Integrating Circular Economy Indicators with Value Stream Mapping

A case study of PET bottle production and recycling.

Master's thesis in the Master's Program Industrial Ecology

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Gothenburg, Sweden 2022
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Abstract

There is an increasing push for the plastic industry to become more sustainable. The concept of Circular Economy has gained a lot of attention and could improve the industry's sustainability performance. Due to the current lack of tools to measure circularity, the industry has a hard time measuring CE performance. The thesis focuses on the integration between Circular Economy Indicators and Value Stream Mapping to provide a tool to measure and improve industries' material circularity performance. Circular Economy indicators measure Circular Economy performance, and Value Stream Mapping maps the value-adding activities in a supply-chain. The integration has the potential to map value-adding activities and measure the Circular Economy performance of a process. The integration was tested on a case study with a global leader in the plastic packaging industry. The theoretical section presents current Circular Economy Indicators and integration methods. The case study was designed to test the integration on an industrial case, but due to problems regarding data gathering, the calculations could not be performed. The results are that there is a problem with defining the concept of Circular Economy and the integration has not been studied enough to be applicable in industry. Future research should contribute to a clear definition of Circular Economy, simple indicators and an integration method that is applicable with data availability in industry and is in line with the Value Stream Mapping ISO standard.

Keywords: Circularity; Sustainability; Lean; Production; Micro level.

Acknowledgments

We want to express our gratitude to our understanding and supportive supervisor Clarissa Gonzáles Chaves who always made time for us, and Jeff Mangers who provided us with invaluable technical guidance. We also want to thank our examiner, Mélanie Despeisse, which helped us form and guide the thesis. We want to thank the Jean-Christoph from Plastipak who helped us greatly and took time out of his tightly scheduled day to meet and discuss with us. Finally, we want to say that everybody who helped us met us with a welcoming and supportive attitude and a positive mindset, which encouraged us to keep working despite unforeseen hinders along the way.

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Abbreviations

CE	Circular Economy
CI	Circularity Index
C-VSM	Circularity - Value Stream Mapping
EoL	End of Life
EU	European Union
LCA	Life Cycle Assessment
LFI	Linear Flow Index
MCI	Material Circularity Indicator
MRS	Material Reutilization Score
OECD	Organization for Economic Co-operation and Development
PET	Polyethylene Terephthalate
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
R-PET	Recycled Polyethylene Terephthalate
RR	Recycling Rate
VSM	Value Stream Mapping

1. Introduction

This chapter first describes the background of the study and the need for further research in the field. The aim and objectives of the study are then presented, followed by two research questions. Thereafter, the scope and limitations present the boundaries of the study, and lastly, the outline of the report is presented.

1.1 Background

Today's economic system has been described as a "take – make – waste" or a linear economy. This means that the raw material is harvested from the source, the material is used to create the desired product, and eventually when the product has served its purpose it is thrown away, either to a landfill or an incinerator. This model is very efficient when it comes to the production of common household goods at an affordable price. However, it does not consider that the resources available are limited and that there are externalities to the manufacturing process that are not dealt with (Ellen Mac Arthur Foundation, 2013). Examples of these externalities are the growing plastic waste barges floating around the world's oceans, global warming, biodiversity loss, emissions of hazardous chemicals, and the unsustainable use of finite raw materials, to name a few (EMF, 2013). These problems have negative impacts on Earth's ecosystems, on which humans rely for the production of necessary services, such as nutrient cycling, production of oxygen, and raw material (Kremen, 2005).

A lot of advances have been made during the last decades to stop this trend of environmental degradation. Increased material and energy efficiency reduces the number of resources needed for the same activities as before (Peck & Chipman, 2007). Recycling schemes have been implemented to try collect the valuable materials that were otherwise incinerated or sent to a landfill (Kaza et al., 2018). Companies and manufacturers are providing customers with alternatives that are more environmentally friendly compared to conventional products. Aside from the technical developments, there has been a strong movement within society and among politicians to counteract environmental degradation. Laws have been implemented to ban hazardous materials, taxes levied on polluting activities, and incentives given for activities that are seen as environmentally friendly (Peck & Chipman, 2007). These activities are all a vital step in solving the environmental crisis, but they do not tackle the underlying problem of a linear economy, that products are designed, produced, and used with the intention of being discarded at the end of their lifetime (EMF, 2013).

Circular economy (CE) is an economic model or a system that aims at solving the fundamental problem with the current economic system i.e., the linear use of materials, and the abundant amounts of waste that it produces. The ideal future for a circular economy is an economic system that produces no waste, only value (EMF, 2013). This is an ambitious goal and to get there, one step at a time must be taken, instead of trying to get there in one large leap, to be able to understand what reaching a circular economy requires. An important step is to measure the circularity of the system as it is today, to acknowledge the current standpoint, and to see what can be easily improved (Hedlund et al., 2020).

As data collection and management techniques implemented, they are deployed in an increasing number of applications to measure and track various types of processes, and increasingly in production and manufacturing facilities (Majeed et al., 2021; Tseng et al., 2021). This newly available information can be utilized to make the production and lifecycle of all products more circular, if the information can be used in the right way to measure what is important (Tseng et al., 2021). Thus, CE indicators are being developed to make it possible to measure the circularity of a product or a process and make use of the increasing amount of data that is available to researchers and developers.

CE has become an important concept in the European Union's (EU) Green Deal (Siddi, 2020), which emphasizes sustainable production design where products can be easily repaired, reused, and recycled. The focus of the European Commission is to use the power of the single market to help companies, consumers, and institutions to transition to a more sustainable, circular economy. To reach this goal, the European Commission is going to implement new legislation and incentives, and support innovation and research, in the field of circular economy (European Commission, 2020).

Plastics are a great example of a material that utilizes all the great possibilities of a linear economy, with a simple, fast, and cheap production. But unfortunately, they also represent the negative sides, with easily replaceable products, and single-use products that are disposed of immediately after use. But due to the crucial role that plastics play today, in everything from car production to specialized medical equipment (Andrady & Neal, 2009), they will not be replaced anytime in the near future, so its use and production has to become more circular.

As previously mentioned, there is a lot of focus on increasing the circularity of the economic system, where the industrial system plays a large role (EMF, 2013; European Commission, 2020). The integration of CE indicators with Value Stream Mapping (VSM) has been proposed as a method that utilizes current practices within most industries to measure circularity (Hernandez Marquina et al., 2021; Mangers et al., 2021). Currently, there is a lack of tools for industries to apply their existing knowledge to measuring the circularity of their products to enable more sustainable decision making (Hedlund et al., 2020).

This thesis will look at what CE indicators are, which CE indicators exist, and how they can be integrated with VSM in the production industry to improve circularity. Further, a case study will be performed on a Polyethylene terephthalate (PET) bottle production system in Luxembourg to validate the CE indicators and their integration with VSM.

1.2 Aim and Objectives

The aim of the study is to support companies in the plastic packaging sector in measuring the circularity of their products by integrating CE indicators with VSM. The proposed integration is tested on a case study of a PET bottle system based in Luxembourg.

The objective of the study is three-fold:

1. Establish the current knowledge level of measuring circularity using CE indicators by reviewing the existing literature.
2. Identify CE indicators which can be integrated into a VSM based on the data available at a company.
3. Analyze the feasibility of the proposed integration of CE indicators and VSM for the plastic packaging sector through a case study of a PET bottle production system in Luxembourg.

1.3 Research Questions

To reach the aim, two research questions are formulated.

The research questions that are answered in the thesis are the following:

1. Which existing CE indicators can be used to measure the circularity of a product?
2. How could CE indicators be integrated to VSM to measure product circularity?

1.4 Scope and Limitations

The study is limited by a defined timeframe of 20 weeks which has influenced the aim of the study. The concept of CE is of value for the study, therefore, the concept will be defined. The influences of different definitions and approaches of the circular economy concept are discussed. Nevertheless, the report does not analyze differences in definitions and the impact of the lacking holistic approach. To be able to contribute to a better definition of the CE concept, only existing indicators that can be used to measure CE performance are investigated in the study and no additional indicators are proposed. The CE indicators are limited to measure circularity. Therefore, no further investigation is made into the social, environmental, or economic aspects respectively. However, the relationship between the dimensions is discussed for an improved CE performance towards sustainable development.

Moreover, the scope of the study is to analyze the potential of using CE indicators integrated with a VSM, which is an already established tool in industry, to allow for an easier and faster procedure of measuring circularity of products. Due to the time limits five existing indicators are chosen to be integrated with VSM by a set of criteria developed based on the literature review and analysis. Therefore, indicators that are excluded in this study are not evaluated for application for an integration with VSM. The potential of integrating the five chosen CE indicators is investigated and evaluated through a case study based on a company within the plastic packaging sector. The data needed for the calculations of the indicators are limited to the data available at the company and assumptions based on expertise within the company, in order to ensure product specific measurements.

1.5 Outline of the Report

The thesis is structured in seven chapters, see Table 1 for an overview of the outline.

Table 1. Outline of the reports structure.

Chapter	Description
1. Introduction	Gives an insight of the environmental problems regarding a linear economy and introduce the CE concept. Presents the opportunities of measuring circularity performance by applying CE indicators as the background of the study. Furthermore, the aim, objectives, and research questions of the study are defined. Lastly the scope and limitations, as well as the structure of the report is presented.
2. Theoretical Background	Explains technical core concepts that are of value for the thesis, such as CE, sustainable development, CE indicators as well as the basic theory of VSM is explained.
3. Methodology	The methods applied during the thesis are presented and explained. The method applied to be able to perform a two-stage literature reviews and how the results were handled is presented. The data collection procedure and the interview method used during the data collection process is explained. Thereafter it is presented how the CE indicators were combined with the VSM and how the results from the integration were managed is explained.
4. Literature Review	Presents the result of the literature review, including existing CE indicators, characteristics, hinders and barriers of CE indicators as well as the chosen CE indicators for the case study in this project.
5. Case Study	Presents the results of the case study, based on the evaluation of the CE indicators.
6. Discussion	Presents the overall analysis and discussion of the two research questions and objectives of the study. The conducted literature review and existing indicator identified in literature as well as the criteria set for choosing indicators is discussed. Moreover, the integration of the five chosen indicators, and the potential to support the plastic packaging sector is discussed.
7. Conclusion and future research	This section presents the conclusion about the possibilities of supporting the plastic packaging sector by measuring the CE performance of the supply chain for a product and integrate CE indicators with VSM. Additionally, recommendations for future research are presented.

2. Theoretical Background

The theoretical background explains technical core concepts that are of value for this thesis. First the two closely related concepts of circular economy and sustainable development are explained i.e., what they mean, where they come from and how they are applied. The basic theory of value stream mapping and indicators is explained as well.

2.1 Circular Economy

The concept of circular economy has been gaining a lot of traction in recent years. This is evident when looking at the number of large-scale global actors who have started to embrace this concept and make it a part of their values and strategies. Among those present in the EU, that defines its Circular Economy Action Plan (European Commission, 2020), the Coca Cola company had its CEO state that circular economy will create value for each bottle they sell (Quincey, 2019), BlackRock which is the world's largest investor has created a circular economy public equity fund (EMF, n.d.), and Renault, the French automotive manufacturer, is developing a circular economy factory for vehicles, which is the first of its kind in Europe (EMF, n.d.). Despite this popularity, the concept is not well defined and until recently, it was scarcely known by industry and academy.

2.1.1 Definition of Circular Economy

There have been numerous studies that have reviewed and categorized the literature about CE as a concept. The most notable result that all the different studies agree upon is that there is no single definition of CE that has reached widespread acceptance (Kirchherr et al., 2017; Korhonen et al., 2018; Murray et al., 2017). The authors found that the CE concept had a lot of different definitions and interpretations. A lacking definition could result in a loss of traction in implementation and the possibility exists that CE will become more of a "theoretical dream" (Kirchherr et al., 2017) rather than becoming a well-defined and applicable concept. A document that has been very influential when it comes to CE, is a report by the Ellen MacArthur Foundation (EMF) published in 2013, which is believed to have kickstarted the CE wave that is seen today (Kirchherr et al., 2017; Korhonen et al., 2018; Murray et al., 2017)

According to the EMF, (2013), a problem with the current economy is that the buyer becomes the product owner at the point of sale. The manufacturing firms benefit from this linear economic system, with mass production of cheap products where the ownership is moved from producer to user at the point of sale, which frees the producer from taking care of the product when it has reached the end of its lifetime. This means that the user has the liability on how to treat the product at the end of its lifecycle, if it should be reused, recycled, or dumped (EMF, 2013). Furthermore, according to the EU's Waste Framework Directive, waste is "…any substance or object which the holder discards or intends or is required to discard" (Municipal Waste Europe, n.d.). This makes the user responsible for deciding when the product does not fulfill its value anymore and in what way it is disposed.

The CE is based on the three principles: design out waste and pollution; keep products and materials in use; and regenerate natural systems, see Figure 1. The three principles of Circular Economy developed by the Ellen McArthur Foundation (*The Circular Economy In Detail*, n.d.) (*The Circular Economy In Detail*, n.d.). A CE ensures reprocessing of products and materials to reduce waste, emissions, and energy use as well as maximize value at every stage in a product's life cycle. It maintains the physical stocks of goods to handle resource security and greenhouse gas reduction and regeneration of natural systems. The business models of the circular economy could be divided into two groups, one that engages to extend lifespan through reuse, repair, remanufacture, upgrades and retrofits; and the other that focuses on recycling materials from scrap and old goods into as-new resources (EMF, 2013).

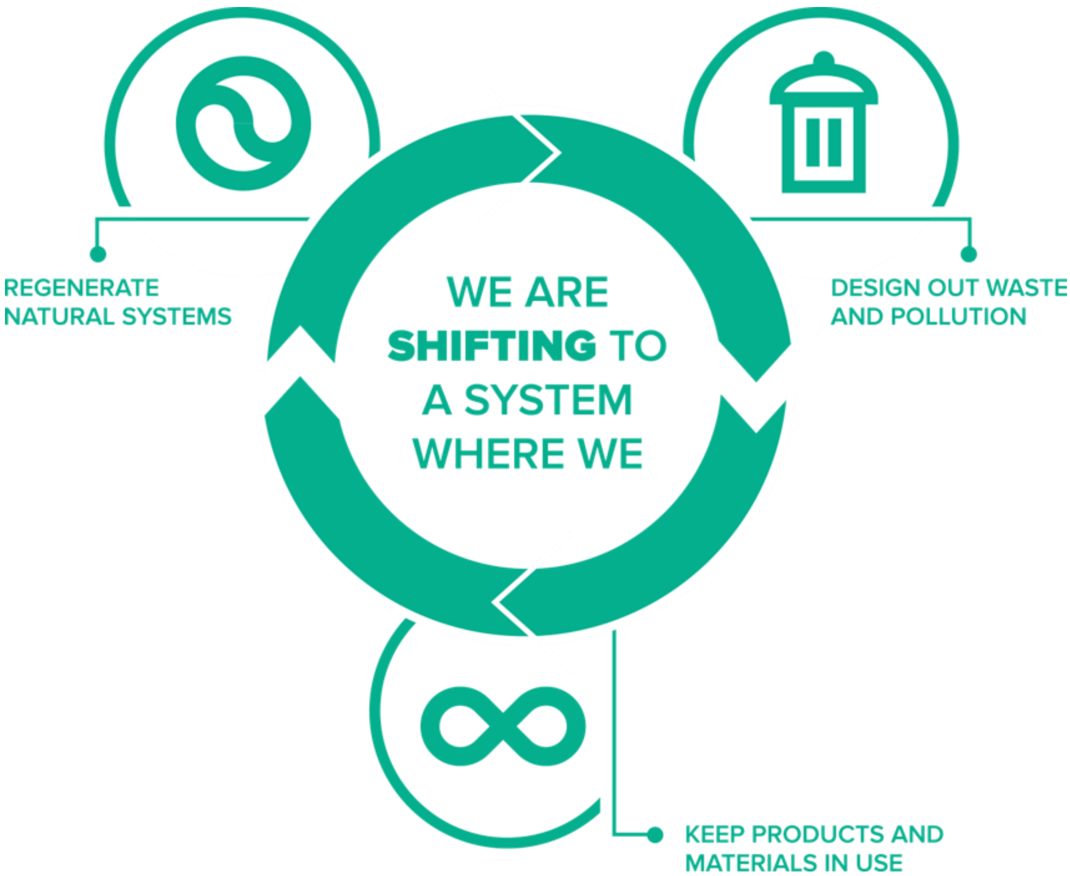

*Figure 1. The three principles of Circular Economy developed by the Ellen McArthur Foundation (*The Circular Economy In Detail, *n.d.)*

The EMF has created a diagram that has become well known within the field of CE, called the "Butterfly Diagram" (EMF, 2013), which can be seen in Figure 2. This diagram explains how the circular economy if correctly implemented can contribute to reducing waste and pollution, increase the circulation of materials and products, and regenerate nature. In other words, it illustrates how materials could theoretically continuously flow through the economy. The diagram, as well as the circular economy, can be divided into two separate cycles, the biological and the technical cycle. The technical cycle, which is represented on the right side of the diagram, shows how different 'end-of-life' (EoL) management techniques keeps products and material in continuous circulation. On the left side, the biological cycle is presented and how through anaerobic digestion and similar processes biodegradable materials are returned to earth's natural cycles (EMF, 2019b).

