöpffer & Renner, 2008). However, the LCSA was also criticized in regards to analyzing only products and not taking into account the bigger picture (organizational level) (Alejandrino et al., 2021). The response to that was the evolution of the Organizational Life Cycle Sustainability Assessment, which covers the lifecycle of all products within the organization. Table 1 shows an evolution of life cycle approaches.

Table 1. Evolution of Organizational Life Cycle Sustainability Assessment (O-LCSA)

#	Concept	Year	Description	Source
1	Life Cycle Assessment (LCA)	1960s	LCA is the robust certified approach that helps to evaluate inputs, outputs, and the potential environmental impacts of product systems associated with the use and reuse of resources. This approach is built on the LCT to provide a comprehensive environmental evaluation of goods and services.	(Amahmoud et al., 2022; Lokesh et al., 2020)
2	Organizational Life Cycle Assessment (O-LCA)	2015	O-LCA is the alternative framework to LCA. The difference to the LCA is rooted in the environmental effects assessment of the entire organization's activities and the provision of the product portfolio.	(Alejandrino et al., 2022; D'Eusanio et al., 2022b; Martínez-Blanco et al., 2015; UNEP, 2015)
3	Life Cycle Costing (LCC)	1960s	LCC is the methodology to assess the economic performance of a system in its whole life cycle through the evaluation of cost flows over a period of analysis.	(Guinée et al., 2011; Sala et al., 2021; Toniolo et al., 2020)
4	Organizational life cycle costing (O-LCC)	2022	The LCC was adapted to O-LCC by the same menace as O-LCA was established from LCA.	(Alejandrino et al., 2022)
5	Social Life Cycle Assessment (S-LCA)	1996	S-LCA evaluates the social impacts across products or services' life cycle: helps to identify the ways to map and engage with the stakeholders (e.g. workers, communities); it provides the double impact assessment which helps to identify both positive and negative impacts on the stakeholder groups.	(Luthin et al., 2023; Ramos Huarachi et al., 2020; Tsalidis, 2022; UNEP, 2020, 2021)
6	Social Organizational Life Cycle Assessment (SO-LCA)	2020	SO-LCA builds on the S-LCA and evaluates the social and socio-economic aspects of the activities of a whole organization vs a single product in S-LCA. This methodology is just raising the interest of researchers and, thus, is poorly applied.	(D'Eusanio et al., 2022b; Tsalidis, 2022; UNEP, 2020, 2021; Martínez-Blanco et al., 2015)
7	Life Cycle Sustainability Assessment (LCSA)	2008	LCSA is the transdisciplinary integration framework. LCSA = LCA + LCC + S-LCA. Methodological development is still an ongoing process, as it faces drawbacks, such as uncertainty, the difference in the system's boundary, lack of quantitative indicators for the social perspective, no standardized methods,	(Alejandrino et al., 2021; D'Eusanio et al., 2022b; Guinée et al., 2011; Klöpffer & Renner, 2008;

			etc.	UNEP, 2010)
8	Organizational Life Cycle Sustainability Assessment (O-LCSA)	2022	O-LCSA is the methodology that combines the O-LCA + O-LCC + SO-LCA. It is a decision-making tool for the evaluation of the sustainability of the company's activities.	(Wafa et al., 2022)

Table 1 describes different life cycle approaches, where some frameworks are more developed than others. A big contribution to the development of social frameworks apart from contributions within research was made by UNEP. UNEP (2020) outlined new guidelines that focused on the identification of social and socio-economic impacts for the improvement of the living conditions of stakeholders across the whole lifecycle. Table 1 also demonstrates the evolution of life cycle approaches that resulted in the creation of a complex O-LCSA framework. The evolution is not displayed in chronological order but rather demonstrates the evolution by blocks (environmental, economic, social, and sustainability). The approach O-LCSA has not yet been tested on a case study but has the potential to be used for sustainable decision-making at the company level (Alejandrino et al., 2021).

2.2 Circular Economy

Circularity is considered to be a potential solution to save primary resources, as well as reduce global warming and preserve biodiversity, and is seen as a concept of sustainability (Kirchherr et al., 2017). Kirchherr et al. (2017) in their research gave the most comprehensive definition of CE. It is associated with the end-of-life concept and R-principles (discussed in Section 2.), which operate at 3 levels (micro, meso, and macro).

The Circular Economy emerged as an alternative to the linear business system that was operating as a take-make-dispose concept (Jørgensen & Pedersen, 2018; Suchek et al., 2021). The paradigm of CE demonstrates a new perspective on industrial ecosystem operation. It allows the decoupling of economic growth from resource consumption and greenhouse gas (GHG) emissions. CE concept proposes that end-of-life materials are conceived as resources rather than waste (Elia et al., 2017). Thus CE becomes "a restorative and regenerative industrial-economic approach" (Çimen, 2021, p. 2). There are 10 main R-principals of CE: Recover, Recycle, Repurpose, Remanufacture, Refurbish, Repair, Re-use, Reduce, Rethink, and Refuse (Çimen, 2021). Figure 1 shows some of the R-principles and the value they can save. The closer the loop is to the center the more value of the product it saves by keeping it as a whole. Additionally, the loops demonstrate cost savings as materials are already in circulation and there is no need for investments in the extraction of new ones (Ellen MacArthur Foundation, n.d.).

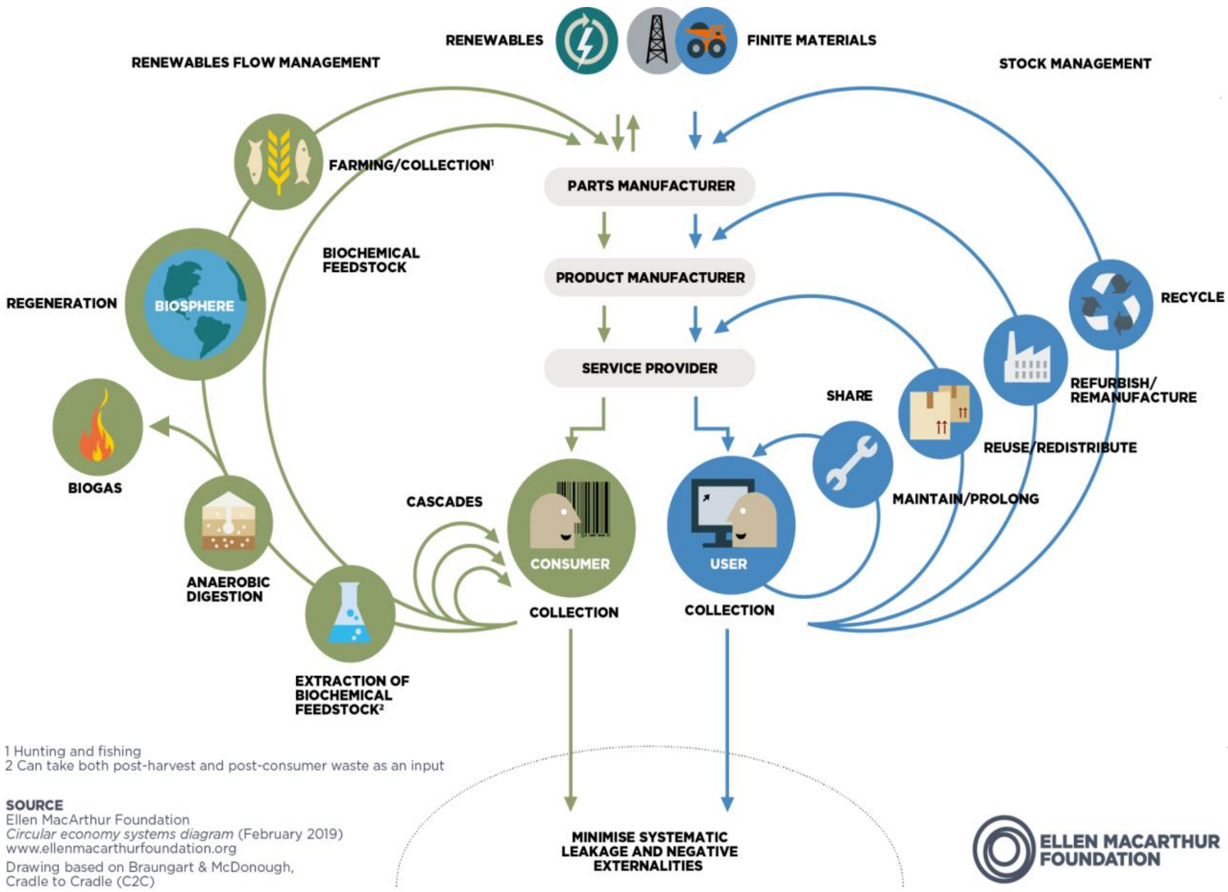

Figure 1. The butterfly diagram: visualizing the Circular Economy. It demonstrates two main cycles - biological (green) and technological (blue). (The Ellen MacArthur Foundation, 2019)

The frontrunner of CE is the Ellen MacArthur Foundation, which highlights that the CE transition will bring not only economic, environmental, and social benefits but also long-term resilience (BSI, 2017). However, there is no exhaustive list of the CE principles that will help achieve circularity (Niero & Rivera, 2018). Thus, different authors define different ones. For example, to achieve the transition the Ellen MacArthur Foundation (n.d.) referred to the three principles of CE: (1) saving and expansion of the natural capital, through control of finite stock and balance of renewable and non-renewable resources, (2) keeping the value of the products by extending their life, (3) increase in the effectiveness of the systems through monitoring and exclusion of negative impacts (Suchek et al., 2021). Another example is British Standard (BSI, 2017), which identifies 6 principles described in Table 2. This standard helps companies to transition towards a more circular and more sustainable operations mode. Therefore, the comparisons in Table 2 demonstrate the similarities and differences between the two approaches.

Table 2. Comparison of British Standard's CE principles and the Ellen MacArthur Foundation Principles. The numbers in the Ellen MacArthur Foundation Principles indicate the principles described above.

#	Principle	Description (BSI, 2017)	The Ellen MacArthur Foundation Principles
1	System thinking	To understand the impact of the organizational decision and activity in the wider system in which an organization sits. That allows for gaining knowledge of the complex, non- linear, and interconnected nature of any system.	1,2,3
2	Innovation	Enabling the sustainable management of resources through value creation by the innovative design of processes, products/services, and business models.	2
3	Stewardship	Management of the direct and indirect impacts (economic, social, and environmental) of the organizational decisions and activities in the wider system. It helps organizations to be responsible for their current and future actions in their supply chain and customer base.	1
4	Collaboration	Collaboration with internal and external stakeholders through formal and informal arrangements. Through the collaborations, the organization will create mutual value with its stakeholders.	N/A
5	Value optimization	Keeping the value and utility of the products, materials, and components at their highest state. It helps to reconsider the life cycle of an item and increase efficiency and find new opportunities.	2, 3
6	Transparency	Open communication of the activities and decisions that affect the organization's transition towards CE. Transparency builds trust with both internal and external stakeholders	N/A

British Standard provides a more detailed description of the principles as well as complements the Ellen MacArthur Foundation by adding "Collaboration" and "Transparency". It introduces the social dimension into CE. The principles help to guide the party (e.g. company, city) towards circularity. Later in this research, they are used to describe the purpose of CE strategies (Appendix 3) and justify the CE indicators (Appendix 1).

2.2.1 Circular Economy in an organizational context

In an organizational context, the CE is a systematic approach to processes, products/services, and business model design. The material and energy should be used efficiently and be renewable by nature (BSI, 2017). CE, as a term, currently has increased in popularity among businesses, as more companies recognize that the linear approach is reaching its limits, and material and energy will become more expensive and cannot be taken for granted (Niero & Rivera, 2018). Linear economy promotes the inefficient management of resources as its model consists of extraction of raw materials, product creation, use, and disposal. Despite the development of technologies that reduce resource losses and pollution, the pattern of increasing consumption outweighs the benefits (Diaz et al., 2022).

However, implementing the CE transition also has challenges and barriers. Thus, according to Kirchherr et al. (2018), cultural barriers constitute the most significant barriers to organizations' progression toward CE. Hesitant organization cultures and lack of interest and awareness of consumers are considered especially significant cultural barriers (Kirchherr et al., 2018). Simultaneously, market obstacles, such as current low virgin material prices and high investment costs, may obstruct the CE transition. These barriers come mostly from the business leaders that doubt the CE transition and believe that "CE is too expensive" (Kirchherr et al., 2018, p. 269).

The research of Quintelier et al. (2023), states that a small number of previous research has been conducted on the manner of social value creation in the CE. In the majority of the research, the social dimensions of CE are either assumed or ignored (Kirchherr et al., 2017). CE is often studied as an economic system focused on closing material and energy loops (Masi et al., 2017). European multinational companies also tend to neglect the social dimension of the CE, instead prioritizing cost-effective practices like recycling (Mhatre et al., 2021).