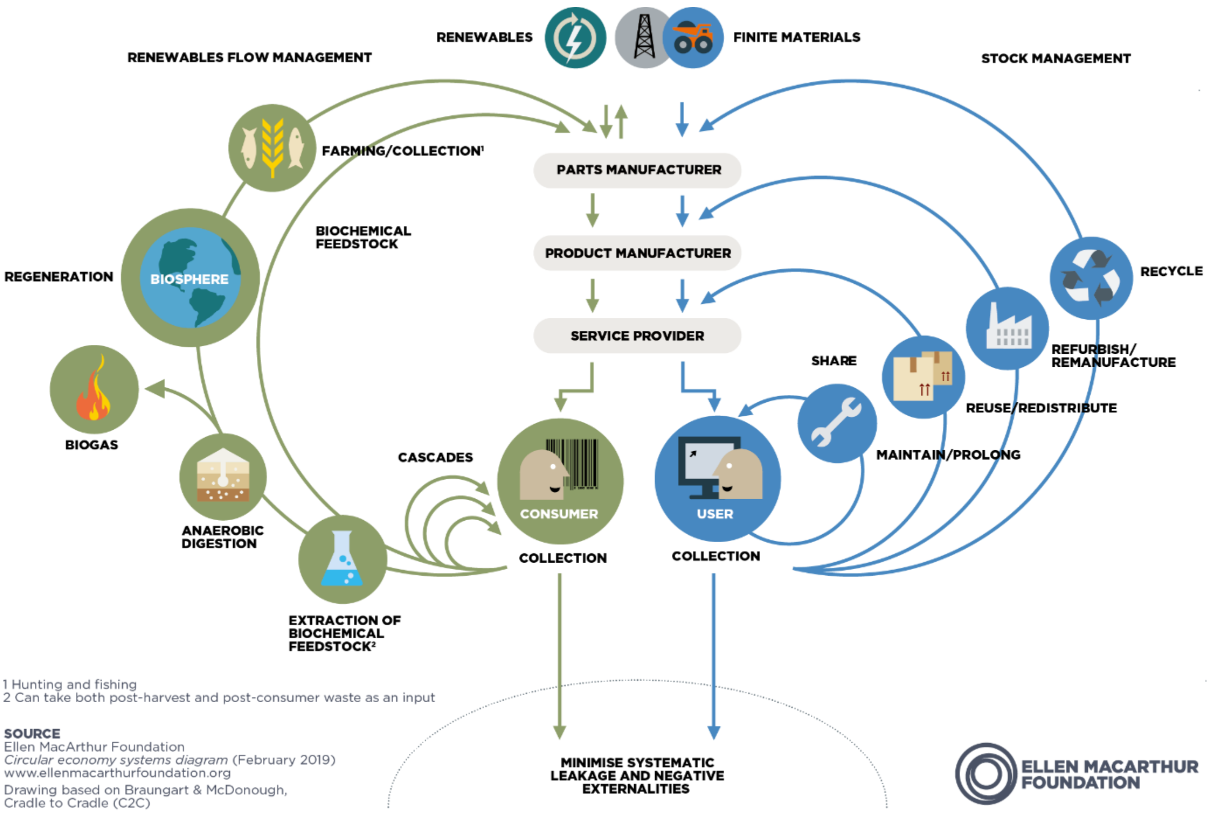

Figure 2. The Butterfly Diagram (EMF, 2019b).

The concept of CE has been defined in multiple ways and has f.e. been described to be concerned with closing the flow, decreasing the flow, and restricting the flow of resources within a cycle of a product (Baumer-Cardoso et al., 2021) to achieve maximum utility (Cong et al., 2019). As a cost-efficient tool in product development to maintain the value of products as long as possible by designing out waste (Mesa et al., 2018). A way to rebuild the traditional model of economic development to maximize social, environmental, and economic benefits, based on material cycles and flows of energy CE is creating a win-win strategy to achieve sustainable development (Yin et al., 2007). The CE aims to reverse patterns of unsustainable development by maximizing the functions of ecosystems and social welfare for every economic activity (Calzolari et al., 2022). The idea of a circular economy is to understand the supply chain, be able to identify its biggest environmental impacts, and ensure less dependence on critical virgin material. The concept promotes mitigating business risks such as price fluctuations, political instability, and damaged reputations, and making better use of the resources so they are constantly kept within the economy (Benton, 2014). So, when summarizing the literature, there are a lot of different definitions and interpretations of the concept, creating a lack of consensus of the definition. There is however a guiding light that the different definitions focus on, which is a more sustainable future economic system.

Recently one definition has been growing in popularity, which was formulated by Kirchherr et al., (2017). The popularity can be seen in the number of academic citations that the article has and the number of articles on the topic that acknowledge that they use this definition in their articles (Corona et al., 2019; Roos Lindgreen et al., 2021; Syu et al., 2022). Kirchherr et al., (2017) based their definition on 114 different definitions of the concept that they found in their literature review. A list was created of the most frequently named CE dimension found in the different definitions included in their review, to base their own definition in. They concluded that, based on the existing definitions, the following dimensions should be included in a definition of CE: the R-framework, the R hierarchy, a systems perspective, environmental quality, economic prosperity, and social equity (Kirchherr et al., 2017). The definition that they came up with and will be the definition used in this article is the following:

”A circular economy describes an economic system that is based on business models which replace the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro-level (products, companies, consumers), meso level (eco-industrial parks) and macro-level (city, region, nation and beyond), with the aim 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).

Finally, it is worth mentioning that work is underway to standardize what CE is, to be able to create a framework around the topic and developed tools for implementation with industry to maximize its contribution to a sustainable development, (International Standardization Organisation , 2018).

As Syu et al., (2022) mention in their paper, the definition of circularity can vary, which is why in this article when referring to circularity, the first section of the definition formulated by Kirchherr et al., (2017), is used as a basis for the definition “… business models which replace the EoL concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes… “. In general, circularity can be defined as the level of material circulation, this is supported by the definition of Kirchherr et al., (2017) which is based on the R-framework and the R hierarchy. Boyer et al., (2021) describe that circularity can be divided into three broad dimensions, similar to (Kirchherr et al., 2017) who further define nine strategies within these three dimensions. The three basic dimensions according to Boyer et al., (2021) are material recirculation, utilization, and endurance. The 9R framework, which is the most extensive R framework looks at strategies that can be applied to slow, narrow, and close material cycles and can be seen in Figure 3. The 9R framework which describes the hierarchy of EoL actions (Kirchherr et al., 2017). The 9R framework provides principles that can be used as a guide to develop both practices and policies so the circularity of companies and products can be improved (Syu et al., 2022).

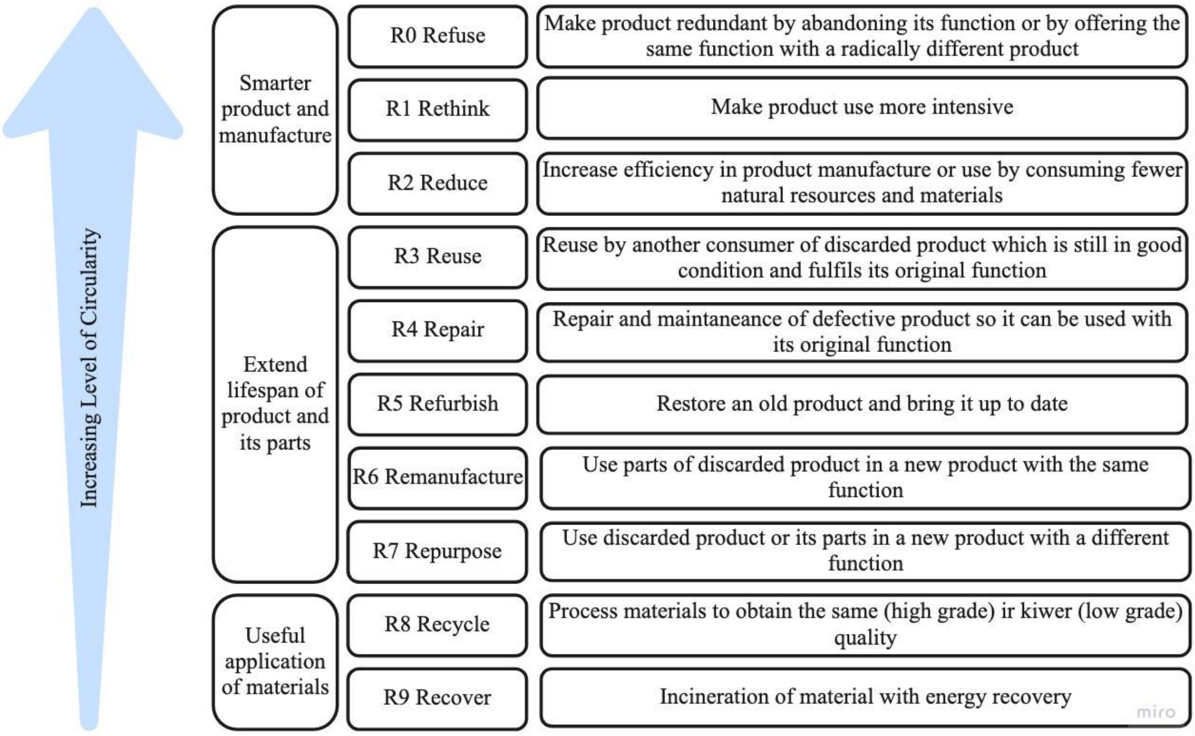

Figure 3. The 9R framework which describes the hierarchy of EoL actions (Kirchherr et al., 2017).

2.1.2 History of Circular Economy

In an article by Murray et al., (2017), it was found that the first time a concept similar to CE was described in 1848, where a theoretically perfect chemical factory was described as a factory that produces no waste and in turn increases its profits. So, the idea of a CE is not as recent as one might have thought. The modern definition has been developing and evolving throughout the second half of the 20th century, one of the earliest definitions similar to a modern one can be found in, The Economics of the Coming Spaceship Earth, from 1966 (Murray et al., 2017). Boulding. Kenneth E., (1966) describes what he calls the "Spaceship Economy" as, "…man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy" (pp. 7-8).

Murray et al., (2017) discuss how the origin of the CE definition has been debated in recent years, with most sources pointing at Japanese and German "loop closing" systems as the inspiration for the concept. Despite the unclear origin of the concept and who was the first author to coin the term, either being an uncited Chinese article from the 1980's or it being used in western literature around the same time. The idea evolved from "closed loop" economies or other similar terms and the topic began to be discussed by researchers and academics in the late 20th century.

The concept of CE has successfully been applied in small scales. Already in 1960s, the Kalundborg Symbiosis in Denmark was started to develop (Clift & Druckman, 2016) on circular economy principles (Stahel, 2016). In 2008 was the first time the principles of CE were implemented into a national policy, which was the Circular Economy Promotion Law in China that also is the first country releasing indicators focused on CE (Harris et al., 2021). According to Vuţă et al., (2018) has China implemented the CE concept into their political strategy of the government, working with assessment methods such as Life Cycle Assessment (LCA), carbon foot-print and eco-efficiency to measure the performance of CE.

CE as it is thought of today, was championed by the Ellen MacArthur foundation, with their report “The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context”, released in 2013. The report has gained a lot of attention for its pioneering work and the Ellen MacArthur foundation is seen as a key actor for developing and pushing the concept forward (Kirchherr et al., 2017; Murray et al., 2017).

2.2 Sustainable Development

Sustainable development plays a large role in the CE definition of Kirchherr et al. (2017), and the concept is widely recognized. The concept was defined in a now-historic report that was published in 1987, called Our Common future (United Nations, 1987), which has become famous under the name “the Brundtland Report” named after the chairwoman Gro Harlem Brundtland. The definition put forward in the report is, “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations, 1987).

Sustainable development originally emerged as a compromise between two social movements. The environmental movement, focused on the maintenance of ecosystems and limited natural resources so that future generations could also be able to provide for themselves and the development movement, focused on eliminating poverty among those living today. Ever since the definition put forward in the Brundtland report, these two movements have been constantly debating how to interpret what sustainable development is. With the environmental movement focusing on their view, which is to preserve earths ecosystems while the development movement has been more focused on economic development and human needs (Hedenus et al., 2018).

Sustainable development is made up of the three dimensions, also known as the triple bottom line, that all work together. These three dimensions are the ecological, the economical, and the social. Sustainable development aims to reach a balance among these three dimensions by aiming to improve the quality of life of people without exceeding the earth’s carrying capacity (Flint, 2013; Hedenus et al., 2018). This means that an action or a policy cannot be called sustainable if the total constraints to all three pillars are higher than the total benefits (Flint, 2013). In other words, if an action improves the environmental pillar significantly, but at the cost of the economy and the society which is higher than the improvement to the environment, the action is not sustainable.

The ecological dimension has to do with making sure that natural systems can continue to provide humans with what they need from nature, this can be divided into two sections, the environment’s production, and assimilative capacity. The environment’s production capacity is the environment’s ability to provide natural resources, such as cropland, fisheries, water, and forests, as well as ecosystem services such as pollination and nutrient circulation and recreational, spiritual, and social value. The assimilative capacity refers to the earth’s ability to take care of environmental impacts and pollutants. Such as absorbing greenhouse gas emissions and breaking down dangerous chemicals. If it were not for these services provided for by nature, the society and the economy within that society could not function (Hedenus et al., 2018).

The economic dimension refers to managing resources that are required to meet the needs of humans. This dimension can also be divided into two, finite natural resources and man-made capital. Finite natural resources are resources such as fossil fuels, metals, and phosphorus, as they are not renewed by the ecological systems. The role of sustainable development is to manage these resources, so they fulfill the needs of current generations but still allow future generations to meet their own needs. Manmade capital is value created by humans so that produce goods and services can be produced, this does not only include physical infrastructure but also knowledge and human capital. Economic growth is often seen as a means to an end to reach economic sustainability, although it can sometimes be an important tool, especially in developing countries, growth in and on of itself should not be the goal of economic sustainability (Hedenus et al., 2018).

The social dimension is the most debated dimension and at the same time the dimension that has been studied the least by academics. The social dimension, similar to the other two can be divided into two horizons, the vertical and horizontal. Horizontal relations are networks between people and organizations, also known as social capital. A community life that is rich and has multiple places for people to meet increases trust among people. Communities that have a high level of trust usually also have better economic growth, democracies that function better and have fewer problems with corruption and crime. The vertical horizon is the formal institutions in a society, that have a structure of hierarchy and rules to abide by such as legal and social insurance systems. These formal institutions are required to have efficiency when working, impartiality and low corruption (Hedenus et al., 2018).

2.3 Circular Economy Indicators

Indicators are information that provides a wider meaning other than their immediate result. They are alternative measures that are used to measure information on complex systems to interpret and identify a status of a concern when it cannot be directly measured. Indicators synthesize masses of data, identify the present position in relation to states of desire, demonstrate progress towards targets, and are used to communicate relevant information (Lundin, 2003). However, Saidani et al., (2019) states that there is no single widespread definition of what an indicator is, so in their article, they used The Organization for Economic Co-operation and Developments (OECD's) definition of an indicator; "Quantitative or qualitative factor or variable that provides a simple, and reliable, means to measure achievement, to reflect the changes connected to an intervention, or to help assess the performance of a development actor" (OECD, 2014, pp. 13).

The definition presented by OECD, (2014) will be used in this article as well. Furthermore, Saidani et al., (2019) found that despite there being different definitions for the terms "measures", "metrics", "index", and "indices", they found the terms were quite freely used and most academics used them interchangeably as a synonym for an indicator. Indicators have the ability to entail complex information into simple and meaningful knowledge by focusing, condensing, and summarizing a dynamic environment (Saidani et al., 2019).

An ideal indicator or index is designed to simplify a large quantity of data. However, the simplification will result in loss of information, but a properly designed indicator or index minimizes the information loss. Furthermore, to create a credible and long-term robust indicator the methodology is important to simplify the identification of appropriate characteristics of indicators to geographical application and effective participation in the development of indicators (Mitchell et al., 1995). Finally, the general rule of indicators is a comparison of a reference value (Kristensen & Mosgaard, 2020).

According to Singh et al., (2009) indicators have an ability to summarize complex systems to an amount of information that is manageable and meaningful. They are useful on multiple occasions, e.g., when creating quantitative targets and tracking their progress (Saidani et al., 2019), and they can also be an important tool to support policy- and decision making (Waas et al., 2014).

According to Kravchenko et al., (2019) sustainability indicators can be divided into leading and lagging indicators. Lagging indicators can be described as reactive indicators since they measure the impact of actions that a company or a government has already undertaken. The use case for lagging indicators is past performance assessments for measuring impacts of an activity. These kinds of indicators are often applied to environmental analysis such as LCAs and corporate reporting such as Global Reporting Initiative (Epstein & Roy, 2001). As opposed to lagging indicators, leading indicators are often called proactive as they are applied when looking at proposed activities and actions. This is helpful for companies who are interested in looking at what impacts their proposed activities will have and give them the possibility to modify their action before implementation (Pojasek, 2009).

2.4 Value Stream Mapping

Value Stream Mapping (VSM) is based on the Lean manufacturing philosophy. The lean tool is a process-based method (Lee et al., 2021) that is used to visualize current states of material and information flows of an organization (Mangers et al., 2021). An example of the outline of a VSM is presented in Figure 4. Lean is aimed at improving the productivity performance through eliminating waste flows and increasing value of the supply chain (Hernandez Marquina et al., 2021). According to Gupta & Jain, (2013), the goal of Lean philosophy is to reach "Highest quality at the lowest cost in the least amount of time by eliminating waste". The Lean philosophy was developed in Japan's post World War two society by Toyota, which at the time did not afford the expensive production lines like those that were being built in the US (Pavnaskar et al., 2003). The goal of Toyota was a production system that would produce in a continuous flow and not have to rely on long production runs in order to be efficient (Melton, 2005). The Lean philosophy has become both well-known and widely used in the global manufacturing industries after it was introduced to western manufacturing firms in the 1990s when a book called "The Machine that Changed the World" was released.

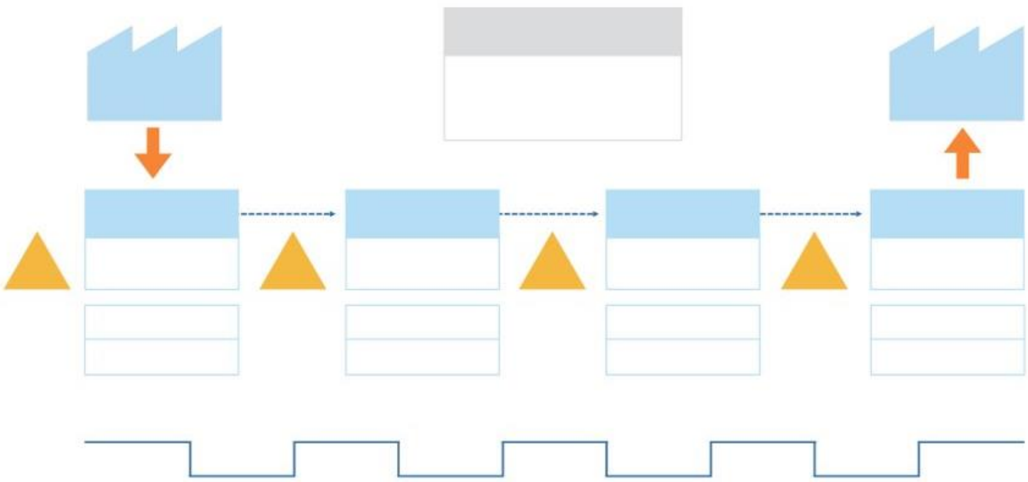

*Figure 4. Outline of a Value Stream Mapping (*Value Stream Mapping Template - Plutora, *n.d.).*

VSM is one of several tools that are based on Lean philosophy and has become world-famous as a graphical tool to scrutinize workflow and locate both non–value and value-adding activities that contribute to the final output (Gupta & Jain, 2013). According to Pavnaskar et al., (2003), the definition of VSM is "A graphical tool used to map the as-is situation of the organization, to identify opportunities for waste elimination, and to decide the improvements to be implemented to eliminate the waste" (p. 3085). This means that it maps both materials and information flows on a single map instead of two separate. This, according to Gupta & Jain, (2013), is one of the main reasons why VSM has become so popular in the manufacturing and process industries. However, the growing popularity of VSM from both academic and practices, resulted in a large variety of methods to apply VSM (Mangers et al., 2020). Therefore, the VSM method was standardized within ISO 22468 to avoid misunderstanding and conflicts within the supply networks caused by the variety (Mangers et al., 2021). Nevertheless, VSM is more than just a tool to create a visual image of the current state, it is also a three-step improvement method. The first step is the mapping of the current state, also known as the as-is state, then a visualization of the desired state is mapped and the final step in the VSM procedure is to create a plan on how to reach the visualized desired (Hedlund et al., 2020).

Minimizing and eliminating waste and emissions throughout the value of the supply chain by the lean philosophy has been receiving increasing scientific attention due to the growing focus on the perspective of sustainable development. There has been a significant attention to VSM, which is one of the most common lean tools (Mangers et al., 2021), due the effectiveness and compatibility (Lee et al., 2021). The VSM applies a bigger perspective of a product, by not only including individual processes or optimization of a certain part, but by following the value stream across firms and facilities (Rother & Shook, 1996). Environmental and social aspects are not explicitly taken into account in a conventional VSM (Hedlund et al., 2020), but the VSM has been developed and modified in various types to assess environmental impacts and wellbeing, such as 'Green VSM', 'Energy VSM', 'Environmental VSM' and 'Sustainable VSM'. Studies on sustainability oriented VSM point out improvement opportunities which could be implemented related to improving sustainability performances, such as societal support and reduced environmental impacts. However, the research on lean tools focused on sustainability is progressing at a slow rate, this is due to a lack of knowledge and elaboration in integrating and systematizing the lean tool (Lee et al., 2021). The latest addition to the array of sustainability uses of VSM is the use of VSM to measure circular economy, as described by Hedlund et al., (2020).

3. Methodology

In this chapter the methods applied in the study are presented and explained. The methodological section is divided into two sections, the literature review method, and the case study. The interaction between the two phases is visualized in Figure 5. A two-stage literature reviews was conducted to reach the aim of the theoretical section of the paper. First the method applied to the literature reviews is presented, second how the results from the literature reviews were handled. The data collection procedure is explained to provide transparency as well as the interview method used during the data collection process. Then the method on how the CE indicators were combined with the VSM and how the results from the integration were managed described.

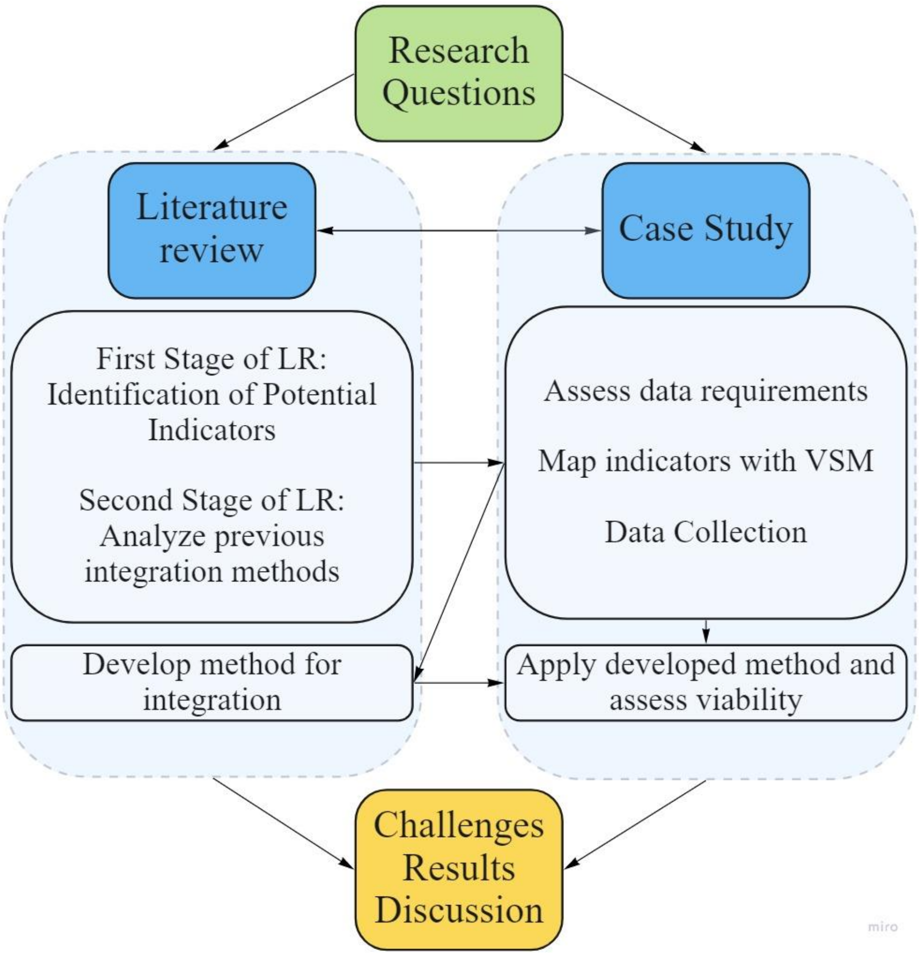

Figure 5. A visualization of methodology and work process.

3.1 Literature Review

A two-stage literature review was performed to reach the desired outcome of the theoretical section of the paper. When performing a literature review it is important to choose the right method to reach the goal of the literature review. To achieve the goal of the literature reviews a method called semi-systematic literature review was applied. A semi-systematic review can be used to gather articles in a structured way but allows for collection of articles using other methods as well. The researchers do not have to assess all articles that fit the selection criteria, it gives freedom to choose articles that are the most relevant (Snyder, 2019). According to Snyder, (2019) this is helpful when the field under study has been approached by multiple disciplines and some of the articles available are not relevant for the study, despite fitting the initial scope of the review. Moreover, a method called "The backwards snowballing method" was applied to support the literature review. The backwards snowballing method is an iterative method for selecting relevant articles to include in a literature review. The method can replace a structured literature search to identify papers to include in a literature review, in this case it was used to support the initial literature search (Wohlin, 2014). The snowballing process is described in Figure 6.

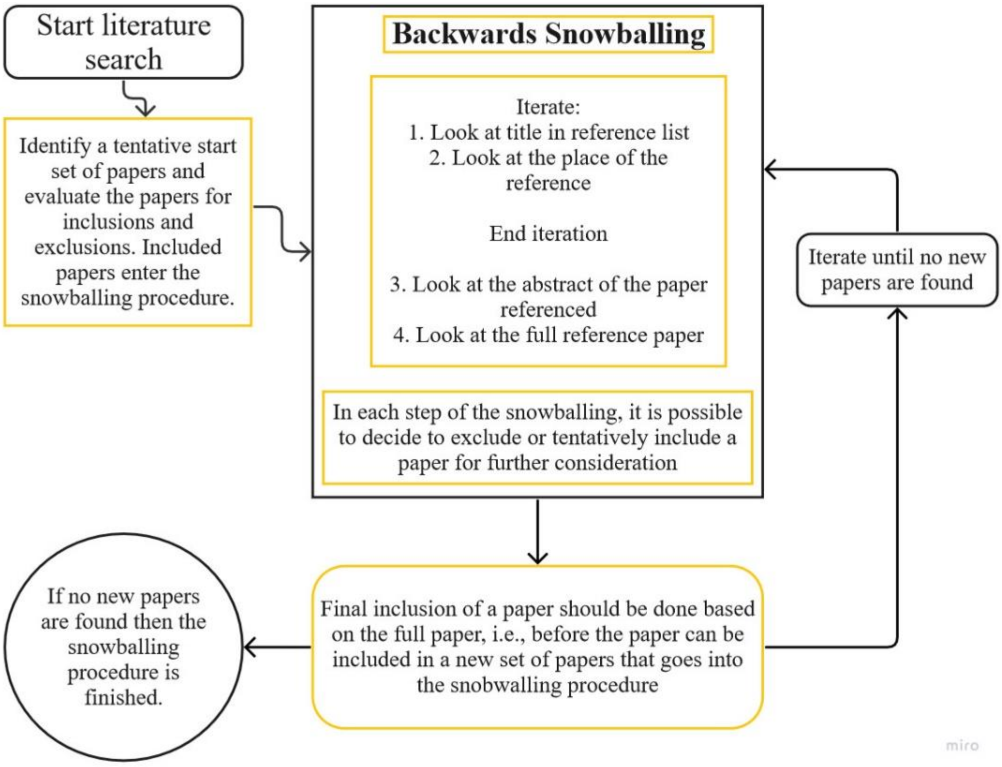

Figure 6. Schematic representation of the backwards snowballing method (Wohlin, 2014).

When performing the literature review, the six-step general procedure presented by Templier & Paré, (2015) was used. The first step, formulating the problem, is to identify the need, purpose, concepts, and research question of the review. The second step, searching the literature, is when the literature is searched for in relevant databases. The third step, screening for inclusion, involves screening the search results for primary studies based on relevance. The fourth step, assessing quality, evaluates studies for eligibility and quality. The fifth step, extracting data, involves gathering what is most important in the selected articles. The sixth and final step, analyzing and synthesizing data, covers the summarizing and discussion of the results.

The first stage of the literature reviewed only focused on CE indicators, this was done to be able to understand how circularity was measured and to identify indicators that could be used to measure circularity and be integrated with a VSM. The second stage focused on the existing literature regarding the integration of CE indicators with VSM and previous integration methods, this was done to get a clear image of where the research is today and how other scholars have approached this method of integration. The goal of the first stage of the literature review was to answer the first research question;

Which existing CE indicators can be used to measure the circularity of a product?

The goal of the second stage was to partially answer the second research question, which will be fully answered when the indicators selected have been integrated with a VSM;

How could CE indicators be integrated to VSM to measure product circularity?

3.1.1 Selection of articles

The first step in the selection of articles was keyword selection and database search. The keywords focused on the concepts of circular economy and indicators, for the first stage and on the integration of CE indicators with VSM for the second stage of the literature review. The keyword searches were performed using the Scopus literature database, which is the largest research content indexer in the world (Lee et al., 2021). The structure of the first stage was meant to capture articles that contain information about the state-of-the-art CE indicators and the second stage was supposed to capture literature that had integrated the CE indicators with VSM. The search queries are presented in Table 2.

Table 2. Search query for the circular economy indicator literature review.

Search	**Keywords**	**Language**	**Publication year**	**Database**
CEI	*(TITLE-ABS-KEY ({circular economy} AND ("indicator*" OR "circularity indicator*" OR "c-indicator*")) AND TITLE-ABS-KEY ("measure*") AND TITLE-ABS-KEY ("sustainab*"))*	English	All publication years	Scopus
CEI and VSM	*(TITLE-ABS-KEY ({circular economy}) AND TITLE ABS-KEY ("value stream map*" OR "VSM" OR "lean") AND TITLE-ABS-KEY (("indicator*" OR "circularity indicator*" OR "c-indicator*" OR "KPI" OR "Key performance indicator*")))*	English	All publication years	Scopus

By using “*” the terms can be either plural or singular and the results can be a variation of the search term (Lee et al., 2021). The searches were performed on the 28 of February 2022.

To manage the results from the literature searches, the information was saved in a data spreadsheet application, to structure the results, provide traceability, and keep track of sources. The information was structured in the according way: Authors, Title, Publication year, Source title, DOI, web link, abstract, and author keywords.