2.2.2 Circular Economy strategies

CE transition is a long-term process that requires the involvement of different stakeholders. Therefore, the companies set goals to reach full or partial circularity in the long-term perspective. Strategy is the long-range plan that helps to achieve stated objectives. It identifies problems and ways to overcome them. However, it does not describe all the actions but rather includes an evaluation of the progress toward stated goals (Tulchinsky & Varavikova, 2014). Mintzberg (1978) distinguishes two ways of strategy generation: 1) planned (top-down) - requires carrying out a predetermined strategic plan; 2) emergent (bottom-up) - strategy evolves without the intervention of professionals (strategic planners). In business practice, both types evolve hand in hand (Diaz et al., 2022).

To provide businesses with the directions for the CE transition, it is necessary to have a set of strategies for slowing, closing, and narrowing resource loops (Diaz et al., 2022). The aim of slowing the resource loop is to extend the product utilization period while the closing strategy aims to connect post-use in production. As for the narrowing, its goal is to reduce the number of resources used per product (Bocken et al., 2016). They seek to save the products' value for as long as possible (Diaz et al., 2022). Later in the paper the list of 40 strategies will be presented (Chapter 3).

During the process of cooperative strategic planning, it is important to consider not only the circularity of the potential decision but also its sustainability output. The following section describes the relationship between CE and life cycle approaches.

2.3 The relationship between CE and Life Cycle approaches

According to García-Muiña et al. (2021), CE strategies are mostly looking at resource flow with a focus on positive environmental effects. However, the circularity in one place can cause negative effects in other places. Therefore, to make more circular and sustainable decisions, companies have to assess and prioritize strategies.

As mentioned earlier, the LCSA is a broad concept combining three sustainability pillars to evaluate the product. LCA can provide the framework for evaluating the environmental effects of CE strategies (Alejandrino et al., 2022; Elia et al., 2017), as it is the most accepted tool by businesses supporting environmental decision-making. To support the choice of CE strategies from the economic perspective, LCC can evaluate the economic performance of a system (Sala et al., 2013). S-LCA is the third pillar that can assist in the process of CE decision-making by accounting influence on the stakeholders (UNEP, 2021). It is especially valuable and it complements the analysis of CE by creating the possibility to evaluate CE strategies.

The system thinking approach that lies at the foundation of LCA approaches helps to ensure the integration of the upstream and downstream components of the value chain into the CE analysis (Peña et al., 2021). At the same time, the eco-efficiency concept is also at the foundation of LCA approaches and in most cases uses the cradle-to-grave perspective (linear economy), which differs from most CE strategies. Despite this common LCA perspective, approaches to multiple cycles in LCA are discussed in different standards (eg.

ISO 14044) as well as in the research articles by Sazdovski et al. (2021) and Tapper et al. (2020) where they used additional parameters in LCA analysis for the reusable and recyclable end-of-life solutions of the products. Therefore, extending the boundaries of the LCA approaches give a possibility to adapt to CE scenarios (van Stijn et al., 2021).

However, LCSA is used for the product level and does not evaluate the influence on the entire organization, which was one of the limitations of life cycle approaches. CE strategy influences the entire organization and, therefore O-LCA, O-LCC, and SO-LCA should be used. Their combination results in the so-called O-LCSA and its use for the evaluation of the CE strategies performance is an emerging field of research (Alejandrino et al., 2022).

The combination of O-LCA and O-LCC is well described by Alejandrino et al. (2022) where a 4-step methodology supporting choice of CE strategies was created. It will be discussed in Chapter 3 in detail. However, the shortcoming of the methodology is the absence of social dimensions of sustainability. Taking this context into account, this thesis will study the integration of social dimensions into Alejandrino et al. (2022) framework, as well as testing of the proposed methodology on the industry.

2.4 Introduction to the case study: Duni Group

To test the developed methodology, the Duni Group (Duni) was chosen. It is a group of companies that operates in the single-use sector but strives for change toward sustainability (Duni Group, 2023). Duni has two brands: the Duni business area and the BioPak business area. Duni business area stands for fiber-based solutions (eg. napkins, placemats). The production units for those types of products are located in Sweden, Germany, Poland, Thailand, and New Zealand. The BioPak business area is focused on meal packaging where Duni acts as a trader with no own production (Duni Group, 2022a).

The company has a 2030 strategy where one of the goals is to reduce virgin fossil plastics use (Duni Group, 2023). One of the examples of Duni's action is the development of bio-based binders for the Dunicel (tissue) range of products. Additionally, to reach the goal, Duni in collaboration with an external company OrganoClick replaced the fossil-based binder of Dunisoft material with a bio-based one Duni Group, 2022a). The bio-based materials are usually seen as more circular and sustainable options (Vural Gursel et al., 2022). The Dunicel and Dunisoft are later converted to different products that have different material volumes and energy consumption.

Rexcell is the paper mill plant in Skåpafors, where the forest fiber is converted into paper rolls, so-called jumbo rolls of tissue (soft paper), or airlaid paper. Rexcell has 196 employees. After production, the jambo rolls are shipped to the converting factories. One of them is Bramsche plant, the conversion unit in northwestern Germany, where jumbo rolls are cut, pressed, embossed, and folded into finished napkins. Bramsche also produces bio-based binders for Bio Dunicel products (Duni Group, 2022a). The converting factory has 481 employees.

3 Methods and Methodology

This section is divided into three parts. First I will describe the four-stage methodology proposed by Alejandrino et al. (2022) (Table 3) as it is foundational for the work of this thesis. The description of stages is proposed later in the section (3.1). Second, I will describe how I amended the Alejandrino et al. (2022) methodology to create a comprehensive assessment for choosing and prioritizing CE strategies (3.2). Third, I will describe how I test the new combined methodology and the data resources used for testing (3.3).

3.1 Methodology by Alejandrino et al. (2022)

To create the assessment for choosing and prioritizing CE strategies and, therefore, answering the research questions, I decided to develop a methodology based on the research of Alejandrino et al. (2022). This section, therefore will be describing the original methodology, where Alejandrino et al. (2022) combined the O-LCA and O-LCC perspectives to support CE strategies in organizations. The Stages and steps are described in Table 3.

Table 3. Stages of the CE strategies justification methodology developed by Alejandrino et al. (2022).

Stages		Materials & Methods	Steps
1	Initial diagnosis: Organisation circularity analysis	● Circular metrics	a. Organization circularity analysis through the circular metrics
2	Analysis and choice of CE alternative scenarios	● CE strategies ● Organization know-how	a. Choice of strategies based on the decision tree and Appendix 2.
3	Environmental and economic performance of scenarios (baseline and alternative)	● O-LCA + O-LCC	a. Identification of the goal and scope of the study b. Inventory analysis c. Impact assessment d. Interpretation
4	Eco-efficiency analysis of alternative scenarios	● Eco-efficiency graph	a. Eco-efficiency graph

3.1.1 Stage 1. Initial analysis of organizational circularity

To be able to define the organization's areas of circularity improvement, the current position of the organization (starting point) in the CE transition needs to be understood. Table 4 describes the metrics chosen for the identification of the organization's starting point. For the baseline scenario (S0) creation, the CE indicators were chosen based on the research conducted by Alejandrino et al. (2022). The S0 will be used for diagnosis of the potential improvement that different strategies can bring.

Table 4. List (non-exhaustive) CE indicators for quantifying the circularity at the organizational level. (Alejandrino et al. 2022).

Category	CE Indicators	Unit
Strategy & vision	1. Circular Economy strategies incorporated into other corporate strategies	number (#) of strategies
Business model	2. Leasing/renting business models	#
	3. Product lifetime extension initiatives	# of products
Environmental management	4. Environmental management system	# of systems
Industrial symbiosis	5. Collaborations with external partners	# of collaborations
Design	6. Products recyclable or reusable	# of products
	7. Products designed for reduced consumption of material/energy	# of products
	8. Products designed for waste minimization	# of products
	9. "Green" packaging initiatives	# of initiatives
Supplier selection & auditing	10. Supplier selected based on CE performance	# of suppliers
	11. Environmental purchasing criteria in the selection of suppliers	# of criteria
Production and consumption	12. Material consumption	t
	13. Water consumption	m3
	14. Electric energy consumption	kWh
	15. Renewable electric energy consumption	%
	16. Fuel consumption	m3
Secondary raw material	17. Recycled content of raw material	%
Waste generation and management	18. Solid waste generated	t
	19. Recycled solid waste	%

	20. Effluents discharged	m3
	21. Carbon emissions generated	t CO2eq
Competitiveness and innovation	22. CE Investment	SEK
Post-sales services	23. Take back systems for products after their use	#

3.1.2 Stage 2: Proposal and analysis of the CE alternative scenarios

After calculations of S0, the improvement scenarios are suggested to improve the current state of the company. The set of 40 CE strategies was chosen based on the research conducted by Alejandrino et al. (2022), which stated that all the suggested strategies have the characteristics that make them suitable for industrial organizations. They are shown in Appendix 2.

To preselect the strategies for each case scenario, Alejandrino et al. (2022) propose the decision tree (See Appendix 4). It is suggested that different stakeholders of the organization should participate in the selection process.

The circular alternative scenarios should be defined through the selection of applicable CE strategies. Each alternative scenario should be also analyzed through the application of the indicators reported in Table 1 to verify they improve the circularity of the organization (Alejandrino et al., 2022).

3.1.3 Stage 3: Sustainability performance of scenarios

To analyze S0 and alternative scenarios from an economic and environmental perspective, the O-LCA and O-LCC should be applied. The combined framework follows the requirements proposed by the UNEP (2015, 2020) and ISO (2006, 2014). The life cycle approaches require the conduction of four steps: identification of goal and scope, inventory analysis, impact assessment, and interpretation.

Goal and scope definition.

The goal of the study is to gain knowledge about the sustainability performance of baseline and alternative scenarios defined in Stages 1 and 2. The system boundary should be set the same for O-LCA and O-LCC. As well as the reporting unit should be defined (UNEP, 2015).

Inventory analysis

In this stage, the quantitative data on input and output flows of the different activities are defined. The inventory models of environmental, and economic aspects of the organization should be consistent with the goal and scope of the study. The sources of data should be prioritized by organizational data, but if it is not available the data from secondary sources can be used. For the environmental data following databases can be used Ecoinvent (Ecoinven*t*, 2023), GABI databases (*Product Sustainability Software & Data | Sphera*, n.d.), and US-LCI (*U.S. Life Cycle Inventory Database*, n.d.). For the economic analysis data from current and potential suppliers could be used and/or adapted (Alejandrino et al., 2022).

Impact assessment

This stage is used to obtain indicators for economic and environmental categories, that will represent the sustainability performance of the organization under study. For **environmental performance**, indicators can be obtained for different impact categories that apply to the case study, such as global warming potential (GWP) (Alejandrino et al., 2022). For **economic performance,** according to (Alejandrino et al., 2021), the most common indicators are life cycle cost. The interpretation of the life cycle cost can be found in Appendix 5.

Interpretation

The interpretation of the results should be conducted in accordance with the goal and scope. The limitations of those results should be identified.

3.1.4 Stage 4. Eco-efficiency analysis

To prioritize the impacts on the circularity of the alternative scenarios, the eco-efficiency analysis should be used. Figure 2 demonstrates the eco-efficiency analysis that describes the prioritization based on economic and environmental performance (Alejandrino et al., 2022). These graphs display the environmental impact on the x-axis and the economic impact on the y-axis, enabling the categorization of each alternative scenario into one of the four eco-efficiency areas.

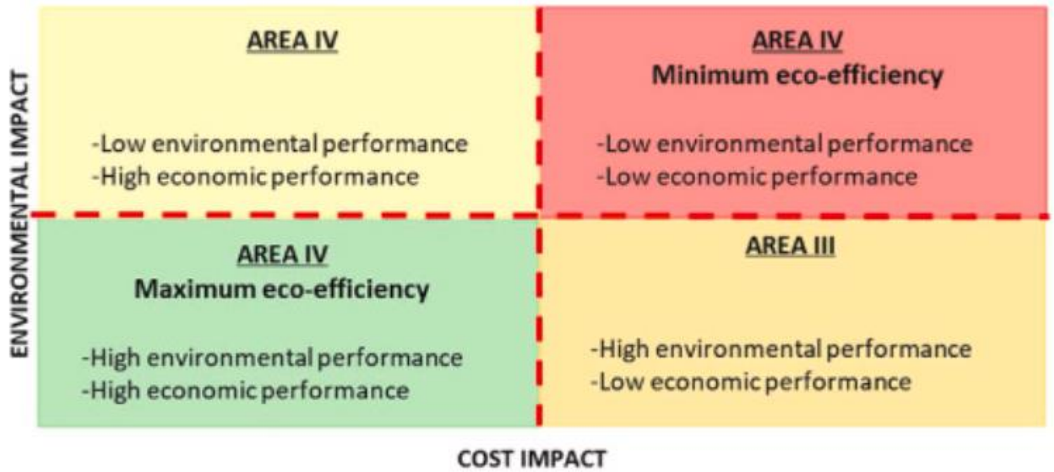

Figure 2. Example of eco-efficiency graph (Alejandrino et al., 2022)

3.2 Integration of social dimensions into the methodology

In order to improve the methodology proposed by Alejandrino et al. (2022), I made several contributions. The CE indicators in Alejandrino et al. (2022) research had little justification for their usefulness for the study as well as were missing the social CE indicators. Hence, for them to be trusted I traced back the indicators and aligned them with the CE principals, as well as added 9 additional social CE indicators. For the second stage, I found it difficult to identify the CE strategies' purpose and, therefore, described each one and aligned them with the CE principles. As the Alejandrino et al. (2022) methodology generally was missing the social dimensions for CE strategies evaluation, it was necessary to include the SO-LCA in the analysis. To evaluate the results of O-LCSA, in Stage 4, I suggested a comparative/prioritization analysis of alternative scenarios. All steps by stage are described in Table 5. The detailed description of each step will be discussed in Chapter 4.