3.1.2 Screening of articles

The second step of the literature review was the screening of articles, where the key words, abstract, and title were analyzed to remove irrelevant articles. Both researchers were active in the selection of all articles, working cooperatively, this was done to reduce the amount of bias each author might have against the article being reviewed as well as to make the selection of articles consequential. No automation tools were used in the screening of the articles. The criteria for exclusion and the motivation for the criteria, for the first stage of the literature review can be found in Table 3. During the second stage of the literature search the search query resulted in very few articles, so it was decided to include all the articles from the result in the eligibility section to make sure that no important information was missed out on.

Table 3. Criteria for exclusion and motivation for screening of articles for the first stage of the literature review.

Criteria for exclusion for screening	Motivation
Articles that did not focus on CE indicators	To remove the articles that were not related to the research topic
Were specific to another field of operation	Articles that focused on specific manufacturing processes, e.g., CE of finger prosthesis
Were based in another field of research	Articles that focused on another field of research, e.g., the circularity of regions or tourism
Focused on the macro and meso level of circularity	To remove articles that were not related to CE indicators on micro level to measure product circularity

To ensure the transparency of the decision making, additions were made to the original data spreadsheet. The information was structured in the according way: Order of who performed the screening, brief description, and decision to include for eligibility.

3.1.3 Eligibility of articles

When the selected articles were analyzed for eligibility, for the first stage, the same criteria that were applied in the screening were still relevant, since the abstract, title and keywords are not fully representable of the article. To improve the eligibility selection two criteria were added to enhance the selection. For the second stage, two criteria for exclusion were selected. The criteria for exclusion and the motivation for the criteria for both the first and second stage of the literature review can be seen in Table 4.

Table 4. Criteria for exclusion for eligibility of articles.

Search	Criteria for exclusion for eligibility	Motivation
CEI	Articles that did not focus on CE indicators	To remove the articles that were not related to the research topic
	Were specific to another field of operation	Articles that focused on specific manufacturing processes, e.g., CE of finger prosthesis
	Were based in another field of research	Articles that focused on another field of research, e.g., the circularity of regions or tourism
	Focused on the macro and meso level of circularity	To remove articles that were not related to CE indicators on micro level to measure product circularity
	Relevance of the indicators presented	Indicators presented that did not measure material circularity
	Were deemed to be of bad quality	To maintain a high level of quality, articles that had poor grammar and structure were removed
CEI and VSM	Did not discuss the integration of VSM and CE indicators	To remove the articles that were not related to the research topic
	Were deemed to be of bad quality	To maintain a high level of quality articles that had poor grammar and structure were removed

The steps and decisions were reported as Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagrams, which can be seen in Figure 7 for the first stage of the literature review and in Figure 8 for the second stage of the literature review. Similar to before, further additions were made to the data spreadsheets to track the decision-making process. The categories that were defined for the first stage of the literature review and the reason for choosing those are presented in table Table 5. Categorization of information from the first stage of the literature review

Table 5. Categorization of information from the first stage of the literature review

Category	Reason
General about CE indicators	To gather the most recent theoretical background about the indicators
One category for each dimension of CE	To gather information about different approaches to each dimension
A category for each application level, micro, meso and macro	To gather information on how the different levels are measured and defined
Indicators presented in the article	To collect and manage the indicators presented in the articles in a structured way

The categories selected for the second stage of the literature review and the reason for choosing them are presented in table Table 6. Categorization of information from the second stage of the literature review

Table 6. Categorization of information from the second stage of the literature review

Category	Reason
CE and Lean	To be able to gather insights into how CE could be represented in the lean philosophy to identify similarities
Hinder and Barriers	To capture the problems with integrating the two methods
Circular VSM	To capture information regarding the use of VSM to measure circularity and identify earlier integration methods
A category for each application level, micro, meso and macro	To gather information on how the different levels are measured and defined with regards to VSM and CE

3.1.4 Synthesis of literature results

To be able to synthesize the information in a structured way a categorization method was applied. The findings from both stages of the literature reviews were summarized according to the categories mentioned before.

After the initial collection of indicators, from the first stage of the literature review, a meta-analysis was performed to be able to manage the indicators in an efficient and structured way. A meta-analysis is a statistical tool to summarize literature review results where multiple studies have been included in the review. The combination of a literature review and a meta-analysis is useful to combine results across multiple studies to gain an overarching understanding of its results and when the results of the study require a quantitative summary (Davis et al., 2014; Pigott & Polanin, 2020). The indicators were identified by who had cited them, to create an overview of how common they were. To simplify the results, only indicators that had been cited twice or more were included in the meta-analysis. Each indicator was labeled based on which system-level the article had identified the indicator. The scope of the study is mainly focused on micro-level indicators, hence macro and meso indicators are excluded. However, to not lose valuable indicators, were indicators with undefined system levels also included. Furthermore, if two articles could identify the same indicator on different levels, then both were included in the analysis.

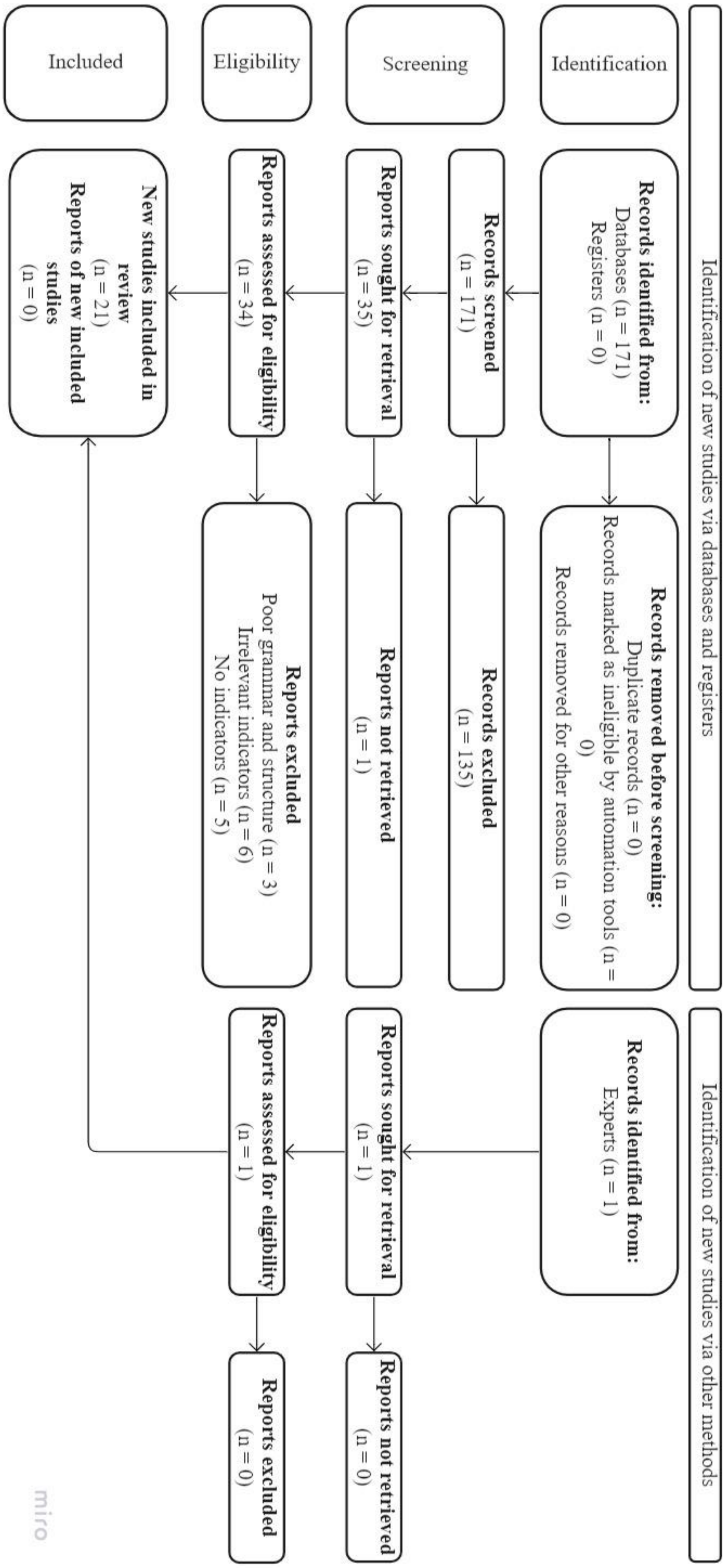

Figure 7. Description of the PRISMA procedure for the first stage of the literature review.

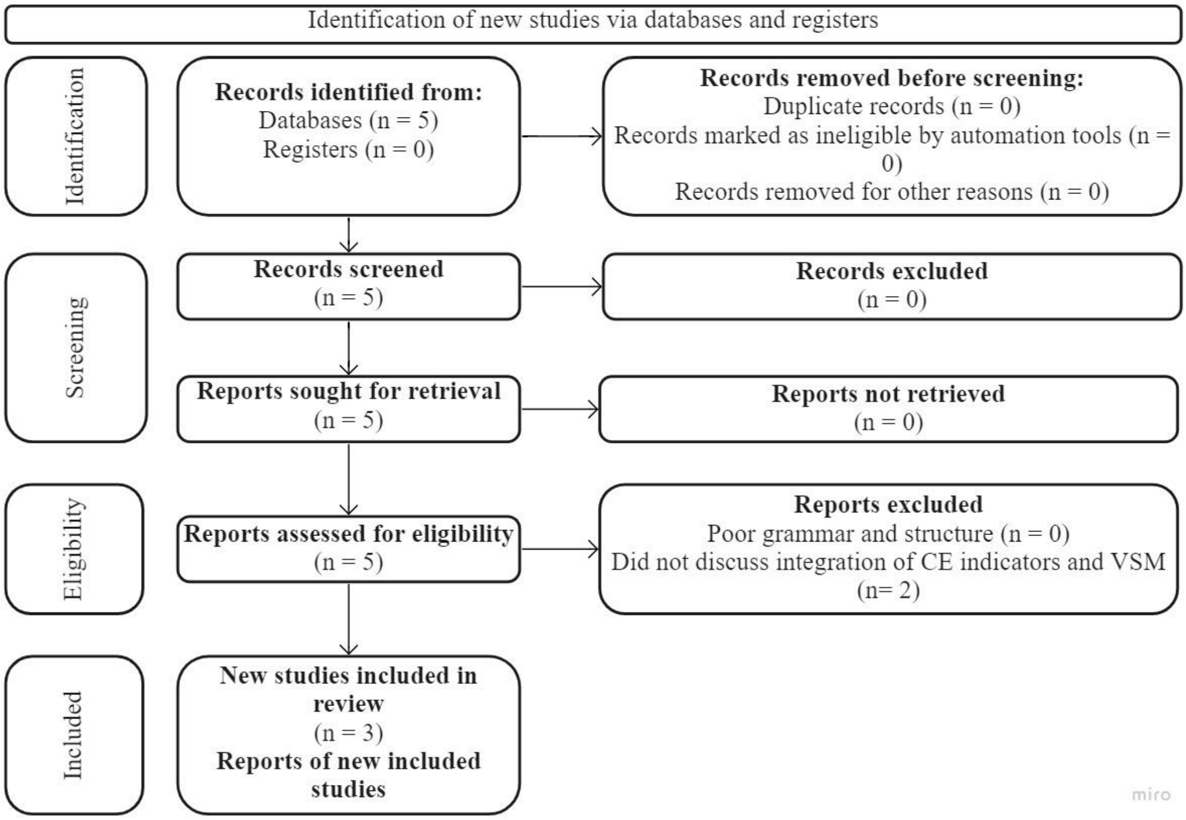

Figure 8. Description of the PRISMA procedure for the second stage of the literature review.

3.2 Case Study

The case study was performed in collaboration with Plastipak, which is a global leader in the plastic packaging and recycling industry. Plastipak has been active in the packaging industry for more than half a century. It has a global presence, being located on more than 50 sites on five continents and employs more than 6.000 employees worldwide. The company produces bottle preforms which is a PET container that is being blown into a bottle. Plastipak produce preforms for a variety of industrial and household uses, such as aerosols, soft drinks and water, consumer cleaning, food packaging, industrial and agricultural products, and personal care items. The business unit of the Plastipak involved in the thesis is active in several different product life cycle stages of PET bottles, with a focus on preform production. Plastipak is located in Luxembourg with a substantial market share in the neighboring region. The unit is focused in implementing more sustainable and recycling oriented features in day-to-day plastic products to reduce the amount of environmental impact and increase the circularity of the products. The contact person from the company has a role as a supply chain manager with a focus on sustainability.

The case study was meant to confirm that the indicators selected from the literature review and the method for integration would be feasible in an actual industrial case. The role of the company regarding the initial integration was to provide VSM and the data for the calculation of the indicators as well as the interviews to assess the useability of the method and indicators within industry. The VSM of the study was adapted from Mangers et al., (2021), which was originally done in collaboration with Plastipak as well. The product that was set to be analyzed during the case study was a 0,5L PET bottle preform.

3.2.1 Selecting Circular Economy Indicators

To be able to fully answer the second research question, the indicators found in the literature reviews were analyzed for integrability with VSM. To categorize indicators in a structured way, selection criteria for the indicators were identified. The selection process was divided into two sections and were managed in a data spreadsheet application.

The first selection focused on efficiently selecting indicators of interest, the criteria for exclusion can be found in Table 7. Exclusion criteria for indicators.

Table 7. Exclusion criteria for indicators.

Criteria for excluding indicators	Motivation
No or bad description of the indicator	The applicability of the indicator could not be assessed without an initial description
Duplicates	Indicators that measured similar impacts were removed to reduce redundancy
Material circularity at macro- or meso level	Indicators that were not focused on the mirco level were excluded
Indicators based on LCA	Performing an LCA study is a time-consuming process that requires a lot of additional data gathering
Indicators based on questions and surveys	The indicators should be calculable based on the information available in a VSM
Cited in less than two articles	To make sure that the indicators chosen were established academically

The second selection was based on the Usability and Usefulness criteria presented by Syu et al., (2022), which can be found in Table 8. To get a deeper understanding of each indicator, the backwards snowballing method was applied to identify the original paper where the indicator was presented and other relevant articles which had discussed or applied the indicator.

Table 8. List of usability and usefulness criteria used to assess the micro-level indicators (Syu et al., 2022) *(superscript annotation: [1]usability, [2]usefulness)*

Criteria	Description
Measureability[1,2]	Can be measured or quantified
Ease of use[1]	Without high costs and time-consuming procedures
Ease of understanding[1,2]	No or little prior knowledge required to calculate and use the indicator
Data availability[1]	Data required readily available or prepared easily
Strategic relevance[2]	In accordance with the company's mission
Validity[2]	Correctly represents the system being assessed
Reliability[2]	Gives accurate and consistent values
Transparency[1,2]	Possibility of third-party verification
Generalisability[2]	Interpretation independent of industry and product
Simplicity[1,2]	Low dimensionality, few indicators or single index
Compatibility[1,2]	Standardized, compatible with other methods
Information sharing[1,2]	Non-sensitive information to enable open exchange with stakeholders
Evolvability[1,2]	Possible to update and meet evolving requirements

In the first selection process, based on the criteria in Table 7 the number of indicators was significantly reduced. If an indicator had already been integrated into a VSM, it would be included as well. This was done to make sure that previous work on the topic would not be disregarded which made the process iterative. By applying the backwards snowballing method to identify the origin of the indicator, and the list of criteria presented in Table 8, indicators that were deemed to be integrable with VSM were identified.

3.2.2 Integrating the Circular Economy Indicators with the Value Stream Mapping

The first step of the integration was to identify what information was required for the indicator that was to be integrated with the VSM. When the information required to calculate each of the indicators had been identified, the potential location for where the information could be found in the VSMs was mapped. The mapping was performed by comparing the data required to calculate each of the indicators with the VSMs, based on the information available at each process in the VSM. Locating where the data could be measured was an iterative process. The initial mapping was presented to the company that supplied the VSMs and asked to review and identify where the information could possibly be located in the VSM.

This step was done based on the method developed by Hernandez Marquina et al., (2021) for integrating CE indicators with a VSM. Similar to Hernandez Marquina et al., (2021), a new data field was added to the VSM inventories for the relevant processes. The integration was an exploratory approach to assess the feasibility of integrating the CE indicators selected. The same process was done for each of the indicators selected, and a data field for each of the indicators was added to the relevant VSM process inventory.

3.2.3 Data collection

The data collection phase was designed to capture two types of information, statistical information to be able to calculate the indicators, and insights into what an industrial actor thought of the integration of the two concepts. To be able to collect as much of the required statistical data as possible, the data collection was done in two steps. VSM analysis and information gathering with the help of the company involved in the case study.

The first step was to review the VSMs that were available from the company. A VSM contains a lot of different information based on what is mapped in the as-is state. This step simply meant that the VSMs that were available from the company which the case study was to be done in collaboration with, was compared against what data was required for the indicators. The second step of the data collection was contacting the company to identify what data they had available, this was the most important step of the data collection process. This was performed by sending a data spreadsheet to the company for them to fill out. The data spreadsheet explained each of the indicators, the equation, and variables. The company was then asked to fill in what data they had available, and in what unit. The structure can be seen in Appendix B. If the data was not available in house, they were asked to either make an educated assumption or reach out to collaborators who could potentially supply the required data.

The second phase of the data collection process aimed at gathering insights about what the company thought about the integration and the indicators that had been selected for integration. It was performed through two separate semi structured interviews with a company representative. The structure of the interview was done according to the structure presented by Wholey et al., (2010). According to Wholey et al., (2010), it is preferable to have a high-level manager involved in the semi structured interview process, the company representative is a supply chain manager. Before the first interview, two questions were prepared in advance regarding the indicators, so that the representative could prepare. The questions can be seen in Table 9, this step was recommended by Wholey et al., (2010). These questions were included in the data spreadsheet sent to the company for statistical data gathering.

Table 9. Questions included in the data spreadsheet sent to the plastic producer for data gathering.

Questions for company representative
Do you see this indicator as useful?
Do you see the application of this indicator as generally feasible in the industry?

The first interview was divided into three sections and took one hour. First was an introduction, of all the participants taking part in the interview and the goal of the thesis. The second step was to explain the indicators and the data that was required and present the initial mapping to the representative. The third step was to answer any questions the representative had about the spread sheet and general questions that he had about the project based on the information sent to the company representative beforehand. The interview was done via Teams, a digital meeting platform, where it was filmed and transcribed. Participants were the two authors, the company representative, and two academic experts.

Before the second interview, the representative had filled in the spreadsheet, answered the two questions for each indicator and provided additional comments and questions. This information was reviewed before the interview and answers to the company representative's questions were prepared as well as new questions based on the information provided by the company. The second interview took one hour, and was performed via the Teams platform, where it was filmed and transcribed. The first section of the interview was allocated to reviewing the information presented in the spreadsheet. The second section was focused on posing questions to the representative about the integration, its usefulness and how to develop the method to make it more suitable to fit the requirements of industry in the future. Participants were the two authors, the company representative, and an academic expert.

3.2.4 Managing results from the integration of Circular Economy Indicators with Value Stream Mapping

The mapping of the indicators will be presented as a VSM, where the indicators have been implemented into the relevant processes. The results from the interviews and spreadsheet sent to the company representative are summarized in a table. This is done to be able to get a good overview of the information available at the company, the usefulness of the proposed indicators as well as the proposed integration to be able to estimate the contribution of the method to the industry.

4. Literature Review

In this chapter the literature review findings from both stages of the literature review are presented. This is related to the first objective, to *establish the current knowledge level of measuring circularity using CE indicators by reviewing the existing literature* and the first research question to map *which existing CE indicators can be used to measure the circularity of a product.*

4.1 Existing Circular Economy Indicators

The first stage of the literature review included 21 articles after the selection, screening, and eligibility. Within these 21 articles were 225 indicators identified that measure CE performance, with a focus on material circularity at the micro level. All the CE indicators found in the literature review are presented in a table with the original 21 articles included in the study, year of publishing and system level according to each article, is presented in Appendix A. Out of the initial 225 indicators identified, only 29 were mentioned in more than one article. These 29 CE indicators are mentioned in 16 articles out of the initial 21. The CE indicators that were mentioned more than once are presented in Table 10, where each indicator is presented with respect to which articles it was presented in, as well as the system level of the indicator. The indicators are mainly defined as micro level or undefined. However, some indicators were identified as micro in one article and meso in another, which is why the meso level was included in the table, despite being outside the scope of the study. The reason for only presenting the 29 indicators mentioned more than once was to improve the readability of the results.

Table 10. Existing CE indicators with two or more references based on the literature review.

◉ = Micro, ◉ = Meso, ◉ = Undefined

CE Indicator \ Reference	Syu et al., (2022)	Roos Lindgreen et al., (2021)	Boyer et al., (2021)	Harris et al., (2021)	Baumer-Cardoso et al., (2021)	Mesa et al., (2020)	Rossi et al., (2020)	Kristensen & Mosgaard, (2020)	Corona et al., (2019)	Moraga et al., (2019)	Pauer et al., (2019)	Saidani et al., (2019)	Mesa et al., (2018)	Figge et al., (2018)	Brown & Bajada, (2018)	Saidani et al., (2017)	Available in total articles
Circulytics		Micro			Micro												2
Circularity Calculator							Micro	Micro				Micro					3
Circular Economic Value	Micro								Micro			Meso					3
Circular Economy Index				Micro			Micro	Micro	Undefined	Micro		Micro	Undefined				7
Circular Economy Indicator Prototype				Micro			Micro	Micro	Micro			Micro	Undefined			Micro	7
Circular Economy Toolkit		Micro		Micro			Micro	Micro				Micro	Undefined			Micro	7
Circular Economy (Performance) Indicator						Undefined			Undefined	Micro			Undefined				4
Circularity Index						Undefined	Micro		Undefined			Micro					4
Circular Pathfinder							Micro					Micro					2
Circular Transition Indicators		Micro			Micro												2
Combined Longevity and Circularity indicator							Micro							Undefined			2
ease of Disassembly Metric			Undefined				Micro	Micro		Micro							4
Eco-efficient Value Ratio							Micro	Micro	Undefined	Micro							4
End of Life Recycling Rate						Undefined	Micro			Micro		Micro					4

Table 10. Cont.

CE Indicator \ Reference	Syu et al., (2022)	Roos Lindgreen et al., (2021)	Boyer et al., (2021)	Harris et al., (2021)	Baumer-Cardoso et al., (2021)	Mesa et al., (2020)	Rossi et al., (2020)	Kristensen & Mosgaard, (2020)	Corona et al., (2019)	Moraga et al., (2019)	Pauer et al., (2019)	Saidani et al., (2019)	Mesa et al., (2018)	Figge et al., (2018)	Brown & Bajada, (2018)	Saidani et al., (2017)	Available in total articles
Global Resource Indicator						🟡			🟡	🔵							3
Input-Output Balance Sheet							🔵					🔵					2
Longevity Indicator									🟡	🔵						🔵	3
Material Circularity Indicator	🔵	🔵		🔵	🔵	🟡	🔵	🔵	🔵	🔵		🔵	🟡		🔵	🔵	13
Material Reutilization Score	🔵	🔵					🔵										3
New Product-Level Circularity Metric									🔵	🔵							2
Old Scrap Rate						🟡				🔵							2
Product Level Circularity Metric	🔵					🟡	🔵			🔵		🔵					5
Recycling Indices							🔵	🔵				🔵					3
Recycling Input Rate						🟡				🔵							2
Recycling Rate						🟡	🔵				🟡	🔵					4
Resource Duration Indicator							🔵	🔵				🔵					3
Reuse Potential Indicator				🔵			🔵	🔵	🟡			🔵					5
Sustainable Circular Index					🔵		🔵		🟡	🔵		🔴					5
Value-based Resource Efficiency						🟡		🔵	🟡	🔵		🔵					5

4.2 Characteristics of Circular Economy Indicators

According to Jain et al., (2018) the overall circularity depends on all stages in a supply chain, from extraction of raw material to end-of-life management of products and materials. A circular supply chain contributes to reducing material consumption and waste, as well as a lower carbon footprint (Jain et al., 2018). The recently published article by Calzolari et al., (2022) highlights the gap found in existing indicators for assisting a transition towards a higher degree of circularity on the supply chain level. Most of the existing CE indicators are focused on analyzing the performance at a firm level rather than for an entire supply chain. The explicit measurements of process or material circularity is a gap in the literature, since a clear minority of the indicators are measuring the amount of byproducts and waste being reincorporated into the supply chain (Calzolari et al., 2022).

The current CE indicators in the literature are developed by both academia and by practice (Baumer-Cardoso et al., 2021). Professional practices are represented by large organizations such as EMF and Cradle2Cradle (Kristensen & Mosgaard, 2020). The indicators developed by academia cover more of the CE characteristics and are therefore more complex compared to the indicators developed by professional practices. Additionally, only indicators developed by academia address all three dimensions of sustainability and they have shown being more likely to address a vision for CE (Baumer-Cardoso et al., 2021). Nonetheless, indicators developed both by academia and practice focus more frequently on the economic and environmental impacts and are lacking the consideration of social and circularity measurements (Calzolari et al., 2022).

Kristensen & Mosgaard, (2020) state that "…the main beneficiaries of the Circular Economy appear to be the economic actors that implement the system" (p. 16), which could be an explanation for why most indicators are related to the economic dimension. Indicators related to business are concerned about measuring aspect that can represent economic advantages, such as minimizing input of material and energy, as well as less waste generated (Baumer-Cardoso et al., 2021). A higher degree of material circularity supports organizations with economic benefits such as reducing material costs, greater resilience and greater value extraction of resources, besides the positive environmental and social impacts (Calzolari et al., 2022). Anyhow, as long as raw materials are cheaper than recycled materials, and production of a new product is cheaper than repairing or remanufacturing an old one, there is less incentivizes for shifting from a linear economy towards CE. This is further decelerating the innovation of CE that is needed for a sustainable development (Kristensen & Mosgaard, 2020). On the contrary, the assessment tools for circularity do not necessarily need to combine all three dimensions to one single metric. A composite score of all dimensions may confirm the purpose of interpretation, but the results will involve compromises (Boyer et al., 2021).

CE indicators related to economic aspects are most common, followed by the environmental aspect and social aspect (Kristensen & Mosgaard, 2020). The environmental perspective is not always addressed properly, for example, closed-loop recycling is not always a more environmentally friendly than open-loop recycling (Haupt & Hellweg, 2019). The social dimension of sustainability in CE indicators is underdeveloped, and focuses on job creations, employee involvement and safe working spaces. The three dimensions of sustainability are crucial to include in the assessment of CE indicators, since a solution that increases the material circularity could be environmentally beneficial while not supporting the social dimension (Kristensen & Mosgaard, 2020).

Indicators measuring CE performance developed by both academia and practices, are addresses characteristics of emission reduction, water use, energy use, material use, generated waste, share of renewable resources and keeping value of the product (Baumer-Cardoso et al., 2021). The material recycling is furthermore related as a key factor to the European Waste Framework Directive 2008 introducing the waste hierarchy. Recycling is described as the least sustainable option towards CE which is illustrated as the outer line in the butterfly framework (Kristensen & Mosgaard, 2020), see Figure 2. The recycling rate is a mass-based indicator which, in its own, fails to cover the environmental perspective (Haupt & Hellweg, 2019). Despite that, measurement related to recycling are common in the CE indicators. When moving inwards to narrower cycles, does the number of developed indicators tend to decrease. The reason for more developed indicators for recycling could be argued to stem from the fact that waste management has a longer history and has had time to develop when compared with CE's short history and low maturity (Kristensen & Mosgaard, 2020).

4.3 Hinders and Barriers of Circular Economy Indicators

The ability to measure and report the progress of CE performance is essential to ensure a successful transition towards a CE (Negri et al., 2021). Holistic strategies towards CE are needed to provide policymakers and industry with guidance (Haupt & Hellweg, 2019). However, CE has not yet achieved a large diffusion of implementations because of technological, regulatory, cultural and market barriers. The most reported barriers for the implementation of CE in EU are the cultural characteristics of hesitant culture in companies and lacking interest and awareness of consumers. The manufacturing firms needs to reduce waste and emissions, minimize their resource use, and lower their impact on the environment in general to contribute to a sustainable development. The manufacturing firms are, however, struggling with the adaption of measuring CE performance due to a lack of a holistic, integrated framework to be scalable for both a general perspective and site-specific insights (Negri et al., 2021). The concept of CE tends upon the approach of being difficult to implement (Kristensen & Mosgaard, 2020).

Researchers have recently raised the question on how to measure circularity and how to evaluate the sustainability performance of CE to be different from a linear economy (Saidani et al., 2019). As mentioned earlier, to support the transition towards CE is the ability to measure the progress essential (Kristensen & Mosgaard, 2020), which can be done by monitoring and using evaluation tools such as indicators (Saidani et al., 2019). Indicators play a crucial role in measuring circularity, but currently, only a few studies are assessing CE strategies with indicators which highlight an early stage in the development of the indicators (Kristensen & Mosgaard, 2020). However, likewise the concept of CE, the term indicator does not have an agreed upon definition and is defined in different ways in existing literature (Saidani et al., 2019).

The CE indicators are commonly classified to a level they are applied, on a micro, meso or macro level. The micro level refers the indicator to be applied on products, companies or organizations, an indicator on a meso level is applied on an eco-industrial park and indicators on macro level is related to regions, cities, countries, or the global economy (Corona et al., 2019). According to Harris et al., (2021) there is a lack of indicators that connect the three system levels. Additionally, the levels create confusion and are misleading because the assessment could be applied on a micro-level but is used in a macro-level to support decision making (Corona et al., 2019).

CE indicators give time-effective support to life cycle decisions and is important to improve the integration and knowledge about CE in order to set targets for industries (Saidani et al., 2019). By improving the CE performance, the firms benefit from both environmental preservations and economic growth. Firms are usually constrained by resources, such as time, personnel, and economic resources. Moreover, firms often lacking the support, and appropriate knowledge to reduce social, economic, and environmental impacts and is less prone to invest in and implement changes for transformation. Awareness is fundamental for diffusion of the concept (Negri et al., 2021).

The lack of a holistic approach regarding the concept of CE and its assessment tools is causing difficulties for implementation, however, it is also creating a space for interpreting a favorable application for companies (Boyer et al., 2021). An in-depth investigation of the completeness, classification and applicability of CE indicators is lacking from the industry and political point of view (Saidani et al., 2019). If a company is interested in working towards CE they can choose to define and measure the performance to support with good results and show progress towards reaching CE at the company. There are multiple assessment tools of reporting and improving CE performance today, and the array is growing (Boyer et al., 2021). The growing number of micro-level indicators shows the effort from academia and professional practices to minimize this research gap (Baumer-Cardoso et al., 2021). Nonetheless, some firms believe that they have to develop their own (Boyer et al., 2021). This could be explained by the barrier of application of the indicators developed by academia into the actual business (Baumer-Cardoso et al., 2021). On the other hand, the lack of a holistic approach could generate an opportunity for companies to use information in a subjective way as a sort of "circular [green]washing" for marketing purposes (Harris et al., 2021). Therefore, the lack of a holistic approach is causing a risk of losing the power of the concept to contribute to a transparent and methodical approach towards a sustainable development. There is a need for a shared conceptual reference point to avoid major contradictions and to have a similar contribution outcome (Boyer et al., 2021).

The high diversity of existing indicators measuring CE performance could be an indication of the wide range of interested parties, including environmental studies, business and economics, engineering, machinery, and metallurgy. This broadness of interested parties could be a factor causing a hinder of implementation since the parties may have slightly different intentions of the concept. Moreover, the relationship between CE and sustainability could be discussed in three different ways in the current academic literature. These three approaches are i) "CE as a condition for sustainability", ii) "a beneficial relationship between CE and sustainability" and iii) "a compensatory relationship between CE and sustainability". Apart from the relation approach, several of the existing definitions of CE do not cover all three dimensions of sustainability (Kristensen & Mosgaard, 2020). According to Kirchherr et al., (2017) when analyzing 114 definitions of CE only 13% of the definitions considered all three dimensions.

There are many existing indicators measuring re-circulation of materials or value within a system as an approximation of environmental impact. Decisions made on these measurements risk to be used as a basis for decision making when trying to increase circularity performance, but which not necessarily be equivalent with an improved environmental performance (Harris et al., 2021). On the one hand, a "grand matric" that covers all pathways to CE is often observed to be complex and/or require expert judgement about the lifespan and uses in the future (Boyer et al., 2021). On the other hand, indicators that produce easy and quick results often fail in including the complexity of CE and are therefore not providing proper guidance (Harris et al., 2021). There is a need for a standardized way to measure CE, but simultaneously, there is a need for more specific indicators. General indicators may lose complexity of certain product type, and specific indicators related to one product type may not suit another product type (Kristensen & Mosgaard, 2020).