Table 5. Contribution to the methodology

Stages	My contribution to Alejandrino et al. (2022) methodology	Steps
1	● Justified the choice of circular indicators ● Added the social CE indicators, through the conduction of a mini literature review	a. Used most recent literature review on social CE indicators (Luthin et al.,2023) b. Traced back indicators in the literature review to find the justification for their use c. Identified to which CE principles each indicator contributes
2	● Described the strategies (Appendix 3)	a. Traced back the strategies to find their description b. Identified their purpose through the CE principles

		in accordance with Table 2
3	● Suggested to incorporate SO-LCA, to create a three-dimensional sustainability evaluation – O-LCSA	a. Conducted mini literature review on how to conduct SO-LCA b. Developed the scale for assessing the social performance c. Proposed the idea of conducting O-LCSA
4	● Suggested comparative/ prioritization analysis of alternative scenarios	a. Suggested the way to prioritize the scenarios

3.3 Testing of the methodology on the case study

To test the developed methodology (See Section 4.1) the case study will be done based on the Duni Group that was introduced in Section 2.4. I decided to limit the analysis to the manufacturing of the following product range: Dunisoft napkins, Dunicel placemats, Bio Dunisoft napkins, and BioDunicel placemats. The production takes place in Sweden (Rexcell) for Dunisoft napkins, Bio Dunisoft napkins and Dunicel placemats, and Germany (Bramsche) for Bio Dunicel placemats. To test the methodology the data will be collected from the following sources (Table 6.).

Table 6. Methods and data sources for methodology testing

Stages	Data source	Methods for data collection
1	● Duni and its specific sites (Rexcell and Bramsche)	● Interviews with management and responsible workers ● Documentation analysis
2	● Duni and its specific sites (Rexcell and Bramsche)	● Interviews with management and responsible workers ● Documentation analysis
3	● 2021 Product LCA (internal report) conducted by the South Pole for Duni ● Duni and its specific sites (Rexcell and Bramsche) ● Health and Safety European data (EU S&H, n.d.)	● Report analysis ● Interviews with management and responsible workers
4	● Data from Stage 3	–

In all four stages of the research, the interviews will be used as the main method of data collection. The main source of the data will be provided by Duni (the primary data).

For stage 3, I use a hybrid approach between Pathway 1 (as Duni had experience with social assessment at the organizational level) and Pathway 2 (as Duni has experience with environmental life-cycle approaches) to conduct O-LCA suggested by UNEP (2015), where the results of Dunisoft and Dunicel LCA were combined for SC0 and Bio Dunisoft and Bio Dunicel LCA – for SC1. Additionally, to fulfill the requirements for O-LCA, the Duni sustainability department provided me with the employee commuting data, both the raw data for inventory and emissions for impact assessment. However, the commuting data was not used for the analysis due to the unchangeability of the scenarios and the complexity of calculations. Due to confidentiality, the emission factors are not disclosed but are based on the Ecoinvent database and come from the South Pole.

4 Analysis and results

As it was proposed in Section 3, this section will be divided into two main blocks: 1) The development of the methodology (4.1) and 2) its testing (4.2).

4.1 Development of methodology (RQ1)

This subsection discusses the description of social dimensions integration into the Alejandrino et al. (2022) framework. It consists of four stages that correspond to the methodology described above. Stage 1 describes the integration of social CE indicators into the circularity analysis. Stage 2 explains the purpose of strategy description. Stage 3 describes the SO-LCA analysis and Stage 4 proposes the idea of results illustration.

4.1.1 Stage 1. Integration of social CE indicators into the baseline circularity analysis

One of the Alejandrino et al. (2022) limitations was the social impacts were poorly assessed (2 indicators of 24). Therefore, to better assess the social aspect of circularity I conducted a small literature review based on the most recent research (Luthin et al., 2023). Table 7 has the social indicators chosen for the methodology. I justified their applicability based on the CE principles and traced back the indicators to understand their purpose (see Appendix 1).

Table 7. The social CE indicators that were chosen from Luthin et al. (2023) research. The number of CE indicators indicates the order in Annex 1.

Category	CE Indicators	Unit
Social sustainability Worker	24. Number of accidents related to CE activities (such as recycling);	#
	25. CE training	(CE training hours)/(hours worked)
Local community	26. Job creation/decline	# of jobs created for CE activities
Value chain actors	27. Number of CE educative workshops for suppliers	# of workshops
	28. Number of CE-related meetings with stakeholders	# of meetings

	29. Number of patents related to innovative technologies applied in CE	# of patents
Consumer	30. Existing marketing practices for greenwashing	# of public accidents of greenwashing
	31. Labels used to promote transparency for consumers	# of labels
Society	32. Number of CE innovation meetings/workshops/ brainstormings for innovation development	# of innovation meetings/ workshops/ brainstormings

Appendix 1 demonstrates that the analysis of the SC0 will be based on 32 CE indicators comprised of the 23 indicators from the Alejandrino et al. (2022) research and 9 social CE indicators developed for this thesis. Additionally, to understand the correlation between indicators and CE principles, I aligned them with each other. In addition, I conducted calculations to determine the number of indicators associated with each principle. Some indicators are covering multiple CE principles. The most frequent CE principle that was covered by 11 CE indicators was “Stewardship”. The second frequent principle is “Value optimization" which is caused by the number of indicators evaluating the material choice of the company. The least frequent principles were “System thinking”, “Transparency” and “Innovation” that is covered by 2, 2, and 3 indicators respectively. The “Collaboration” principle was covered by 5 indicators. The addition of social sustainability indicators improved the framework by covering the missing aspect of the “Transparency” principle in the Alejandrino et al. (2022) research as well as adding 2 more collaboration principal indicators.

4.1.2 Stage 2. Description of the Circular Economy strategies

In this stage, I described the strategies proposed by Alejandrino et al. (2022) in Appendix 3, as well as aligned the strategy purpose with the principles of CE described in Table 2. For it, I traced back the sources of the strategies to find their description and aligned their purpose with the CE principles (Table 2). Appendix 3 shows that most strategies aim to cover “Value optimization” and “Stewardship” principles. I excluded the “Systems thinking” principle from the analysis of the strategies as all strategies are following it.

4.1.3 Stage 3. Integration of SO-LCA

Another limitation of the Alejandrino et al. (2022) research was the absence of social impacts from a sustainability assessment point of view. Therefore, I propose to conduct the SO-LCA to understand the

social performance of the scenarios. The Guidelines (UNEP, 2020), Methodological sheets (UNEP, 2021), and research by Tsalidis (2022) and D'Eusanio et al. (2022b) can be used to guide the process of SO-LCA. This stage consists of 4 parts "Goal and Scope", "Inventory analysis", "Impact assessment" and "Interpretation".

Goal and Scope.

The systems boundary should be set the same for SO-LCA and inventory models should be consistent with the goal and scope of the study.

Inventory analysis

According to UNEP (2021) to assess social performance, the Reference Scale Social Life Cycle Impact Assessment approach should be used. This approach will provide a general understanding of the ordinary scale from non-compliant to best practice. To evaluate the performance of the company the three-level scale will be used (Table 8).

Table 8. The scale for evaluation of social performance

Scale level	Description
1	Best performance (eg. involvement beyond regulations; higher investments compared to competitors in the same region or industry/sector; etc.)
0	Average performance (eg. compliance with international and national laws; performance comparative to the competitors in the same region or industry/sector; etc.)
-1	Non-compliance (eg. non-compliance with international and national laws; lower performance to the competitors in the same region or industry/sector; etc.)

The data can be gathered from the organization and its stakeholders or come from secondary sources (eg. database).

Impact assessment

Assessing the data against the referring scale for the chosen stakeholder categories and their indicators. The activity variable and waiting of the results can be applied (UNEP, 2021).

Interpretation

This phase is the final stage of SO-LCA which provides the results of the analysis. The limitations of those results should be discussed.

The supplementing of O-LCA and O-LCC with SO-LCA gives the grounds for O-LCSA. Figure 3 proposes the O-LCSA framework.

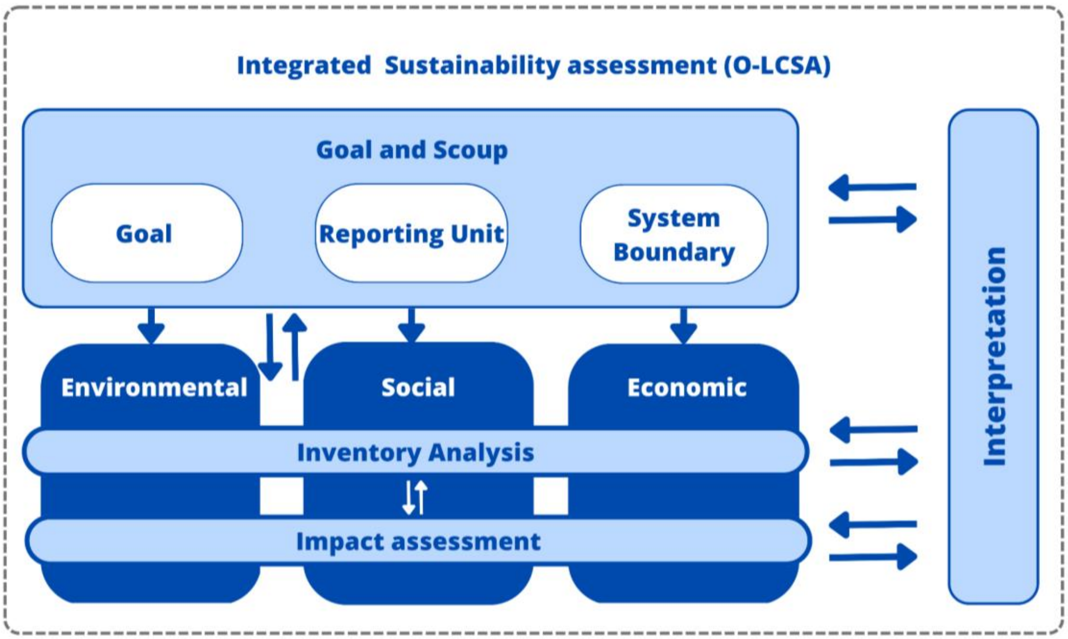

Figure 3. Proposal of O-LCSA framework adapted from Alejandrino et al. (2022). The light blue squares illustrate the phases of the O-LCSA, the white squares – the initial parts of the goal and scope phase, and the dark blue squares – the three perspectives of sustainability. The arrows indicate the relationship between the phases and perspectives.

4.1.4 Stage 4. Prioritization of the scenarios

Due to adding the SO-LCA into Stage 3, the evaluation of the scenarios has to be adjusted. One of the options would be parallel coordinates, which is a type of graph that allows comparing of several scenarios based on multiple parameters. In this type of graph, each parameter is represented by a vertical axis and a line connects the values for each parameter for a particular scenario. This allows you to compare scenarios based on how their lines intersect or diverge.

4.2 Testing of the methodology

To understand the applicability of the developed methodology, I decided to test it on the chosen case study. The steps can be found in Table 9. Stage 1 (4.2.1) describes the applicability of the CE indicators in the single-use industry. Stage 2 (4.2.2) proposes the alternative scenario and describes the improvements and deteriorations. Stage 3 (4.2.3) describes the O-LSCA analysis of the scenarios to identify their sustainability performance. Stage 4 (4.2.4) illustrates the results obtained in Stage 3 and helps with the prioritization of scenarios.

Table 9. Testing of the developed methodology on the case study

Stages	Done in this thesis	Steps
1	● Baseline scenario circularity analysis (SC0)	● Collection and aggregation of data
2	● Comparison of alternative scenario to the baseline (SC1)	● The alternative scenario was chosen based on an ongoing project in Duni ● Comparison with the SC0
3	● All three stages of the O-LCSA were conducted	● O-LSA (only global warming potential) ● O-LCC (with limitations) ● SO-LCA (stakeholder groups: Workers)
4	● The stage was not tested	● Due to not completed O-LCC

4.2.1 Stage 1. Initial analysis of organizational circularity

SC0 is based on the sales that were conducted in 2022 for Dunisoft and Dunicel. It is used as a potential sales scenario that has been confirmed in practice. Table 10 and Appendix 6 demonstrate the analysis of the initial circularity performance of the organization using the indicators presented in Appendix 1. The SC0 shows that Duni has initiatives related to categories: Strategy & vision, Environmental management, Supplier selection & auditing, and Consumers. The rest of the indicators present the areas of improvement.