4.4 Relation between Circular Economy Indicators and Value Stream Mapping

The research on refined VSM tools already start in 2008, focusing on the economic and environmental perspective of sustainability (Lee et al., 2021). The usage expansion has been developed to focus on product development and environmental impact, such as energy consumption and waste management (Hedlund et al., 2020). Furthermore, integration of mixed approaches has been conducted to identify parameters of value to support tools such as life cycle analysis, total cost analysis, and energy consumption analysis. Several published studies have proven the effectiveness of VSM to determine the environmental impacts of production processes and to improve sustainability performance (Lee et al., 2021), such as reduced waste and material consumption, as well as increasing efficiency of production. Moreover, VSM is a well-known method in the industry (Hedlund et al., 2020).

The concept of CE promotes a circular use of resources to reduce pollutions and waste by redesign products and services for longevity, as well as regenerate natural systems (Hernandez Marquina et al., 2021; Mangers et al., 2021). In other words, CE is aiming for reducing the use of raw material by using existing materials more efficiently in a closed loop. Lean tools, on the other hand, aim to eliminate pollution and waste, create more value to the supply chain and therefore more efficient systems. These two concepts could benefit the manufacturing sector by posing different meanings of value and waste that could complement each other (Hernandez Marquina et al., 2021). Hedlund et al., (2020) states that a VSM is nothing without a definition of value since the purpose is to improve the value stream. Nevertheless, the definition of the term is not always explicitly defined in the VSM literature. According to Peter Nadeem et al., (2019) is the concepts of lean manufacturing and the CE gives the following definitions of waste and value. Waste is defined as “Any activity that leads to the harmful outputs for the stakeholders (People [present and future] and Planet) and does not incorporate the sustainability of the two in long-term, is a wasteful activity” (pp. 7). Value is defined as, “Any activity/output that utilizes its required resources in a manner that maximizes its utility at all stages of its lifecycle including the afterlife, as well as to ensure the longevity of its lifecycle while satisfying the needs/demands of the stakeholders (People [present and future] and Planet) and making impact for them” (pp. 7).

The value stream can be improved by minimizing waste flows within the system, due to the non-adding value of waste (Hedlund et al., 2020). The two concepts' different perspectives of waste elimination and value creation complement each other and a combination of these two would result in effective and beneficial outcome for the manufacturing industry (Peter Nadeem et al., 2019). The research field of sustainable VSM has a knowledge gap, whereby the concept of CE is not considered in the sense of being able to evaluate circularity of supply chain related processes and its connections between actors. Recently, research on integrating the CE aspect with VSM has been developing, there have been some attempts to apply VSM to a supply chain based on CE to evaluate the circularity, e.g., by Mangers et al., (2021). To increase the circularity of material flows, there is a need for tools that is effective and easy to use in industry to analyze and support decision making towards CE (Hedlund et al., 2020). Nevertheless, there is an existing research gap of CE within the literature of sustainability oriented VSM (Lee et al., 2021).

Figge et al., (2018) explored the combination of measuring circularity and longevity to ensure a circular use of resources. Circularity measures how many times a resource is used in a product system and longevity is measuring the length of the time a resource is being used (Hernandez Marquina et al., 2021). A combination of the two approaches make it possible to estimate the efficiency of the resource by the frequency and length of usage (Figge et al., 2018). Hernandez Marquina et al., (2021) further evolved the combination of the indicators to be able to evaluate the performance of circular systems and to measure the "value creation" with VSM. The two CE indicators was integrated into a VSM by a proposed model vision of the final product. The CE indicators were calculated for each component of the product and results in number of cycles and number of years. The study resulted in a conclusion that VSM allows evaluation of circular systems and support improvement.

4.5 Chosen Circular Economy Indicators

Five indicators that were chosen for integration based on the criteria formulated based on the results of the literature review, follow the method described in chapter 3.2.1. The five chosen indicators are presented in Table 11.

Table 11. Indicators chosen for integration

Indicators chosen for integration
Circularity Index
Combined Longevity & Circularity
Material Circularity Indicator
Material Reutilization Score
Recycling Rate

The following subsection will describe what the indicators measure, their variables and how they are calculated.

4.5.1 Circularity Index

The Circularity Index (CI) is grounded in material circulation but includes a degree of quality by taking into account the ratio of energy that is required for material recovery and the ratio of energy that is required for primary production of that same material. The index is measured using a circularity degree, ranging from 0, a fully linear system to 1, a fully circular system. Thus, the indicator attempts to avoid increasing material circularity by increasing the energy use (Corona et al., 2019). The Circularity Index is calculated according to equation (1) and is the ratio between materials and energy inputs, considering recycling and raw material extraction,

$$CI = \alpha\beta. \tag{1}$$

α is the ratio between how large a share of the total material demand is recovered through EoL processes, which can be approximated based on EoL recycling and production data (Cullen, 2017), and is calculated according to equation (2),

$$\alpha = \frac{recovered\ EoL\ Material}{total\ material\ demand}. \tag{2}$$

β is the ratio of the energy that is required recover the material through recycling and the energy that is required for the primary production of that material (Cullen, 2017), and is calculated according to equation (3).

$$\beta = 1 - \frac{Energy\ Required\ to\ Recover\ Material}{Energy\ Required\ for\ Primary\ Production} \tag{3}$$

4.5.2 Combined Longevity and Circularity

The combination of the two indicators, Longevity and Circularity, makes use of the strength of both while covering each other's weaknesses, the indicator is developed by Figge et al., (2018). The problem with using only the circularity indicator is that it incentivizes products that are easily recyclable but do not have a long lifetime, while the longevity indicator incentivizes the design of products that hold for a long time but do not take into account how recyclable or reusable they are at the EoL. Thus, the advantage of combining these two indicators, by measuring both the longevity and circularity the final score represents both the circularity as well as the longevity of the product.

The indicator is calculated using three steps, first, the circularity is calculated, then the longevity, and finally the two are combined in a matrix to create a final score for the indicator. When performing the calculations for both circularity and longevity, it is assumed that the return, reuse, recycling, and recovery rates for the products are constant every time a material enters the circulation and that all materials that are returned are either recycled or refurbished. For the longevity calculations, it is also assumed that the lifetime of each product decreases constantly for every cycle.

The Circularity is measured using equation (4) and is expressed as the number of times a resource is used in a product system, it is measured on a scale from 1, meaning a fully linear system, to infinity, meaning a fully circular system. The initial use of the product is represented by N^A , which is dimensionless and always equal to one, the proportion of the initial resource that is reused is presented by N^B and is calculated according to equation (5), the proportion of the initial resource that is recycled is presented by N^C and is calculated according to equation (6),

$$Circularity = N^A + N^B + N^C, \tag{4}$$

$$N^B = (ab)\frac{(1-(ab)^n)}{\left(1-(ab)\right)}, \tag{5}$$

$$N^C = \frac{p}{1-p}\frac{(1-(ab)^{n-1})}{(1-(ab))}. \tag{6}$$

The percentage of products that are returned is presented by variable a, the percentage of products that are refurbished is presented by variable b, the number of cycles the material goes through is presented by n, and the fraction of the initial material that will be recycled is presented by p and is calculated according to equation (7), where the percentage of material that can be recovered from each product is presented by d,

$$p = acd(1 + (n-1)a^{n-1}b^{n-1}. \tag{7}$$

Longevity of the product is calculated according to equation (8), and is measured using time, the time unit used for measuring the longevity depends on for how long the product is used for.

The initial lifetime of the product is presented by L^A how long the refurbishment extends the lifetime of the material is presented by L^B, which is calculated according to equation (9) and finally, the life extension contribution by recycling is presented by L^C which is calculated according to equation (10), where the decrease in longevity is presented by α,

$$Longevity = L^A + L^B + L^C, \tag{8}$$

$$L^B = L^A(ab\alpha)\frac{(1-(ab\alpha)^n)}{\big(1-(ab\alpha)\big)}, \tag{9}$$

$$L^C = L^A\left(\frac{p}{1-p}\right)\frac{(1-(ab\alpha)^n)}{\big(1-(ab\alpha)\big)}. \tag{10}$$

When both the longevity and circularity have been calculated, they are inserted in a Combination Matrix to estimate their combined score, the Combination Matrix is presented in Figure 9. The matrix is a continuous scale, with the four sections used to measure the contribution of each activity to the circularity, longevity, or both.

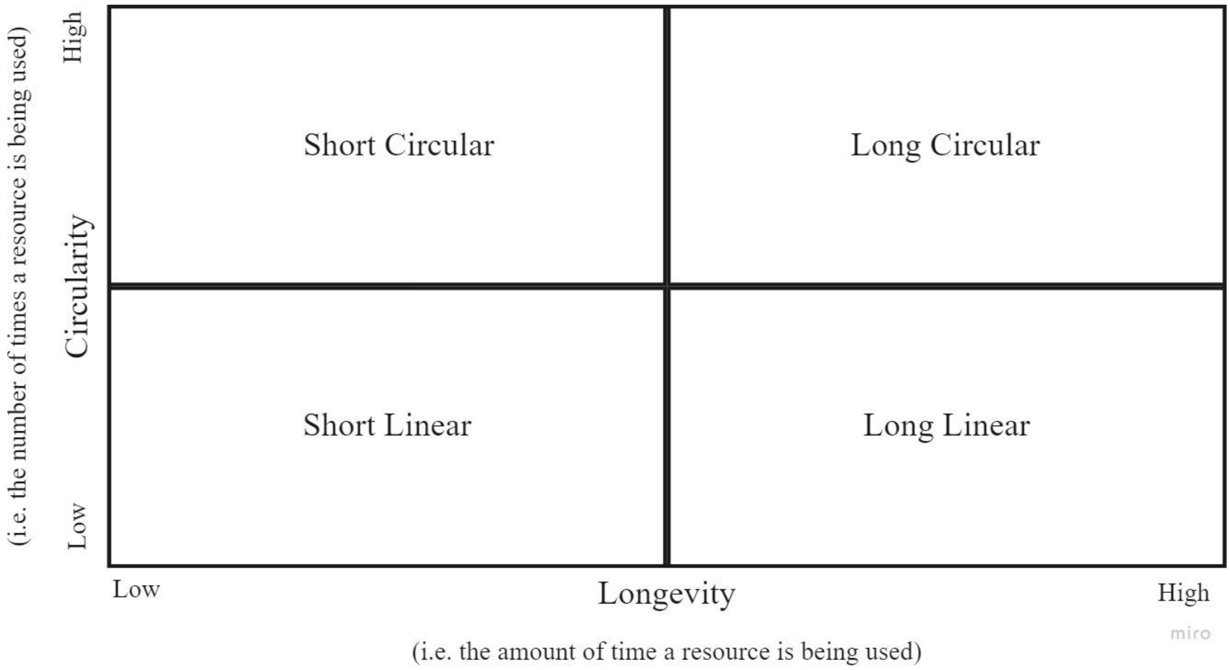

Figure 9. Combination Matrix for estimating the final score of the combined Longevity and Circularity indicators (Figge et al., 2018).

4.5.3 Material Circularity Indicator

The Material Circularity Indicator (MCI) enables the identification of the circular value of materials (EMF, 2015) by measuring the restorative and regenerative characteristics of material flows of a product or company (EMF, 2019a). The MCI on a product-level measures the extent of minimized linear flows and maximized restorative flows of the materials in the product, and how long and intensively the use phase is compared to a similar product of industry-average (EMF, 2019a). Furthermore, the environmental, regulatory and supply chain risk of their product is analyzed and evaluated through optional complementary indicators (EMF, 2015). However, the complementary indicators are not considered in this study.

To measure the MCI is the input in the production process important to elucidate the ratio of virgin and recycled materials and reused components. The utility during use phase is also included in the calculation of the MCI, where the length of the use phase and the insensitivity of usage of the product is compared to a product of a similar type. Furthermore, the end-of-life destination is of interest for the calculation of MCI, i.e., the amount collected for recycling, reuse, energy recovering, and amount ending up in landfills. The last input for the calculation is the efficiency of the recycling, to evaluate the amount of recycled material that could be used as input after use. The MCI results in a value between zero and one (0-1) where a higher value indicates higher circularity (EMF, 2015). As example, a product manufactured by only virgin materials and ends up at landfill is considered to be a linear product and is, therefore, closer to a value of zero. On the other hand, a product made of only recycled materials or reused components and have a fully recycling efficiency is a circular product and is therefore having a value closer to one (EMF, 2019).

When calculating the MCI for products, hereafter referred to as MCI and is defined according to equation (11), you first have to calculate MCI*, which is calculated according to equation (12). The MCI* is based on two variables, the Linear Flow Index (LFI), calculated according to (13), and a function of the product's utility, calculated according to equation (14),

$$MCI = (0, MCI^{*}), \tag{11}$$

$$MCI^{*} = 1 - LFI * F(X), \tag{12}$$

$$LFI = \frac{V + W}{2M + \frac{W_C - W_F}{2}}, \tag{13}$$

$$F(X) = \frac{0{,}9}{X}. \tag{14}$$

To be able to calculate equations (13) and (14), first, it is necessary to calculate the mass V of virgin material used in the production process, using equation (15), the mass W of unrecoverable waste related to the product, which is waste that goes to either landfill or energy recovery, and is calculated according to equation (16), and the utility factor X which is based on the length of the use phase and the insensitivity of usage of the product, and is calculated according to equation (17) (EMF, 2019),

$$V = M(1 - F_R - F_U - F_S), \tag{15}$$

$$W = M(1 - C_R - C_U - C_C - C_E), \tag{16}$$

$$X = \frac{(L)}{(L_{av})} \frac{(U)}{(U_{av})}. \tag{17}$$

When calculating the mass of virgin material V, is the ratio of recycled resources of the feedstock presented by F_R, the ratio of reused sources is presented by F_U, the ratio of the biological materials from Sustained Production is presented by F_S and is the mass of the final product is presented by M. When calculating W , the amount of unrecoverable waste, is the ratio of the mass that is being collected for recycling at the end of the use phase of the product is presented by C_R, the ratio of the mass of the product that is collected to be reused is presented by C_U, the mass of the product that is being composted is presented by C_C, and the mass of the product being used for energy recovery is presented by C_E. When calculating the utility factor X, is the products lifetime presented by L, and the average lifetime of similar products is presented by L_{av}, the use intensity of the product is presented by U, which is measured by how many functional units are achieved during the products lifecycle, and finally, the use intensity for the industry average presented by U_{av} (EMF, 2019).

4.5.4 *Material Reutilization Score*

The Material Reutilization Score (MRS) was developed to eliminate the concept of waste by optimizing material economy and encouraging companies to use recyclable materials in their products. The MRS is calculated according to equation (18).

$$MRS = \frac{\begin{pmatrix} \%\,recycled\ or\ rapidly \\ renewable\ product\ content \end{pmatrix} + 2\begin{pmatrix} \%\,of\ product\ recyclable\ or \\ biodegradable/compostable \end{pmatrix}}{3} * 100 \qquad (18)$$

The first step is to calculate the percentage of recycled or rapidly renewable product content, by summing the individual percentage of recyclable and biodegradable/compostable materials in the product. Then the percentage of recycled or rapidly renewable product content is calculated. This is done by *"multiplying the individual percentage of recycled and rapidly renewable content present within each homogenous material by the percentage of those materials within the overall product and adding up the results"* (pp. 48) (Cradle to Cradle Innovations Institute, 2016). The MRS gives a dimensionless score.