4.2.2 Stage 2. Proposal and analysis of the CE alternative scenarios

In this paper, the decision tree was not applied as the alternative scenario was chosen based on the proposed idea of a bio-based replacement for the binder. The SC1 represents the scenario where the binder in Dunisoft and Dunicel were fully replaced with the bio-based alternatives. The bio alternatives differ from the original products because of the bio-based binder and bio-based packaging. Therefore, the SC1 will be based on strategies 12 “For recycling” and 16 “Bio-based” materials (Appendix 3). The circularity of the alternative scenario was assessed by applying the circular indicators defined in Appendix 1. Table 10 reports the percentage of improvement for the alternative scenario (SC1) in comparison to the baseline scenario (SC0). The full results of the circularity analysis of the scenarios can be found in Annex 6.

Through the research it was found that the Bio Dunicel binder produced in-house and fossil-based material was replaced with potato starch, hence material design aims for recyclability. As for the Bio Dunisoft binder, it is supplied by OrganoClick to Duni and the recipe is confidential. Both binders have a lower stickiness, therefore, their usage in the production of Bio Dunisoft and Bio Dunicel materials is increased.

Table 10. Influenced CE indicators for baseline scenario (SC0) and percentage of improvement in the alternative scenario (SC1). (*) The CE indicator 22 improvements is shown not in percentage, but in kEUR. The green cells indicate the improvements in the CE indicator, and the red cells indicate the deterioration of the CE indicator.

CE Indicator	Unit	SC0 (Not bio)	SC1 (Bio)	Difference between SC0 and SC1
1	number (#) of strategies	5	20.0%	The company integrated 25% more strategies in the SC1.
5	# of collaborations	0	100.0%	The company started more collaborations with external partners.
6	# of products	0	100.0%	100% of products in SC1 can be recycled.
9	# of initiatives	0	100.0%	100% of packaging was switched to a bio-based alternative.
12	t	9063.73	6.8%	The total material use increased by 6.8%. (see Appendix 6)
12.1 Pulp	t	7129.21	-6.6%	The overall pulp consumption decreased by 6.6% as Bio Dunisoft napkins use less pulp, while Bio Dunicell - is unchanged. (Appendix 7)
12.2 Binder	t	1791.21	60.6%	The overall binder consumption increased by 60.6%. For product specifics check Appendix 7.
12.3 Packaging	t	143.31	1.5%	The overall packaging consumption increased by 1.5%.
13	t	91.44	63.9%	Water consumption increased by 63.9%.
15	%	0.48	0.1%	The percentage of renewable energy increased by 0.1%.
16	kWh	13 251 567.60	-0.2%	The overall energy consumption was reduced by 0.2%
18	t	485.96	96.5%	Solid waste increased by 96.5% due to losses in the production of bio-binders for both products

				(see Appendix 7).
21	t CO2eq	10092.26	3.8%	The overall increase in emissions by 3.8%.
22*	K EUR	N/A	19	For this indicator, capital expenditures show long-term investments.
32	# of innovation meetings/etc.	0	100.0%	The number of meetings increased by 100% compared to SC0.

The scenario analysis based on the circularity indicators demonstrates the heterogeneous results. The improvements were reached on 21,9% of indicators (1, 5, 6, 9, 15, 16, 32), where deterioration – 12.5% of indicators (12, 13, 18, 21) and 65.6% stayed unchanged (Appendix 6). Moreover, during the analysis, I identified two parameters (2, 3) that are not applicable to the company that produces hygiene single-use products such as napkins. They require long-lasting products while the products under study have a short life cycle.

4.2.3 Stage 3. Sustainability performance of scenarios

This stage will describe the steps of O-LCSA. The Stage consists of 4 parts “Goal and Scope”, “Inventory analysis”, “Impact assessment” and “Interpretation”. Where the last three are combined.

Goal and scope

This stage aimed to analyze the environmental, social, and economic performance of the baseline scenario (SC0) and the scenario that will replace binder and packaging materials with bio-based alternatives to improve the circularity of the company (SC1). The scope of the study is limited by the analysis of the Dunisoft, Dunicel, Bio Dunisoft, and Bio Dunicel materials’ production at the production site Rexcell and conversion site Bramscheof the materials to napkins and placemats to test the framework. Therefore, the reporting organization for this case study is Duni business area which is responsible for these products. The functional unit for this analysis will be 1 m^2 of product. The material lifetime is one-time use. The products are evaluated for their carbon footprint within the European market (Global Warming Potential, or GWP). Products are evaluated for production in the year 2021 but assumed that the metrics will not change for the production year 2022. In 2022 Duni conducted an additional assessment and updated the emission data. The system boundary was proposed to be the cradle-to-gate approach (Figure 4) and the downstream activities were excluded.

Figure 4. The cradle-to-gate model (South Pole, 2022)

The system boundary for the two types of products is shown in Figures 5 and 6. The production process for DuniSoft napkins begins with the airlaid process that converts the pulp into fluff mixed with air. The process involves the steam that acts like a ”glue” and makes fiber strength up. Acquired material goes to the binder station where it is combined with one of the alternative binders. The next step is shipping the material to the Bramsche conversion site and, through cutting and design, producing the final product – napkins. The final product is then packaged and sent to the customer. The company claims that some of the material waste from the conversion stage can be transferred back to Rexcell and integrated into the material production. The percentage of material recycling is missing.

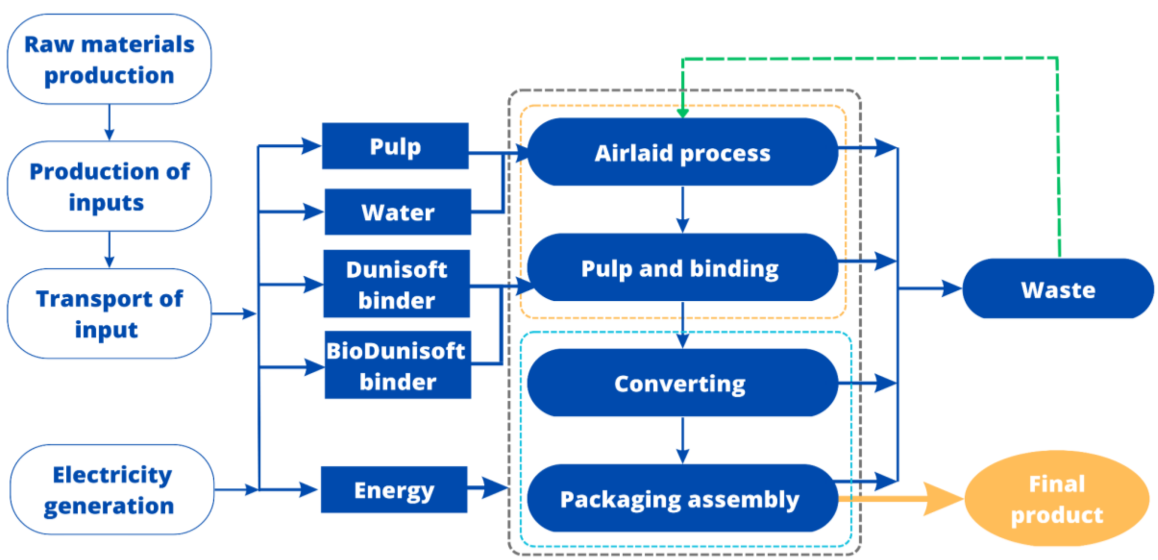

Figure 5. The system boundaries (cradle to gate) for DuniSoft and BioDuniSoft. Where the yellow dash-line is the Rexcell boundary, the blue dash-line – the Bramsche site boundary, gray dash-line is the production boundary. The green dash-line represents the potential reuse of the production waste. (Self-made)

The production process for Dunicel placemats begins with the production of tissue from the pulp. Then the material is converted to placemats by combining tissue with a binder, cutting, and packaging. The first stage is conducted in the Rexcell factory and then the tissue is shipped for converting and packaging to the Bramsche site. In each step of the production process for all the placemates products the waste is generated.

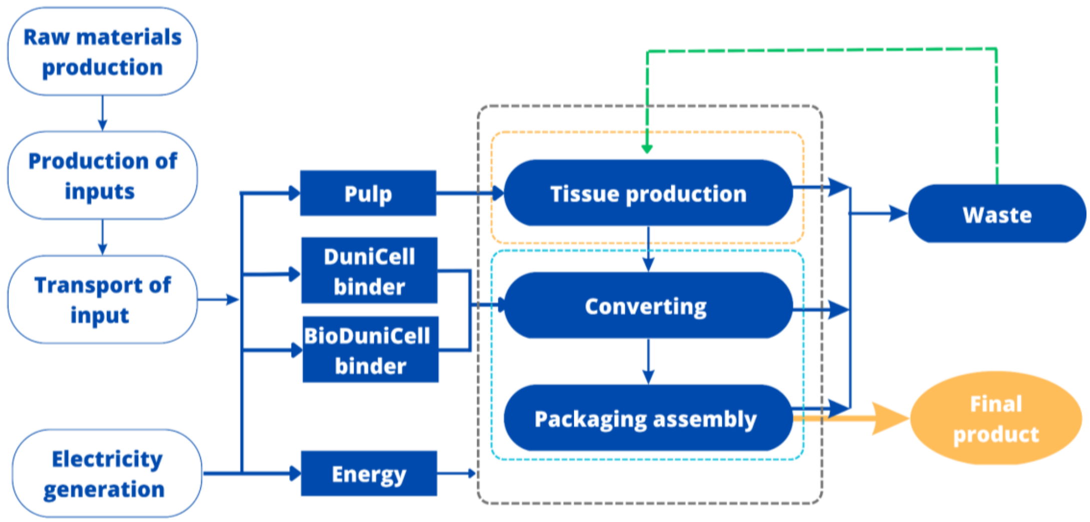

Figure 6. The system boundaries (cradle to gate) for Dunicel and Bio Dunicel. Where the yellow dash-line is the Rexcell boundary, the blue dash-line – the Bramsche site boundary, gray dash-line is the production boundary. The green dash-line represents the potential reuse of the production waste. (Self-made)

For the SO-LCA the only stakeholder group "Worker" with the subcategory "Health and Safety" and subcategory "Working hours" was chosen. As the scope of the study was limited to cradle-to-gate, therefore the biggest influence the company is having on the workers. Thus, it is important to assess the stakeholder category, and in this case, the study will be based on three indicators: "Presence of a formal policy concerning health and safety", "Number/percentage of injuries or fatal accidents in the organization" and "Number of hours effectively worked by employees". The indicators in the subcategory "Working hours" was chosen as it is expected that the number of productive hours will decrease as the new technologies require adjustments and learning from the employees' side. As for the subcategory "Health and Safety", the hypothesis is that the integration of new technologies may decrease the risks of injuries (Sider, 1985).

Inventory analysis, Impact assessment, and Interpretation

For this case study, only the GWP impact was chosen for calculation, due to the availability of the data and limited time for the research. The scope of this study is cradle-to-gate, the use and end-of-life stage was excluded from the analysis.

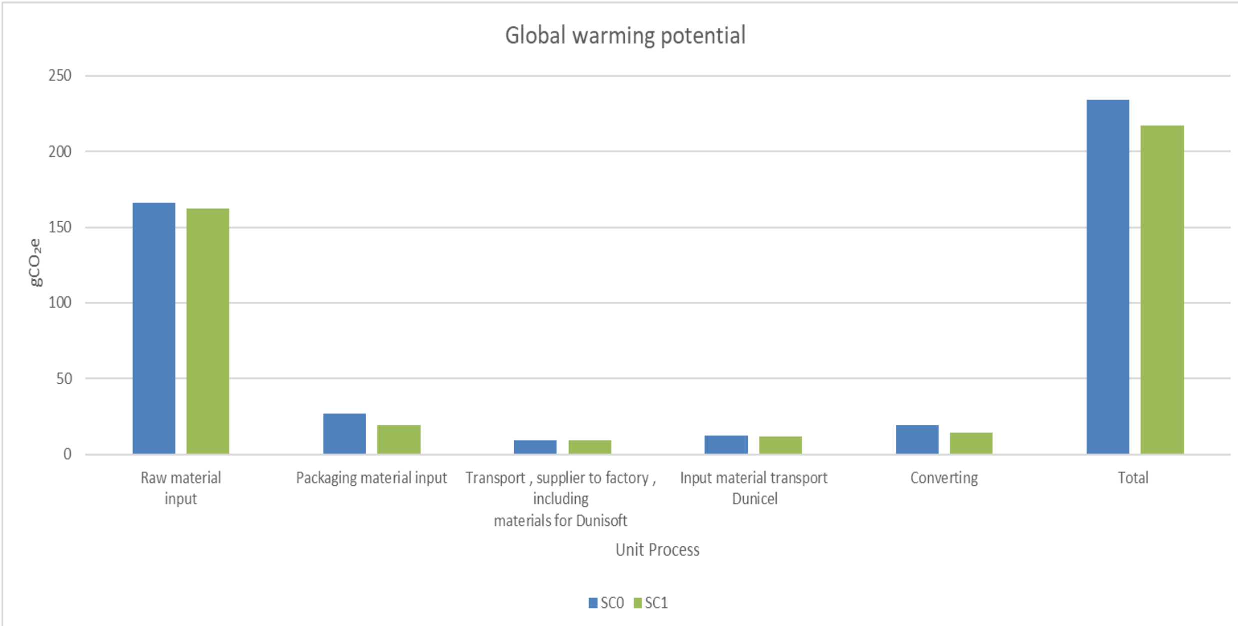

Figure 7. Comparison of base and alternative scenario based on global warming potential impact.

Figure 7 demonstrates that the total emissions of the organization in SC1 are lower than in SC0 by 7.34%. This change was caused by the decrease in total (cradle-to-gate) emissions of Bio Dunicel placemats compared to Dunicel by 12%, while Bio Dunisoft increased compared to its alternative by 3.95% (Appendix 8,9). The unit processes emissions for Raw material input and Transport decreased in SC1 by around 3%. The biggest decrease happened in unit process and converting, where the decrease was 28.89% and 25.77%. The employee commitment stayed the same as the SC1 did not create jobs at the sites.

For the *economic impact assessment,* Duni has provided 2021 data for each alternative project (Bio Dunisoft and Bio Dunicel) that included operating expenses (k€) and payback period (Y) (Table 11). Operating expense interprets as the total annual cost in this case study. The comparison between SC0 and SC1 is not applicable as data for SC0 is unavailable.

Table 11. The total economic impacts of the alternative scenario. (*) Y1 is 2022

	Bio Dunisoft	**Bio Dunicel**	**Total (SC1)**
Operating expenses (k€)	216	400	616
Payback period (Y)*	>5	4	–

For the *social impact assessment* as the scope of the analysis is limited by the cradle-to-gate perspective, the most material stakeholder group is “Worker”, as most of the activities are happening on Duni’s sites.

To assess the indicator “Presence of a formal policy concerning health and safety”, I developed a reference scale (Table 8) to assess the performance of Duni BA. The reference point (the existence of the document in Duni) will be compared to the average sector (production) performance in Sweden (EU S&H, n.d.) (Figure 8).

More than 95% of Swedish companies have a document describing the obligations or procedures for health and safety. The Duni Group has the “Global Health and Safety Directive” (Duni Group, 2022b) that covers Rexcell and Bramsche sites. Therefore, the performance of Duni BA for SC0 should be ranked as “0” as the company falls under the majority of Swedish companies and pursue average performance. An additional factor was that through the interviews with the employees, no additional documents covering this indicator were found. As the production sites are not changed and they are already covered by the policy the ranking of the SC1 won’t change (See Table 12).

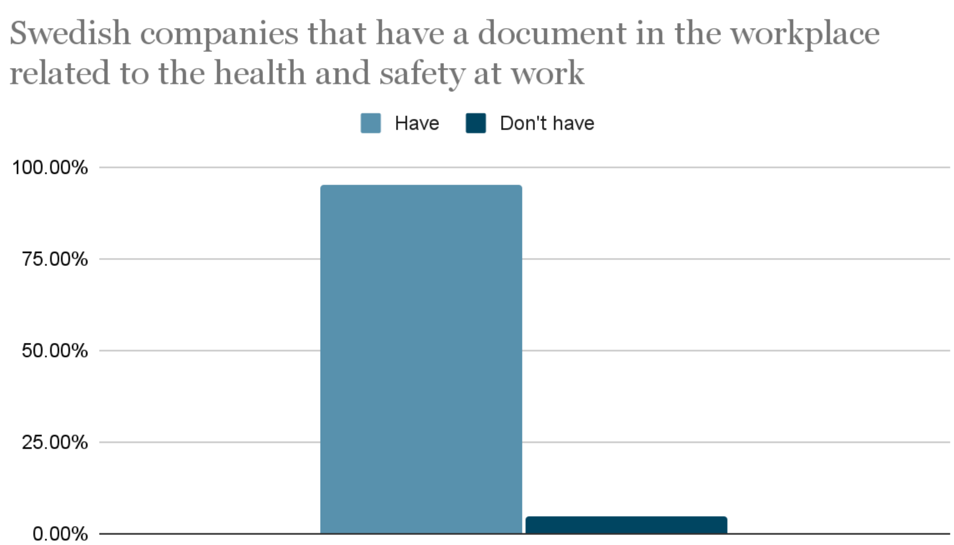

Figure 8..Statistics on Swedish companies that have a document in the workplace describing the obligations or procedures related to health and safety at work (EU S&H, n.d.)

For the indicator “Number/percentage of injuries or fatal accidents in the organization”, as a referencing point, I will use the number of accidents per 1000 employees. The reference scale will be based on (Eurostat, 2020), which provided the non-fatal accidents rate for the EU level, which was 14,44 per 1000 employed people. The EU level was chosen as the sites are located in different countries. In 2021 Duni BA had 17 injuries on their sites in Rexcell (9 injuries) and Bramsche (8 injuries). The rate for Duni BA is 25.11

accidents per 1000 employees. Thus, the accident rate for SC0 is higher than the average and the indicator is equal to “-1”.

In the SC1 hypothetically the number of accidents will decrease with the implementation of new technology (Sider, 1985). However, previously production of the original binder was outsourced, thus, the injuries that occurred in that process were not considered. As a result, the number of injuries may instead increase. For this case, the data on injuries for SC1 was not available, but through the interview with the project manager, it was decided to state that the number of injuries will stay the same compared to SC0. Thus, SC1 will be ranked as “-1”.

The last indicator that will be assessed in this paper is the “Number of hours effectively worked by employees”. In both scenarios, the working hours are aligned with the national and local regulations and therefore won’t change. However, due to the change in technology, the productivity index will decrease from 100 to 95. The decrease is caused by the need to include learning time to know the operation of the technology. Therefore, this indicator won’t have a reference scale and the indicators will be compared with each other through the productivity index.

Table 12. Comparison of base and alternative scenarios on the social performance (SO-LCA). (*) The company is compliant with the national regulations in both scenarios, therefore, color-coded yellow. However, the numbers represent the productivity index.

Stakeholder’s group	Subcategory	Indicator	SC0	SC1	Improvements
Worker	Health and Safety	SOLCA1: Presence of a formal policy concerning health and safety	0	0	No change
Worker	Health and Safety	SOLCA2: Number/percentage of injuries or fatal accidents in the organization	-1	-1	No change
Worker*	Working hours	SOLCA3: Number of hours effectively worked by employees	100	95	Decrease

Table 12 demonstrates that the indicators of social performance have varied but have not shown a positive impact on the social performance of SC1. The subcategory “Health and safety” stayed unchanged with the low performance in the indicator SOLCA 2. The subcategory “Working hours” have not changed from the perspective of compliance with the regulations regarding working hours. However, the productivity index decreased by 5%.

4.2.4 Stage 4. Prioritization of the scenarios

This case study was based on one alternative scenario with limited assessed impacts. Figure 9 demonstrates the parallel coordinates chart of SC0 and SC1 to illustrate the results of the analysis. The O-LCC was excluded from the graph as only SC1 has the available data. The results demonstrate that the SC1 has only improved the environmental performance compared to the SC0.

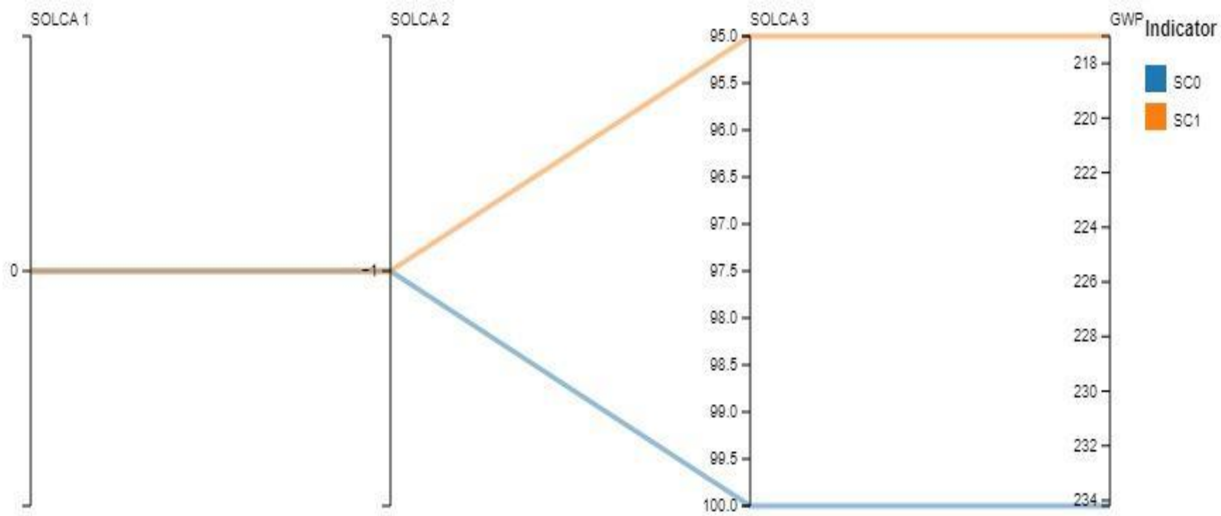

Figure 9. Parallel coordinates chart of SC0 and SC1.

5 Discussion

This section presents a discussion of the principal contributions, limitations, and potential future developments of the proposed methodology, as well as the implications of the case study results.

5.1 Methodology: Benefits and Challenges (RQ1 & RQ2)

The proposed methodology is the framework that can help organizations choose potential CE strategies from circularity and sustainability. It involves data collection, stakeholder engagement, and analysis. However, the lengthy process of conducting the methodology can pose challenges for companies. For instance, the time spent on the data collection and analysis can take months, and slow down the decision-making process, but at the same time increase its validity. However, in practice, a company usually chooses strategies based on intuition (Miller & Ireland, 2005; Sinclair & Ashkanasy, 2005) and postfactum to justify its choices.

The main contribution of the methodology is the inclusion of social dimensions into the analysis. It gives the opportunity to evaluate the impacts of CE strategies on the stakeholders both from circularity (CE indicators) and SO-LCA.

5.1.1 Challenges and limitations of CE indicators

As for the social CE indicators, I found it hard to choose and justify them. Their choice was based on the most recent literature review conducted by (Luthin et al., 2023), which limits the research as other papers were not taken into account. To justify the CE indicators I traced back each indicator through the referenced literature. The analysis showed that in some cases the indicator did not have an empirical background. Therefore, it was hard to find the justification for the measurement's intended impact (How does it affect stakeholder groups?; How can it contribute to a more circular company's decision-making?). For this research, I chose only the indicators that had a clear justification for their purpose. Therefore, it is important to conduct future research on the CE indicator analysis, especially in the context of social CE indicators.

The chosen CE indicators are assigned to the existing stakeholder group, which corresponds to the SO-LCA Guidelines proposed by UNEP (2020). It should be noted that there are not yet established CE indicators for the stakeholder group "Children", as this group was proposed only at the end of 2020 (Luthin et al., 2023). The inclusion of the social CE indicators into the analysis gave the opportunity to evaluate the commitment of the company to follow all the CE principles. Additionally, according to (Luthin et al., 2023) some CE indicators can overlap with the O-LCSA calculations which can lead to double counting. Through the choice of CE indicator for the proposed methodologies, the double counting of the parameters was avoided.

5.1.2 Benefits and challenges of CE strategies' list

Another benefit of the proposed methodology is the list of the CE strategies with the description and purpose that corresponds with the CE principles. The list will give the companies an idea of how to cover the gaps that have been found in Stage 1 of the methodology. The list was based on the Alejandrino et al. (2022) research. Through the process of description and finding an aim of each strategy, it was found that there is a lack of strategies that are oriented toward Collaboration (3), Innovation (3), and Transparency (3). It limits the options of the companies for improvement. Therefore, it is important to conduct additional research to increase the variety of strategies.

5.1.3 Challenges and limitations of SO-LCA

The benefit of Stage 3 is the inclusion of the SO-LCA into the analysis of the CE strategies sustainability. There are many tools that help companies analyze their social sustainability. These assessments are helping companies to evaluate their current position and identify the areas for improvement. However, the assessments do not give the opportunity to evaluate the potential impacts of their decisions and do not have the option of scenario analysis. For instance, the SA 8000 certification is the standard that helps companies to assess social issues such as health and safety, working hours and wages, forced and child labor, discrimination, and freedom of association (SAI, n.d.). Another option for the performance analysis can be the EcoVadis ranking scheme, which covers not only social (ethics, labor & human rights) but also environmental performance (sustainable procurement) (EcoVadis, n.d.). Therefore, the proposed methodology is helpful for decision-making.