Recyclable material is defined as material that is recyclable, at a minimum one time, on pilot scale anywhere in the world. Biodegradable material is defined according to the OECD's definition. Compostable material is defined as being capable of breaking down under biological decomposition in a compost site. Recycled material is the combined percentage of both post- and pre-consumer recycled materials. Finally, rapidly renewable material has to be grown and harvested in ten years or less, FSC certified wood can also be counted as rapidly renewable material (CCII, 2016)

4.5.5 *Recycling Rate*

The Recycling Rate (RR) is the ratio between both open and closed loop recycled materials (variables g, h_1, and h_2 in equation (19)), and waste generated flows (variables b and c in equation (19)). The indicator can be visualized in Figure 10, where the flows are represented in a flowchart (Haupt et al., 2017). The RR is the ratio of material that is actually recycled, not only the ratio of material that is sent to recycling facilities. Some of the material that is sent to recycling facilities cannot be recycled or ends up as waste because of inefficiencies in the process, this is excluded in the RR (Haupt et al., 2017). The RR is given in percentage by calculation according to equation (19), and the variables are explained in Table 12.

$$RR = \frac{(g + h_1 + h_2)}{(b + c)} \qquad (19)$$

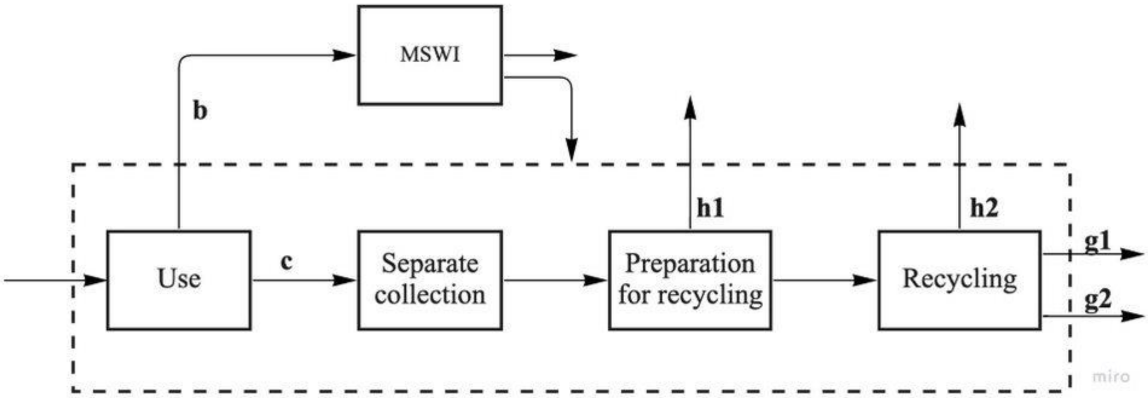

Figure 10. Visualization of the Recycling Rate and its variables, flowchart adapted from (Haupt et al., 2017).

Table 12. Explanation of variables required to calculate the RR (Haupt et al., 2017).

Name of Variable	Explanation of variable
g1	Amount of recycled material that becomes new products through open-loop recycling, measured by weight
g2	Amount of recycled material that becomes new products through closed-loop recycling, measured by weight
h	Recycling of other materials from the process of preparing for recycling and the recycling process, measured by weight
b	Material going to municipal solid waste incineration, measured by weight
c	Material sorted for separate collection, measured by weight

5. Case Study

In this chapter, the findings from the case study are presented. This is related to the second objective, to *identify CE indicators which can be integrated into a VSM based on the data available at a company* and the second research question to identify *how CE indicators could be integrated to VSM to measure product circularity*. First, reasoning for why the five indicators were selected is presented, then insights into the integration and the VSM are shown. Finally, results based on the spreadsheet sent to the company and results from the interview are presented.

5.1 Integration of Circular Economy Indicators with Value Stream Mapping

All of the five chosen CE indicators have fulfilled the criteria presented in Table 7. Further explanation of the reasoning behind the choice is provided in the subsection below. Furthermore, the integration of the CE indicators with VSM is presented, as well as the interpretation of the information received through data gathering.

5.1.1 Chosen Circular Economy Indicators

The CI was found in four of 21 articles included in the first stage of the literature review. The advantage of CI is the simplicity of the indicator, it only requires four different inputs to calculate which should make it simple to map on a VSM and measure the relevant data for its calculations. The indicator considers the energy use for the recycling process, this is an important step when considering the sustainability of the product, since it makes sure that the material circularity is not increased on the cost of increased energy use. This indicator is also the only material circularity indicator, except for the MCI, that also takes into account the energy use.

The Combined Longevity and Circularity index was only mentioned twice in the first phase of the literature review, it was however the only material circularity indicator that had been implemented into a VSM before, according to the second phase of the literature review, which made it an interesting indicator to look at. Since the indicator has been implemented before, it is confirmed that the integration of the indicator with a VSM is technically feasible. The strength of the indicator is in the possibility to measure the material circularity in two ways, how often the material is recycled and reused, and for how long the initial product is used for, which is only partially included in the MCI and excluded in the other three indicators. By taking the longevity of a product into account, the speed of the material cycle is also taken into account, which is an important step in increasing the circularity of a product.

The MCI was mentioned 13 times in the first phase of the literature review, which made it the most cited CE indicator in the entire literature review. It is the indicator that has reached the most attention of all the indicators found, as well as being developed by the EMF, which is seen as the root of the CE wave seen today. The MCI considers the products entire supply chain, which results in an indication of the product circularity on a much more detailed level compared to the other indicators chosen. This gives the MCI a great contrast to the others and contributes to a diversity of CE measurements.

The MRS was mentioned three times during the first phase of the literature review. The MRS was the indicator which required the least amount of data to measure the circularity of a product, as well as making it simple to integrate with the VSM. The indicator was chosen since it measures the material circularity of a product in a simple and well-defined way. The two variables complement each other well, by making sure that the material is not only recyclable, but also that the product uses actually recycled material.

The RR was mentioned four times in the 21 articles found in the first phase of the literature review. In total, there were five different indicators that measured some kind of recycling rate found in the first phase of the literature review, the other four were Old Scrap Rate, Recycling Indices, Recycling Input rate and EoL Recycling Rate, so it was of interest to include at least one recycling rate in the integration. The reason for why RR was chosen above the other four, was its holistic approach to recycling as well as being the most common recycling indicator found in the literature. It did not only take into account how much material was gathered in for recycling, it also accounted for how much material was actually recycled, and how much was sent to other recycling processes. The data requirements for the indicator were also deemed to be suitable for the VSM, with simple to measure information required for the calculation of the indicator.

5.1.2 The Integration of the Circular Economy Indicators with Value stream mapping

The five chosen indicators are integrated to a VSM based on a PET-bottle supply chain network in Luxembourg. The original VSM was conducted by Mangers et al., (2021) and is a version of a new Circular - Value Stream Mapping (C-VSM), which refer to the R-framework hierarchy. This model enables evaluation and visualization connected to process-chains regarding CE on different levels. The C-VSM maps the overall resource flows throughout the supply chain, and the visualization is based on ISO 22468:2020. The data collected by Mangers et al., (2021) for the processes is removed since it was not relevant to the CE indicators integrated with the VSM. The data needed for the five chosen indicators has been defined and mapped in related data-boxes for each partner's process in the supply chain, see Figure 11 below. The meaning of the abbreviations is presented in Appendix C.

The activities in Figure 11 shows the processes in the supply chain of the PET bottle system in Luxembourg. The preform production is producing preforms of PET bottles by virgin raw material and recycled material from the granulate production. The preforms are then transported to the bottle production where the preforms are blown into bottles. The bottle is transported to get filled and transported to the retailer which sells the bottles to the customers. When the users have consumed the drink and used the bottle, the bottle either ends up for collection and sorting or as litter. The bottles that are collected and sorted are collected from households by a truck and is transported to a sorting facility. To sort different types of packaging a Near Infrared Measurements (NIR) is used, and bottles covered with labels will be detected. PET-bottles are sorted in three main groups: transparent/light blue; blue/green; and color. The transparent/light blue bottles are the primary resource going back to the bottle production and the others are ending up in other sectors, such as the clothing industry. The material going back to the bottle production is transported to the flake production which produces transparent flakes out of the bottles. The flakes are thereafter transported to the granulate production to produce granulates that can be used in the preform production.

The integration resulted in a mapping of the indicators on the VSM, which made it possible to identify and locate where the data required for the indicators selected could be found. The mapping resulted in indicators that measure micro level circularity to be mapped on a macro level VSM, to be able to capture all the relevant data needed when measuring the circularity of a products entire lifecycle. However, it was unfortunately not possible to gather the data required, despite the mapping, and that is why the data field the VSM process inventories are empty. It has to be noted that the information received from Plastipak, based on the data spreadsheet sent to the company for them to fill out, was not as expected, the information was to be used to fill out the relevant data fields, and then applied to calculate the indicators. The company could only provide with numerical data for one variable, which was the content of the product being recyclable, which was 100%.

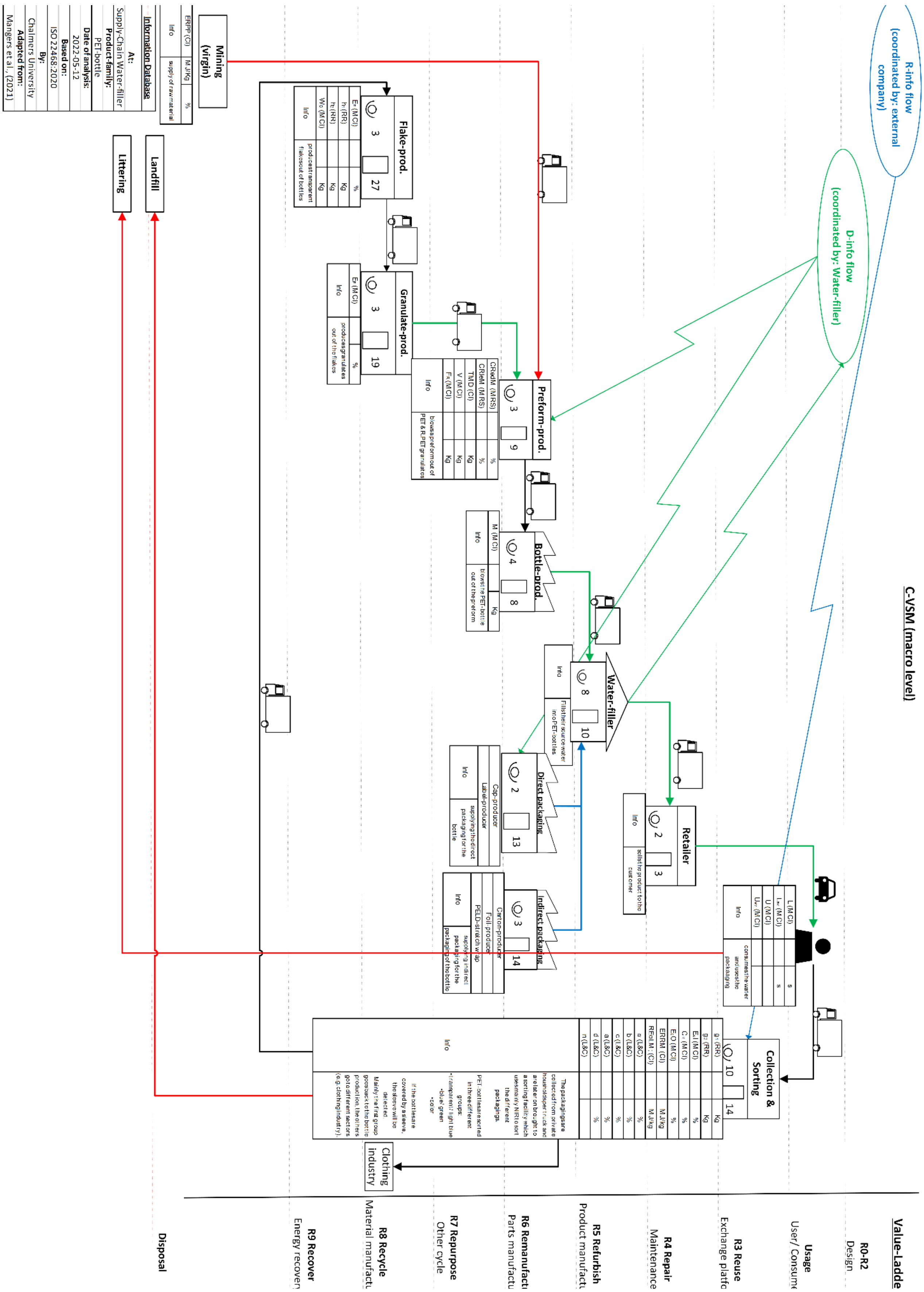

Figure 11. C-VSM with required data mapped for the five chosen CE indicators. Adapted from Mangers et al., (2021).

5.1.3 Interpretation of the information received through data gathering

The company was sent a data spreadsheet where it was asked to fill out the data required to calculate the indicators. However, as was mentioned before, the data received, was not the as expected. Unfortunately, Plastipak couldn’t provide the data that was asked for. Plastipak did however fill out the data spreadsheet with other information relevant to the case study. In this section, these findings are presented. The data availability is addressed, and they estimated that most of the data required, could potentially be gathered. It was estimated that 16 out of 33 datapoints required to calculate the indicators could be collected internally, 13 externally and the company could not define where nine of the datapoints could be collected, this result can be found in Table 13. The only indicator that the company could potentially provide all the information for was the MRS.

In the data spreadsheet sent to the company, two questions were presented to the company, which they were asked to answer, this is summarized in Table 14. The main findings from answers are that the company is positive when it comes most of the indicators and find they measure information that is relevant to the company’s development towards a more sustainable production. When it comes to the general industry application, the company expects more pushback from the industry in large. Finally, there is a general confusion from the companies’ side on what the indicators are measuring, due to unclear definitions of the concepts used and the way that they seem to mean different things in different indicators.

Table 13. Data availability from internal, external, or undefined sources.

Indicator	Variable	Internal	External	Undefined
Circularity Index	Total Material Demand	◉		
	Recovered End of Life (EoL) Material		◉	
	Energy Required for Primary Production			◉
	Energy Required to Recover material	◉	◉	
Combined Longevity and Circularity	Percentage of bottles turned in for EoL treatment, a		◉	
	Percentage of bottles turned in for refurbishing, b		◉	
	Percentage of bottles that are recycled, c		◉	
	Percentage of each bottle that is possible to recycle, d	◉		
	Decrease in lifetime of a PET bottle through refurbishment, α			◉
	Number of cycles a bottle is recycled and refurbished, n		◉	
	How long a product is used for the first time before being discarded, $L\hat{}A=Inital\ Lifetime$			◉
Material Circularity Indicator	Virgin feedstock, V	◉		
	Recycled feedstock, Fr	◉		
	Reused feedstock, Fu	◉		
	Biological material feedstock, Fs	◉		
	Mass of final product, M	◉		
	Unrecoverable waste associated with the product, W	◉		
	Collection rate, Cr		◉	
	Reuse rate, Cu		◉	
	Composted waste, Cc			◉
	Energy recovered waste, Ce		◉	
	Efficiency of the recycling process, Ec	◉	◉	
	Efficiency of the recycling process to produce recycled feedstock, Ef	◉	◉	
	Lifetime, L			◉
	Lifetime average, Lav			◉
	Frequently used, U	◉	◉	
	Frequently used average, Uav			◉
Material Reutilization Score	% recycled or rapidly renewable product content	◉		
	% of product recyclable or biodegradable or compostable	◉		
Recycling Rate	Closed-loop recycling, g	◉		
	Open-loop recycling, h	◉	◉	
	Waste generated flows going to municipal solid waste incineration, b			◉
	Waste generated flows sorted for separate collection, c			◉
Total		16	13	9

Table 14. Answers and comments from data spreadsheet sent to the company.

Indicator	Do you see this indicator as useful?	Do you see the application of this indicator as generally feasible in the industry?	Comments from company
Circularity Index	• Seems constraining when you have a huge range of SKU, many being identical from a design shape/weight, but totally different from a material content (from 0 to 100% recycled).	• Fear a lots of pushbacks.	• Confusion of the word *collection* in the measurement of recovered EoL material. • Difficult to get information of required energy for primary production from suppliers.
Combined Longevity and Circularity	• Combining both makes a lot of sense, even more if you consider the energy factor at the first production and during the recycling loops. • This is an index that would further classify the packaging solutions, promoting refill vs. single use.	• Longevity data is something that should be easily available.	• Definition of initial lifetime is important. • The initial lifetime could depend on the applications the bottle is used for.
Material Circularity Indicator	• Positive approach to multi-criteria indicators such as MCI		• The origin source of data for composted waste and an average of the frequently used is undefined.
Material Reutilization Score	• Makes more sense to use the indicator in a closed-loop recycling than considering any reusable application (downcycling). • Within a closed-loop recycling there will be a non negligeable part of preforms/bottles derated.	• The application and relevance of MRS is doubt within the PET container industry.	
Recycling Rate	• Identifying the weak link of the chain, including which step(s) is less efficient • Segregate recyclable vs. recycled material/packaging, as consumers frequently get confused by the wording used to promote the virtue of the solution. • Could educate and raise attention of the consumers.	• The packaging solutions with low RR index would certainly lobby/fight against it. At the contrary, the solutions with good performances would like to positively differentiate from alternative. • Most probably, a political decision at EU level should decide and impose.	• The recycling world is not very loud about performances. • The statistics for sorted municipal waste is only presented at national level.