From my experience, the biggest challenge in the SO-LCA is the data collection and reference scale creation. However, as these assessments and others (e.g. BCorp) are popular and recognized by businesses and consumers alike, they can be helpful with data collection for social indicators. According to D'Eusanio et al. (2022a), SA 8000 can be the starting point of the data collection, especially for the subcategory "Worker", as it covers most of the subcategories, except "Employment Relationship" and "Sexual Harassment". EcoVadis ranking helps create a reference scale to evaluate social performance as the system collects and compares information from different companies in the same sector. EcoVadis particularly will be useful for the subcategories "Workers" and "Value chain" (EcoVadis, n.d.). Thus, for this thesis, the data on injuries was available due to Duni's participation in the EcoVadis ranking.

Additionally, the scope of O-LCSA pillars may vary from case to case, which can result in the exclusion of certain stakeholders and value chain actors from the analysis (Alejandrino et al., 2021). As such, researchers such as Fauzi et al. (2019) have identified differences in system boundaries as one of the challenges that need to be addressed.

5.1.4 Limitations of scenarios' prioritization

As for Stage 4 of methodology, the heterogeneity of the result coming from qualitative and quantitative indicators makes understanding O-LCSA difficult. The graphical representation can be useful (Alejandrino et al., 2021). The parallel coordinate method was proposed to illustrate and compare scenarios. However, the integration of each assessment and ranking of the scenarios based on O-LCSA is not proposed and required further development. The future researcher can integrate the operation research methods, with a good overview from Thies et al. (2019).

Therefore, the framework provides a deep understanding of the current position of the company as well as gives an opportunity to holistically assess the circularity and sustainability of potential decisions. But further and diverse application and testing is necessary for its development.

5.2 Results of testing (RQ3)

Through research question 3, I aim to understand to which extent the methodology is useful. Therefore, to answer this question the testing on a case study was conducted. It illustrates that the proposed methodology is useful to provide an overview of the circular and sustainability impacts that strategies implementation can bring. The CE indicators help in the identification of the most suitable strategies while the O-LCSA prioritize them. The test revealed both potential synergies and trade-offs between the implementation of CE strategies and their sustainability.

The test showed the differences and similarities between the two proposed scenarios through the CE indicators and the O-LCSA assessment (excluding O-LCC). The test demonstrated that among sustainability parameters that were tested, only one parameter showed an improvement and one showed a temporary decrease. As for the CE indicators – 8 showed improvement and 4 deterioration. The majority of the parameters for both circularity and sustainability assessments stayed unchanged. Therefore, revealing that the implementation of strategies brings synergies and trade-offs. It showed the move of the impact of GWP on material consumption and waste generation. Therefore, the methodology is giving the opportunity to see the broader picture of the impacts of organizational decisions.

Through the test, I experienced the challenge of finding the data. Starting with the CE indicators, I conducted interviews with over 5 employees to obtain the data. It indicates that the data is partially available for analysis, but time-consuming for gathering. Additionally, some stakeholder groups and O-LCA impact assessments groups were excluded from the testing which might cause challenges for future data collection. Thus, for example, the injury rates in the suppliers of the Bio Dunisoft binder were excluded from the analysis as it was not feasible to conduct interviews in the given time frame of this thesis.

5.2.1 Outcomes of baseline scenario circularity assessment

As for Stage 1, the selection of CE indicators has to be carefully conducted based on the specific context the organization is located in. Thus, for example, the case study showed that CE indicators 2 and 3 do not apply to Duni as indicators are oriented toward long-lasting products. Additionally, Duni could not provide data for indicators 17, 19, and 20. The data for indicator 17 "Recycled content of raw material" was missing due to the absence of measurement of the use of the materials that are sent back to the production site Rexcell. As for 19 "Recycled solid waste" and 20 "Effluents discharged", due to the limitation of the study to assess only 4 product types produced in the company, the calculations for the indicators were not feasible.

5.2.2 Outcomes of alternative scenario proposal and analysis

Testing of Stage 2, was not fully conducted. The decision tree was excluded from testing, as the alternative scenario was based on the ongoing project of binder replacement with a bio-based alternative. The SC1 was still assessed with the CE indicators proposed in Appendix 1 and compared with the baseline scenario. The comparison helped in the identification of deteriorations and improvements. From the perspective of social CE indicators only 32 "Number of CE innovation meetings/workshops/etc." showed an increase. It means that SC1 has a low influence on the social aspects of the company's circularity. However, the social dimensions of CE are poorly explored on the micro level as CE primarily provides insights into the resource flow efficiency, which can be easily quantified, compare to the social impacts (García-Muiña et al., 2021).

This research is the first attempt to use the social CE indicators in the scenario analysis of the CE strategies and it brings opportunities for future research.

5.2.3 Limitation of O-LCSA testing

Regarding Stage 3, the biggest limitation of the case study was the scope of the O-LCSA. The “cradle-to-gate” system boundary excluded the end-of-life stage of the product life cycle. One of the main advantages of bio-based alternatives is as they have lower GHG emissions in the last stage of their life (South Pole, 2022). Therefore, the inclusion of the end-of-life stage would increase the positive impact of the SC1 O-LCA. Additionally, this case study was limited to the GWP aspect of O-LCA, which included the assessment of the other impacts on the environment.

As for the O-LCC, the analysis at this stage can only provide the information that the SC1 is economically beneficial for the company as the payback period is around 5 years. The limitation of O-LCC analysis, however, is the absence of data on the SC0, which made it impossible to compare scenarios between each other.

The study had some limitations in terms of the scope and time constraints of the SO-LCA. As a result, the analysis focused only on the "Worker" stakeholder group and only included three indicators. No improvements were observed in the indicators under the different scenarios. Therefore, the tested indicators are not enough to evaluate the social impact of the CE strategies chosen for SC1. For instance, the indicator SO-LCA1 can be useful for identifying the current position of the company. However, if the company has already adopted the formal policy concerning health and safety there would not be changes for the alternative scenarios. Additionally, for this indicator, the reference scale created in this study does not clearly state what the “above average” performance of the company means. Therefore, it is hard to evaluate the scenarios based on the 3-level scale in this case.

Another challenge encountered in the data collection process was the lack of mature social commercial databases, as noted by Alejandrino et al. (2021). Although the reference scale was identified for two of the three indicators, the case study did not provide the reference scale for the "Working hours" subcategory, as the parameter was repurposed to identify the productive hours spent. The results indicated that working hours remained the same, while productivity decreased by 5% which is caused by the learning of new technology.

Another limitation of the SO-LCA in the scenario analysis was the double comparison of the indicators to the reference scale and between scenarios, which closed a sensitivity shortcoming. For example, the number of injuries in SC0 was 10 below the average reference scale, and SC1 decreased the injury rate by 5 injuries compared to SC0. SC1 would still be below the average reference scale (by 5 injuries) but better than SC0. This could lead to a misinterpretation of the data. Therefore, it is important to develop a more sensitive evaluation scale.

5.2.4 Limitations of scenarios prioritization

The limitation is also identified in the graphical presentation (Stage 4) and potential difficulty in the interpretation of the results. As in the case study, the number of scenarios was limited to two and the number of indicators to four, as O-LCC was excluded from the graph, the visualization is clear. However, if the number of scenarios and indicators will increase the overlap of graphs and will lead to interpretation difficulty. Therefore, additional research is necessary to establish a clearer interpretation graph.

The following section will describe how the proposed methodology contributes to sustainability.

5.3 The methodology and sustainability

The proposed methodology integrates several approaches for identifying and prioritizing strategies to support evidence-based decision-making in organizations. However, this can be challenging due to the complexity, conflicting objectives, and uncertainty in evaluating multidimensional results, as noted by Halog and Manik (2011). The proposed methodology revealed uncertainty around injury rates. I used assumptions based on the company's risk assessment to mitigate this uncertainty. The testing also revealed conflicting outcomes (material consumption and GWP), which makes it hard to decide between scenarios. Additionally, I note that the complexity of the methodology makes it time-consuming. Nonetheless, since strategic planning is typically done over a medium to long term (Silvestre & Fonseca, 2020), the methodology can be used periodically, such as every 5-10 years. Therefore, making it realistic to use the holistic assessment for the CE strategy decision-making.

To adopt the methodology the companies will need to collect the data required for all stages of the analysis, which would potentially lead to additional costs. The limited availability of data for the reference scale for the SO-LCA can bring additional difficulties to the analysis. This study was primarily focusing on quantitative-based indicators for all stages of the analysis; however, the Guideline for SO-LCA by UNEP

(2020) suggests the analysis of the qualitative data, which may cause an additional challenge for the evaluation of the results.

However, evidence-based strategic decision-making can contribute to the improvement of production systems and consumption patterns (Rigamonti & Mancini, 2021). The change in production practices will potentially contribute to reaching international goals (eg. SDG 12). The motivation for evidence-based CE strategy implementation will be the communication of the commitment toward a more circular and sustainable future. As highlighted by (Rigamonti & Mancini, 2021) it can establish positive relationships with customers and enhance their reputation among stakeholders. However, the primary reason for organizations' motivation for sustainability and circularity improvements is the increasing pressure from government regulation, compliance issues, and market requirements to develop sustainable products and find circular solutions (Rigamonti & Mancini, 2021).

Pursuing circularity can have both positive and negative implications for sustainability. It is crucial to carefully evaluate and address potential trade-offs and complexities to ensure that Circular Economy initiatives contribute effectively to broader sustainability objectives (Morales et al., 2021). The proposed methodology helps to reveal trade-offs that can appear after the implementation of the CE strategies, therefore aiming to find synergetic strategies. The proposed testing has not revealed the scenario that will have a better circularity performance while at the same time contributing to sustainability. Therefore, future research is needed to find the strategies that will bring synergistic sustainability.

6 Conclusion

To conclude, Circular Economy (CE) is a new production and consumption paradigm that can become a solution to existing production and consumption problems. However, CE solutions are not always sustainable. To provide businesses with the directions for the CE transition, it is necessary to have a set of CE strategies. This thesis aimed to discuss the need for the creation of holistic methodologies that can help companies to choose and prioritize CE strategies.

The main contribution of this study is the integration of social dimensions into the methodology proposed by Alejandrino et al. (2022) and the development of the new methodology based on CE indicators and Organizational Life Cycle Sustainability Assessment (O-LCSA). The inclusion of social CE indicators gave an opportunity to extend the analysis on the missing aspect of the "Transparency" principle of CE, as well as deepening the understanding of the contribution to other CE principles. Integration of Social Life Cycle Assessment (SO-LCA) into sustainability analysis of CE strategies brings the opportunity to assess the social impact that can be caused by the implantation of strategies. Additionally, the methodology of Alejandrino et al. (2022) was missing the purposes of CE strategies as well as the reason for choosing the CE indicators. Therefore, the additional contribution of this study is the justification and description of the CE indicator and CE strategies, which allowed to understand the importance of their calculation through the alignment of them to CE principals.

The proposed methodology showed its usefulness in the case study (Duni Group) as it allowed to find trade-offs between the circularity and sustainability performance of the SC0 and SC1. The biggest trade-off of the testing was found between material consumption and impact category Global Warming Potential (GWP) (t CO2e), where the CO2 emissions in SC1 have decreased while the material consumption and waste generation have increased. The test provided a visualization of the results that can help decision-makers.

The proposed methodology consists of 4-stages. Therefore, it brings the challenge of the length and cost of the process, a limited number of CE strategies (Stage 2), data availability (Stage 1-3), scenarios' prioritization illustration, and interpretation difficulty (Stage 4). However, it is important to note that the methodology provides a framework for evidence-based decision-making that can contribute to the improvement of production systems and consumption patterns. Therefore, these limitations should be considered and overcome through further research and testing to refine and enhance the methodology.

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8 Appendices

8.1 Appendix 1. List (non-exhaustive) CE indicators for quantifying the circularity at the organizational level. (Alejandrino et al. 2022), (Luthin et al., 2023)

The table provides the justification of the parameters as well as what CE principles (Table 2) they cover. Yellow highlights the social indicators

Category	CE Indicators	Unit	Justification	CE principle
Strategy & vision	1. Circular Economy strategies incorporated into other corporate strategies	number (#) of strategies	Vinante et al. (2021) state that both practitioners and researchers find it important for a business to include circularity in sustainability and corporate strategy as it influences the organization's values and actions.	Stewardship Innovation System thinking
Business model	2. Leasing/renting business models	#	Vinante et al. (2021) identified the metric as important. The metrics identify the effort of the company to keep the value of the product.	Value optimization
	3. Product lifetime extension initiatives	# of products	These criteria lay in the core of the CE principles that promote the extension of the product's value.	Value optimization
Environmental management	4. Environmental management system	# of systems	According to Mura et al., (2020), the environmental management system (e.g. ISO 14000) helps the company to be more material-efficient and reduce costs. It also contributes to a more resilient supply chain through the sustainable criteria used.	Collaboration
Industrial symbiosis	5. Collaborations with external partners	# of collaborations	According to Ioannou et al. (2016), through collaboration companies, find new solutions to the circularity challenges. Therefore, the criteria show how involved the company is in industrial symbiosis.	Collaboration
Design	6. Products recyclable or reusable	# of products	The indicator demonstrates the commitment of the company to save the value of the product (Masi et al., 2018).	Value optimization
	7. Products designed for	# of products	The indicator demonstrates the effort of the company to aim for saving and	Stewardship

	reduced consumption of material/energy		expansion of the natural capital. (Masi et al., 2018).	
	8. Products designed for waste minimization	# of products	The metric shows the level to which the company tries to use resources efficiently as well as reduce the negative impacts of waste on the environment. (Kazancoglu et al., 2018)	Stewardship Value optimization
	9. "Green" packaging initiatives	# of initiatives	The metrics chosen as the focus of circularity within the company should be not only on the product that is produced in the company but also on the packaging. "Green" in this context includes the use of biodegradable and bio-based raw materials, or the inclusion of recycled content, for the packaging as well as the ability of the packaging to be recycled (Mura et al., 2020).	Value optimization System thinking
Supplier selection & auditing	10. Supplier selected based on CE performance	# of suppliers	The criteria will show the commitment of the company to increase its circularity through the number of suppliers that are committed to the CE. (Ioannou et al., 2016)	Collaboration
	11. Environmental purchasing criteria in the selection of suppliers	# of criteria	Suppliers' selection should be based on environmental criteria (e.g. certification) to ensure a lower environmental impact throughout the supply chain. The metrics will show how ensured the supply chain is. (Ormazabal et al., 2018)	Collaboration
Production and consumption	12. Material consumption	t	The criteria show the total material consumption of the organization.	Stewardship Value optimization
	13. Water consumption	m3	The criteria show the total water consumption of the organization.	Stewardship Value optimization
	14. Electric energy consumption	kWh	The criteria show the total electricity consumption of the organization.	Stewardship Value optimization
	15. Renewable electric energy consumption	%	The criteria demonstrate the amount of electricity coming from renewable sources.	Stewardship Value optimization

	16. Fuel consumption	m3	The criteria show the total fuel consumption of the organization.	Stewardship Value optimization
Secondary raw material	17. Recycled content of raw material	%	Circular procurement can be indicated through the amount of recycled material in the final product (Masi et al., 2018).	Stewardship Value optimization
Waste generation and manageme nt	18. Solid waste generated	t	The indicator demonstrates the amount of natural capital that was used inefficiently.	Stewardship
	19. Recycled solid waste	%	The percent of waste that was recovered in value.	Stewardship Value optimization
	20. Effluents discharged	m3	The indicator demonstrates the amount of natural capital that was used inefficiently.	Stewardship
	21. Carbon emissions generated	t CO2eq	The indicator demonstrate the contribution of CE solutions to the global warming.	Stewardship
Competitiv eness and innovation	22. CE Investment	SEK	The amount of money invested into the CE demonstrates the level of involvement in circularity.	Innovation
Post-sales services	23. Take back systems for products after their use	#	The metric shows the dedication of the company to keep the value of the product as long as possible.	Value optimization
Social sustainabil ity **Worker**	24. Number of accidents related to CE activities (such as recycling);	#	This indicator demonstrates the direct evidence of a company's social condition (UNEP, 2021).	Stewardship
	25. CE training	(CE training hours)/(h ours worked)	According to Medina-Mijangos et al. (2021), education contributes to the change in workers' behavior towards a more circular lifestyle.	System thinking Stewardship
Local communit y	26. Job creation/decline	# of jobs created for CE activities	Job creation/employment was the most addressed impact of the CE, according to (Luthin et al., 2023). The indicator demonstrates the influence of the company on the local community.	Stewardship

Value chain actors	27. Number of CE educative workshops for suppliers	# of workshops	The metric shows the commitment of the company to promote CE initiatives within their supply chain and make the supply chain more responsible (Luthin et al., 2023).	Collaboration
	28. Number of CE-related meetings with stakeholders	# of meetings	According to (Droege et al., 2021), the metric demonstrates the stakeholder engagement that cross-cutting the issue of lower rates of involvement in the CE transition.	Collaboration
	29. Number of patents related to innovative technologies applied in CE	# of patents	The metric demonstrates the level of the company's respect for intellectual property rights (Moraga et al., 2019).	Innovation
Consumer	30. Existing marketing practices for greenwashing	# of public accidents of greenwashing	According to (Opferkuch et al., 2022), reporting the progress of the CE transition remains a responsibility of the companies that can stimulate greenwashing through the availability to select only indicators that are useful for the company.	Transparency
	31. Labels used to promote transparency for consumers	Yes/No	Transparency is key to creating trust between customers and producers. Thus, according to (Luthin et al., 2023), transparency was found important in the literature review.	Transparency
Society	32. Number of CE innovation meetings/workshops/ brainstormings for innovation development	# of innovation meetings/ workshops/ brainstormings	Innovation is one of the principles of the CE, therefore it is important to indicate to which extent the company is facilitating the acceleration of CE ideas (Droege et al., 2021).	Innovation

8.2 Appendix 2. CE strategies applicable to industrial organizations (Alejandrino et al., 2022)

Approach	Circular Strategy	References				
		Kalmykova et al. (2018)	European Commission (2020)	BSI (2017)	Lopes de Sousa Jabbour et al. (2019)	Acerbi and Taisch (2020)
Business model	1 Customization	•	•	•	•	•
	2 Collaborative consumption	•	•	•	•	
	3 Product-service systems	•	•	•	•	•
	4 Dematerialization	•	•	•	•	
	5 Regenerate				•	
Design	6 For disassembly	•	•	•	•	•
	7 For modularity	•	•	•	•	
	8 For durability		•	•	•	
	9 For flexibility				•	
	10 Eco-design	•	•	•	•	•
	11 For reduction	•	•	•		
	12 For recycling			•	•	•
Material sourcing	13 Low impact materials	•	•		•	
	14 Renewable materials	•	•	•	•	
	15 Recycled materials		•	•	•	
	16 Bio-based materials	•	•	•		
	17 Non-harmful substances	•	•	•		
Manufacturing	18 Energy efficiency	•	•	•	•	•
	19 Material efficiency	•	•		•	•

	20 Tracking and mapping of resource		•		•	
	21 Industrial symbiosis	•	•		•	•
Distribution and sale	22 Efficient packaging	•	•			
	23 Product labeling	•	•	•		
	24 Digital information		•			
	25 Efficient surplus management			•		
Consumption and use	26 Resource and energy efficiency		•	•		•
	27 Re-use	•	•	•	•	•
	28 Repurpose			•	•	
	29 Upgrading	•	•	•	•	
	30 Maintenance	•	•	•	•	
	31 Repair	•	•	•	•	•
Reverse logistics	32 Incentivized return	•		•	•	
	33 Infrastructure	•	•	•	•	•
	34 Separate collection	•	•		•	
End of life valorization	35 Refurbishment	•	•	•		•
	36 Remanufacture	•	•	•	•	•
	37 Recycling	•	•	•	•	•
	38 Energy recovery	•		•	•	
	39 Composting	•	•	•		
	40 Extraction of biochemicals	•				

8.3 Appendix 3. The definition and purpose of 40 CE strategies are based on (Acerbi & Taisch, 2020; Alejandrino et al., 2021; Kalmykova et al., 2018; Lopes de Sousa Jabbour et al., 2019; BSI, 2017, European Commission, 2020).

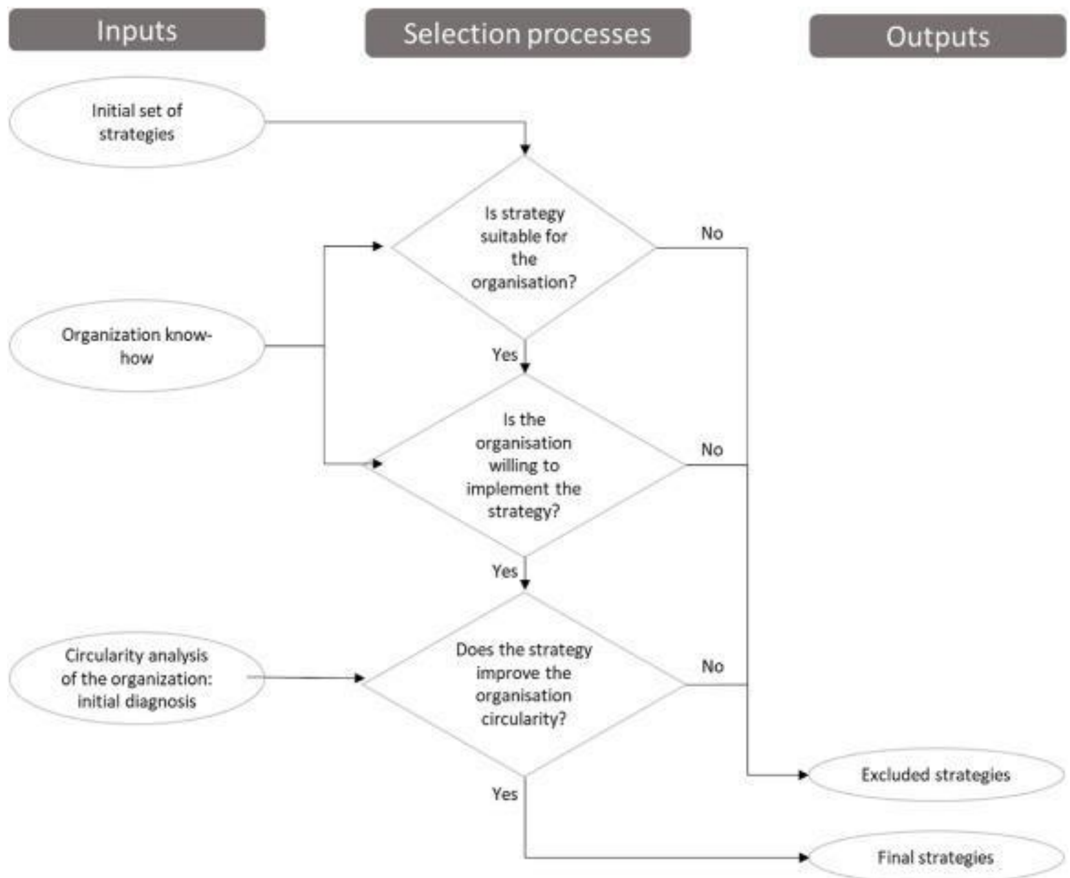
Approach	Circularity Strategy	Purpose (CE principal)	Description
Business model	1 Customization	Value optimization	The strategy strives to meet the needs and preferences of the customer through the individualization of the product. The strategy contributes to circularity through product life extension, reduction of waste, and prevention of overproduction. The key feature the strategy is based on is customer loyalty.
	2 Collaborative consumption	Collaboration	The strategy aims to involve the community in sharing the resources and providing guidance on how to extend the product's life.
	3 Product-service systems	Collaboration	The strategy aims to provide the product as a service, that helps to extend the life of the product as the producer provides design, usage, maintenance, repair, and recycling throughout the lifetime of the product.
	4 Dematerialization	Stewardship	Conversion of the products into the digital/virtual solution, which requires a lot of customization.
	5 Regenerate	Stewardship	The use of renewable materials, including biodegradable materials, and renewable energy. As well as activities aiming for the restoration or protection of ecosystems.
Design	6 For disassembly	Value optimization	The strategy seeks to create a product that can be disassembled to be repaired, refurbished, or recycled.
	7 For modularity	Value optimization	The product consists of modules for an easier upgrade with the newer features as well as easier to repair.
	8 For durability	Value optimization	The product is designed in a way that it lasts for a maximum potential lifetime.
	9 For flexibility	Stewardship	The flexibility in the production to deal with the uncertainty of supply. As well as adaptability to the different qualities of the material.

	10 Eco-design	Stewardship	The strategy aims to limit negative environmental impacts throughout the whole lifecycle of the product.
	11 For reduction	Stewardship	The strategy aims to reduce the use of the material and eliminate the use of harmful substances.
	12 For recycling	Value optimization	The products should be designed in a way that they can be recycled.
Material sourcing	13 Low impact materials	Stewardship	The choice of materials based on their lifecycle performance
	14 Renewable materials	Stewardship	The strategy aims for resilient production to price fluctuations and resource scarcity through the replacement of the materials for more abundant/renewable.
	15 Recycled materials	Stewardship	The preference/replacement of virgin materials with recycled alternatives.
	16 Bio-based materials	Stewardship	To use bio-based materials, that can easily be regenerated, to replace plastics, etc, and contribute to the longer life of the product.
	17 Non-harmful substances	Stewardship	Replacement of hazardous substances with non-harmful materials.
Manufacturing	18 Energy efficiency	Stewardship	The strategy aims to reduce the consumption of energy but keep the required services.
	19 Material efficiency	Stewardship	The strategy aims to improve sustainability by reducing and preventing industrial waste and increasing recyclability and reusability.
	20 Tracking and mapping of resources	Stewardship Value optimization	The strategy aims to reduce losses in the upstream and downstream cycle, to reduce the losses and reuse the materials.
	21 Industrial symbiosis	Collaboration	The strategy aims to facilitate the exchange and/or sharing of resources and services through an increase in relationships between companies

Distribution and sale	22 Efficient packaging	Innovation Stewardship	The strategy aims to design the packaging, that follows the regulations and makes the most of the materials' end-of-life.
	23 Product labeling	Transparency	The strategy aims to provide consumers with comprehensive information about the ingredients, raw materials' origin, and other relevant details, enabling them to make informed decisions. Unlike eco-labeling, this approach doesn't indicate any environmental or other preference for specific products.
	24 Digital information	Transparency	The strategy aims to provide comprehensive information about the product in the digital form to be more transparent with their stakeholders.
	25 Efficient surplus management	Stewardship Transparency	The strategy aims to increase the efficiency of the collection and redeployment of used or surplus items, which can also improve the transparency of returned items.
Consumption and use	26 Resource and energy efficiency	Stewardship	Material productivity refers to the economic value generated per unit of material input or consumption at the company level.
	27 Re-use	Value optimization	By allowing products or their components to be used second-hand, direct secondary re-use extends the product's lifespan, leading to a reduced need for producing more items that serve the same purpose.
	28 Repurpose	Value optimization	The aim of the strategy is to reuse the product for another function. For example, make a bag from jeans.
	29 Upgrading	Value optimization	The strategy's purpose is to provide the possibility for an upgrade of the product, therefore prolonging its use.
	30 Maintenance	Value optimization	Maintenance is the most efficient way to ensure that equipment performs at its desired level and that after-sales service is essential for businesses to gain a competitive advantage and pursue new opportunities.
	31 Repair	Value optimization	The strategy aims to prolong the life of the product through maintenance which requires repairing

Reverse logistics	32 Incentivized return	Value optimization	A technique to incentivize regular and repeated recycling of recyclable materials, such as providing a refundable deposit.
	33 Infrastructure	Innovation	The objective is to establish facilities that enable cost-effective, time-saving, and environmentally safe post-consumer collection and disposal. The aim is to develop solutions that optimize the collection process.
	34 Separate collection	Stewardship Value optimization	The strategy aims for the prevent mixing of biological constituents and technical nutrients, to increase the possibility of remanufacturing for technical and restoration or degradation of biological
End of life valorization	35 Refurbishment	Value optimization	The aim of the strategy is to facilitate the refurbishment of a product by substituting malfunctioning parts with reusable ones.
	36 Remanufacture	Value optimization	Strategy increases the durability of the product by remanufacturing the defective components
	37 Recycling	Value optimization	The strategy aims to recover pure-form materials for use as secondary raw materials.
	38 Energy recovery	Value optimization	The strategy aims to convert waste materials into usable energy through different methods for example combustion.
	39 Composting	Stewardship	The restoration process involves the breakdown of biological nutrients by microorganisms and other species, followed by their return to the soil.
	40 Extraction of biochemicals	Stewardship	The process of converting biomass into valuable chemical products that take up less space while producing heat, power, fuel, or chemicals is known as biomass conversion.

8.4 Appendix 4. Decision tree for selecting CE strategies proposed by (Alejandrino et al., 2022)



8.5 Appendix 5. The equations for the life cycle cost analysis by (Alejandrino et al., 2022)

Life cycle cost can be defined as the overall annual expenses (TAC) (eq. (1), under the organizational framework, and payback period (PB) (eq. (2)), which indicates the duration required to regain the original investment. These two measures are established based on net annual savings (NAS) (eq. (3)), representing the organization's net annual savings after discounting the initial investment. Therefore TAC and PB help to assess whether different scenarios can decrease the organization's expenses and whether the initial investment can be recuperated (Alejandrino et al., 2022).

$$TAC_k = I_k \left[\frac{r(1+r)^n}{(1+r)^n - 1} \right] + OMC_k \; [\$/\text{year}] \qquad \text{(eq. 1)}$$

$$Payback_k = \frac{I_k}{NAS_k} \; [\text{years}] \qquad \text{(eq. 2)}$$

$$NAS_k = TAC_0 - TAC_k \; [\$/\text{year}] \qquad \text{(eq. 3)}$$

“where k is the scenario under analysis, Ik is the investment cost in the base year, r is the discount rate, n is the lifetime of the equipment/facility, and OMCk is the annual operating and maintenance costs” (Alejandrino et al., 2022, p.4).

8.6 Appendix 6. CE indicator for baseline scenario (SC0) and percentage of improvement in the alternative scenario (SC1) excluding CE indicator 22 (CE investments).

The green cells indicate the improvements in the CE indicator, and the red cells indicate the deterioration of the CE indicator.

CE Indicator	Unit	SC0 (Not bio)	SC1 (Bio)	Comment
1	number (#) of strategies	5	20.0%	Appendixes 2 and 3 were used to identify the strategies used in the production of SC0 and SC1. SC0 - strategies 5, 11, 14, 23, 39; SC1 - strategies 5, 12, 14, 16, 23, 39.
2	#	0	0.0%	
3	# of products	0	0.0%	
4	# of systems	1	0.0%	Both production sites are covered by the environmental management system ISO 14001.
5	# of collaborations	0	100.0 %	OrganoClick is the external partner that provides the bio-based binder for Bio Dunisoft.
6	# of products	0	100.0 %	Bio alternatives can be recycled as they do not contain any fossil-based materials.
7	# of products	0	0.0%	
8	# of products	0	0.0%	
9	# of initiatives	0	100.0 %	For bio alternatives, the company uses bio-based packaging.
10	# of suppliers	0	0.0%	
11	# of criteria	5	0.0%	The company has the Business Code of Business Conduct, which proposes the criteria that suppliers have to comply with. Additionally, Duni requires suppliers of curtain materials to have a certification, such as FCS.
12	t	9063.73	6.8%	The total material use increased, caused by the increase in the usage of bio-binder and packaging.
12.1 Pulp	t	7129.21	-6.6%	The pulp consumption decreased as Bio Dunisoft napkins needed less pulp for

				production, while Bio Dunicell - was unchanged. (Appendix 7)
12.2 Binder	t	1791.21	60.6%	To produce both bio-based products, the new technology requires the use of more binders. For product specifics, check Appendix 7.
12.3 Packaging	t	143.31	1.5%	Both bio-based products have bio-based packaging instead of plastic films. However, it increases the consumption of materials.
13	t	91.44	63.9%	The production of bio-based products increases water consumption.
14	kWh	12 020 941.07	0.0%	
15	%	0.48	0.1%	The increase in the percentage of renewable energy is caused by reduction in fuel consumption in total energy consumption.
16	kWh	13 251 567.60	-0.2%	As the scenarios consider the fuel consumption for both products, the reduction is low compared to the total consumption. However, Appendix 7 shows that if we look at the Bio Dunicel separately the reduction will be 26.7% compare to Dunicel (see Appendix 7).
17	%	N/A	N/A	In the research, I could not get the data on % of recycled materials used in the production of the products. However, during the interviews, the company mentioned that material (bio alternatives) waste from the conversion goes back to Rexcell and is reused.
18	t	485.96	96.5%	The increase in solid waste is caused due to losses in the production of bio-binders for both products (see Appendix 7)
19	%	N/a	N/a	Duni has the information only for the full organization. Therefore, it is hard to identify the indicator for chosen products.
20	m3	N/a	N/a	Duni has the information only for the full organization. Therefore, it is hard to identify the indicator for chosen products.

21	t CO2eq	10092.26	3.8%	The scope of the GHG emissions was chosen from cradle to gate. Appendix 7 demonstrates that the production of Bio Dunisoft has an increase in emissions while Bio Dunicell has a reduction. However, in this case study Duni sold significantly more m2 of Dunisoft napkins than m2 of Dunicel placements (99.53% and 0.47% respectively).
22	K EUR	N/A	19	For this indicator, the capital expenditures were used to show long-term investments.
23	#	0	0.0%	
24	#	0	0.0%	The number of accidents (specifically injuries) did not increase.
25	(CE training hours)/(hours worked)	0	0.0%	Currently, the company is working on CE e-learning and aims to implement it in 2023.
26	# of jobs created that involve CE activities / # of closed jobs	0	0.0%	According to the interviews with the company, the number of jobs did not change within the company. However, it is unknown how the implementation of the strategy in Duni influenced the job market for suppliers.
27	# of workshops	0	0.0%	
28	# of meetings	0	0.0%	On the company level, there are meetings with the consumers, where the sales department talks about the company's goal “Circular at scale” and specifically narrowing the loop. However, Duni does not hold meetings specifically regarding these 4 products.
29	# of patents	0	0.0%	Duni does not hold any patents for these 4 types of products.
30	# of accidents of greenwashing	0	0.0%	So far there have been no accidents of greenwashing that involved Duni.
31	# of labels	3	0.0%	The FSC certification is present on all products, which serves as confirmation that the forest is being managed in a manner that promotes the preservation of biological diversity and benefits the lives of local individuals and workers, while also maintaining its economic sustainability

				(FSC, n.d.). Also, both Dunisof and Bio Dunisoft have OK COMPOST HOME certification, that the products can be composted at lower temperatures, and hence can go into the compost heap at home (OK Compost, n.d.).
32	# of innovation meetings/ workshops/ brainstormings	0	100.0 %	To come up with an idea for bio-based binders and implementation of it, different departments of Duni held over 150 meetings in 2021.

8.7 Appendix 7. CE indicator for baseline scenario (SC0) and percentage of improvement for alternative scenario (SC1).

The green cells indicate the improvements in the CE indicator, and the red cells indicate the deterioration of the CE indicator.

CE indicator	Unit	Dunisoft	Bio Dunisoft	Dunicel	Bio Dunicel
12. Material consumption	t	8,970.16	6.9%	93.57	6.4%
12.1 Pulp	t	7,085.55	-6.6%	43.66	0.0%
12.2 Binder	t	1,753.13	61.7%	38.09	9.9%
12.3 Packaging	t	131.48	0.0%	11.82	18.6%
13. Water consumption	t	87.66	66.7%	3.78	0.0%
14. Electric energy consumption	kWh	11,862,818.59	0.0%	158122.48	0.0%
15. Renewable electric energy consumption	%	47.0%	0.0%	61.0%	31.1%
16. Fuel consumption	kwh	13,148,444.24	0.0%	103123.36	-26.7%
17. Recycled content of raw material	%	0.0%	0.0%	0.0%	0.0%
18. Solid waste generated	t	482.11	97.0%	3.85	39.3%
19. Recycled solid waste	%	0.00	0.0%	0.00	0.0%
21. Carbon emissions generated	t CO2eq	9,978.21	4.0%	114.05	-12.0%
22. CE Investment	K EUR	N/A	19	N/A	0.0%
31. Labels used to promote transparency for consumers	# of labels	2.00	2.00	1.00	1.00
32. Number of CE innovation meetings/workshops/ brainstormings for innovation development	# of innovation meetings/ workshops	0	116	0	56.00

8.8 Appendix 8. Life cycle impact assessment data for the production of 1 m2 of Dunisoft and Bio Dunisoft material (South Pole, 2022)

Unit process	Dunisoft emissions (gCO_2e)	Bio Dunisoft emissions (gCO_2e)
Raw material input	55.8	59.8
Rexcell Airlaid	55.8	59.8
Raw material input		
Pulp	6.6	6.2
Water	0	0
Binder : - Dunisoft = copolymer EVA dispersion - BioDunisoft = bio-based (Organoclick)	18.9	25.3
Packaging material input	0.2	0.2
Input material transport	3.3	1.3
Converting	26.8	26.8
Electricity, renewable, Sweden	0.8	0.8
LPG	25.9	25.9
Waste	0.1	0.1
Packaging material input	1.7	1.3
- Dunisoft = cardboard and plastic matrix - Bio Dunisoft = cardboard and paper matrix	1.7	1.3
Transport, supplier to factory, including materials	9.3	9.1
Converting	1.5	0.8
Electricity (grid, Germany)	0.7	0.7
Waste	0.8	< 0.1
Total	68.3	71

8.9 Appendix 9. Life cycle impact assessment data for the production of 1 m2 of Dunicel and Bio Duniel material (South Pole, 2022)

Unit process	Dunicel emissions (gCO_2e)	Bio Dunicel emissions (gCO_2e)
Raw material input	110.6	102.8
Rexcell tissue	26.6	26.6
Raw material input		
Pulp	8.7	8.7
Water	0	0
Packaging material input	0.2	0.2
Input material transport	1.3	1.3
Converting		
Electricity (Sweden, renewable)	0.7	0.7
LPG	15.2	15.2
Heat from boiler	0.5	0.5
Waste	0.1	0.1
Dunicel binder	96.9	76.2
Raw material input	42.5	16.3
Input material transport	2.2	1.5
Converting	52.2	58.4
Electricity (Germany, grid)	36.6	40.5
Natural gas	14.6	15.2
Waste	1	2.7
Packaging material input	25.3	17.9
Dunicel = cardboard/plastic matrix Bio Dunicel = cardboard/paper matrix	25.3	17.9
Input material transport	12.1	11.7

Converting	17.9	13.6
Electricity	15.8	13.4
Waste	2.2	0.2
Total	165.9	146