5.2 Interview findings

The findings presented below are based on the second interview with Plastipak. The most interesting findings of the interview are summarized and presented in the following subsections. For a summary of the transcription and questions asked in the interview, see Appendix D.

5.2.1 Lack of agreed definition

An agreed definition of CE and circularity is fundamental. Non-academic actors and actors from the industry, with less contact and knowledge about sustainability aspects within the industry, could be confused when the concepts are used with different definitions. To avoid confusion should the same word not have multiple definitions. If circularity and sustainability were described through a cold eye review, the industry would better understand from scratch what is wanted and needed.

5.2.2 Applicability of the integration between Circular Economy Indicators and Value Stream Mapping

The market and customers are progressively looking at the packaging world from a sustainable perspective, and therefore the integration of CE indicators and VSM is visualized to be a useful tool in the future. The industry wants demonstrations on how to get facts, data, and numbers instead of generic quotes of their sustainability work. There is a need to evaluate sustainability to support decision making and not just take decisions based on feelings. A feeling might be a starting point, but at some point, the decisions need to be based on a scientific approach. This is the reason for introducing the CE indicators. The industry must be able demonstrate measurements based on reliable methods to give a value for their circularity and to further reduce their environmental impact. Moreover, the customers' willingness of getting facts and data increases to promote a different approach and drive strategic decision making at the company level.

Once the methodology of measuring circularity is set, the next step is to collect the data needed to make the calculations. However, the data is not always easy to collect. A complex indicator might have difficulties with data availability and might therefore be harder to adopt. The complexity of an indicator is therefore essential for adoption. An example presented by the company during the interview, calculating energy consumption for a preform implies difficulties due to a multi-generation injection machines which are consuming different quantities of energy but produce the same preforms. Therefore, the energy needed for producing a specific preform is not available, and aggregated numbers are used instead. When using aggregated numbers, it is a risk of losing certain elements that could have made a difference between preform A and preform B. By using indicators with less complex characteristics and matching what the industry is able to calculate would give more accurate results.

The difficulties in measuring circularity on the product level are the lack of product-specific data. Currently, aggregated data is required at some level to be able to calculate the performance at the product level. It is important to be aware of the impacts of using aggregated numbers. However, there is a purpose to having a starting point for measuring circularity instead of waiting with applying indicators until the industry is able to measure everything. Investments are needed to monitor performance, but also to make sure that what is required to be measured is calculable. Otherwise, if data is simply not feasible, indicators will be worthless.

There is a good indication of the data availability within a closed loop recycling, due to a better control of the material flows. The open loop recycling, on the other hand, has more external impacts. An open loop recycling contains bottles coming from other beverage companies and other types of application of PET containers. Moreover, the material input will be affected by the geographical boundaries, related leakage, and influx of PET bottles when people are crossing country boarders. There is a need for studies performed by core plastics recycler in Europe to provide with reliable information. On the other hand, accurate information could be applied for open loop based on knowledge of the closed loop. A clear PET has a value, and therefore, will be sorted, sold to recycler to become recycled PET (R-PET), or other application mainly in the bottle industry. Due to the EoL value of a PET bottle is the material most likely to end up in a PET bottle again.

5.2.3 Usefulness of Circular Economy Indicators

The CE indicators are useful to identify the most important factors that make a product more circular. It would be helpful to evaluate how different applications, and which elements would deteriorate the circularity of a bottle. To analyze this the CE indicators could be applied to two extreme cases. An example presented by the company during the interview, there is, on the one hand, a monolayer, transparent, 100% R-PET, no barrier, preform. On the other hand, there is a combination of two assembled preforms, contains silver color, barrier, it is not recycled, and it does not contain any recycled material. Between these upper and lower limits of the two extremes, there are a lot of articles with different degrees of circularity. Furthermore, it is of interest to analyze the circularity of a PET bottle and compare with an alternative beverage packaging. The indicators enable a scientifically differentiate of other types of beverage packaging and ensure which packaging type will be best for a certain application. By introducing the indicators to the beverage packaging industry, the indicators become a scientifical source of comparison between alternatives.

Lately, the plastic industry has been receiving a lot of critique. The plastic industry includes several different types of plastics with varying properties and possibility for recycling. Europe has confirmed that 30 % needs to be recycled plastic in all plastic packaging types by 2030. This target is a huge challenge for some of the plastic types. This is a question of technology and huge investments. The industry is probably challenged beyond its feasibility, based on current knowledge. Fundamental research is required from the industry to be able to reach the goal. Support by academia is required. Moreover, the integration between the industry and the academia is crucial to be ensure a good integration and demonstration of CE indicators. Introducing CE indicators would structure boundaries and requirements for the industry. The indicators should be seen as an element to stimulate challenges and reflections within the industry and the costumers by contributing to a more environmentally friendly design, material usage and more circular solutions. Additionally, the indicators should also be an element that educate costumers and consumers.

6. Discussion

This chapter presents the overall analysis and discussion of the objectives and research questions of the study. The conducted literature review and the existing indicator founded in the literature is first discussed to address the first objective. The criteria set to choose indicators are further evaluated for investigate the validity and to address the second objective. Moreover, the integration of the five chosen indicators, and the potential to support the plastic packaging sector is discussed based on the dialogue with the company and on the outcome from the evaluated indicators related to the third objective.

6.1 Existing Circular Economy Indicators

The CE indicators gathered from the first stage of the literature review, have a high diversity, this is represented by the fact that only 29 indicators out of the 225 indicators found in the literature were mentioned more than once. However, the indicator titles refer to very similar themes, the main themes of the indicators are related to material circularity, recycling rate, and environmental performance. Despite the focus on circularity in this thesis, it should be noted that by only adding indicators evaluating the circularity of a supply chain, the CE performance is not covered in its entirety. The other dimension of sustainability needs to be included to be able to cover the full CE performance, according to the definition of CE presented earlier in the article. The 29 indicators cited in more than one article presented in Table 10, are all cited in articles published later than 2017. A trend in systematic literature review of CE performance measurements in manufacturing is spotted in the latest articles published in the years 2020-2022. This could be a response on the recent growing generation of indicators. Additionally, articles such as Syu et al., (2022) review, select, analyze, and test micro-level circular indicators, which is evaluating the usefulness and usability of existing indicators. There is a need for applying indicators in real case studies to demonstrate and analyze their applicability and helpfulness in the industry.

The number of indicators found in the literature was unexpectedly high when compared to other review articles included in the literature review. A clear majority of the articles highlighted the lack of a holistic approach of the concept, this could be the reason for the number of indicators found. This aligns with the statement by Boyer et al., (2021) that firms might feel forced to develop their own indicators, since they feel that no indicator fits their purpose. This might have the same effect on the academia, there are multiple indicators that are very similar but differ slightly. There are e.g., different indicators measuring recycling, since recycling is not clearly defined, recycling could mean any use of a material after the initial EoL, while recycling could also mean closed loop recycling. While it holds true that the lack of holistic approach can hinder the standardization of the indicators, it can also be viewed as flexibility for the practitioners that apply the indicators. This also applies when it comes to the level of circularity the indicators are measuring, i.e., the micro, meso and macro level. An indicator can be used to measure different levels of circularity, as the examples in Table 10. Existing CE indicators with two or more references based on the literature review.show, different authors classify the same indicators to measure different levels, which can allow the practitioner freedom to apply the same indicator to measure different levels of circularity.

The conducted literature search in this study was based on keywords chosen in the beginning of the project with less knowledge of the research field. This, of course, has an impact on the results given in the literature review in the manner of risking to excluding papers of relevance, but also to include irrelevant articles due to a lack in specifying the search. The backward snowballing method was therefore useful to find more articles in the research field. This method might be too narrow if the articles are all supporting each other, which is needed to be aware of.

6.2 Integration of Circular Economy Indicators and Value Stream Mapping and result of circularity

The selection of CE indicators as well as the integration of the CE indicators and VSM are discussed. Moreover, the potential of the integration and the results from the integration are reflected upon to support the plastic packaging sector.

6.2.1 Indicator selection

Selecting the indicators was a key step in the thesis, it was based on both stages of the literature review, and the integration section. The selection of the indicators was however a very complicated process and multiple steps in the process impacted the final results of the indicator selection. Beginning with the initial keyword search for the literature reviews, which was the foundation for the indicator selection. The fact that so few papers presented originally developed indicators was an unexpected result when considering that the review articles based their reviews on original indicators. This makes it clear that the original article search query is an important step of the literature search, which could have been revised to capture more original indicators instead of synthesized results from other literature reviews. The iterative selection processes, where stricter exclusion criteria were implemented for every step could have played a large impact as well. The criteria selected had a large role in what articles were selected as well as making sure that no crucial information is missed by the authors during the initial screening as well as when reading through the articles. It requires a lot of concentration to make sure that all articles are handled equally.

The selection of the indicators found in the review might have been the process that could have impacted the final selection the most. The criterion for exclusion with the largest impact was "non-existing or badly written description of the indicator" since it could have potentially removed relevant indicators, however, without an initial description it would have been hard to reasonably handle the large amounts of indicators found in the articles. By using the number of citations as a support in the selection, the indicators selected were meant to be more established and contribute to a more solid foundation for the indicators in the future. This however could have contributed to a lock-in effect, where established indicators might have been favored over indicators that were more relevant but not as established.

6.2.2 The chosen Circular Economy Indicators

The five chosen indicators measure the current circularity of the PET bottle preform, and as was mentioned in the background, sustainability indicators can be generalized into two categories, leading, and lagging. Leading can be interpreted as potential, based on preforming changes, while lagging tries to measure the current state. Since the indicators chosen were supposed to measure the as is state, it can be argued that they are all lagging indicators, i.e., measuring what is. This can however be unclear, since the Combined Longevity and Circularity and the MCI can be used to measure the current state, but also potential, f.e. the potential longevity of a product. The indicators do this by measuring factors that can be hard to control by the producer, e.g., numbers of cycles and intensity of use. The MCI is even harder to categorize, since it has a great variability in what variables are used for the calculations, e.g., the recycled content of the product, but also for how long the product is used. When it comes to the CI, MRS and RR, the indicators are based on current information regarding the product, e.g., the amount of recycled content in the product or the energy required for harvesting of the raw material, which suits measuring the current state.

When it comes how the indicators measure the circularity performance, all of the indicators use a recycling variable to calculate the circular performance. When taking into account that recycling is one of the least desirable actions in the waste hierarchy, this can be questioned. This can however be explained by taking into account that recycling has been around for a long time and is relatively simple to measure. Recycling is also involved in the more complex indicators, e.g., the MCI and Combined Longevity and Circularity, despite that they also take into account refurbishment and repair. Recycling will always be a part of the waste hierarchy, even if it is not the optimal solution, since all products will eventually break to the point that they cannot be fixed and have to be recycled.

6.2.3 Integration of Circular Economy Indicators

The integration was supposed to test how the selected indicators could be integrated with the VSM, as well as provide guidance for future integration of other indicators. Micro level indicators were mapped on a macro level VSM, to be able to capture all the relevant data needed when measuring the circularity of a product's entire lifecycle. The first step of the integration, the mapping, was a quite simple task to perform by identifying what data would be required for the indicators and pairing it with information that could be found in the VSM. The disadvantage of this is, however, that it is not standardized, different companies have different processes, and have different information available based on what they are interested in measuring. This would make it hard to standardize the mapping and require that the VSM operators have a good understanding of both the indicator and all the data that is required to calculate each indicator and have a good overview of the processes at the company and what information might be available from each process. This however, also makes the method flexible, by allowing actors with different processes to include the processes that are the most relevant to calculate the circularity of their product. The issue of standardization when it comes to VSM is nothing new, as mentioned by Mangers et al., (2020), and was solved by implementing an ISO standard to make sure that every VSM practitioner would similarly perform the method. However, the mapping does diverge from the standard and would not be VSM according to the standard.

Furthermore, there is a lack of other researchers who have performed a circularity analysis using a VSM, there were only two papers that were found in the literature review. The article by Mangers et al., (2021) integrated the circularity by adding the R-framework and locating where the most value according to the CE principles was located. In the article by Hernandez Marquina et al., (2021), the method that was applied in this paper, was presented, where a CE indicator was integrated with a VSM. They, however, applied the indicator to a fictional case and estimated the information from each process, which is how a VSM is supposed to be performed, measuring the same information at every process. It might however not be relevant to measure the circularity of each process, it is more likely that the circularity is relevant for a product or a supply chain, at least when looking at the micro-level. So, it might be relevant to update, or modify the VSM ISO standard to allow for an integration of CE indicators so it is possible to measure the information required only at the processes of interest instead of measuring the information at every process.

The indicators selected were supposed to, based on the criteria for selection, be integrable with the VSM. Which they were until it came to collecting the relevant data. It turned out that the company had almost no data that was relevant to calculating the indicators. This was very unexpected since the selection was supposed to make sure that the data would be possible to gather with a VSM. Therefore, the data gathered for the integration of the CE indicators and VSM is mainly based on semi-structured interview with the supply chain manager at the Plastipak. During the second interview, and based on the answers from the spreadsheet questionnaire, it however became clear that the data requirements were very broad and required a more precise definition. Another problem was that the initial definition of the product that was supposed to be used in the case study was too broad. There are over a thousand products that the company produces, all with very similar properties.

These problems could have been avoided by involving the company earlier to create a better dialogue. The company provided multiple insights on how their processes worked and what kind of data they had available from their processes. Some indicators, such as the MCI, required very specific data from certain processes, which is complicated for any company to measure and provide. The company did however try to provide general information that was available in public reports and from national statistics. The reason why it was decided to not perform the calculations based on this information is that it did not fulfill the goal of the study. Which was to use already available information in a VSM or information that a company could include in their VSM to measure the circularity of a specific product. Basing the entire calculations on extreme estimates and assumptions, as well as using general data from e.g., LCA data bases for calculations could have resulted in general measurements for circularity. However, this study is aimed to measure the circularity at a micro level, and non-specific product data would not represent value for the integration nor increase the validity of the results.

These results make any of the indicators hard to evaluate individually when it comes to the integration since they all face similar problems, and no actual calculations could be performed. The problems are based on the lack of data availability and unclarity about the definition of the variables as well as the definition of the product that the company was supposed to provide data on since their product portfolio is very varied. The only indicator that the company could potentially provide internal data for was the MRS. Based on the nature of PET bottles being made out of pure PET plastic and the way the indicator is structured it was a simple estimation to reach a circularity score of 66%, as the representative presented in the data spreadsheet. This, however, is not based on any figures, only on simple assumptions and basic calculations. This makes it hard to evaluate the integration of the indicator, since it has nothing to do with the mapping of the indicators on the VSM.

The representative from Plastipak had good knowledge to give answers of high quality, however, having interviews with additional parties within the company or other actors in the supply chain, could have been beneficial to strengthen the validity of the results due to a higher diversity of perspectives and knowledges. This was unfortunately challenging due to time limits. On the other hand, this study primarily focuses on establishing an integration of already existing CE indicators into VSM based on the knowledge and information available at the producing company. The data spreadsheet sent to the company with required data for calculation of the CE indicators was not easily completed, and the findings of the study was therefore better described qualitatively.

6.3 Supporting circularity improvements in the plastic packaging sector

The main concept that attracted the company was the possibility of measuring circularity using indicators. The information could be used by the company to improve their own circularity product design. An example was to apply the indicators to estimate what kind of design impacted the circularity the most and make sure that all products excluded that kind of design. The main advantage was however the ability to provide transparency to the customer about the circularity of the product. The objective of the study was to provide the plastic packaging sector with methods to improve their circularity, but Plastipak had a broader scope and focused on the packaging industry in general. Plastipak stated that they found it important that all different kinds of packaging solutions could be measured using a standard method, so the packaging sector could provide the customer with hard facts with regards to what solution was the most circular and allow the customer to choose the most circular product. So, the interest in the

method was twofold, to be able to improve their own circularity performance and to be able to use the indicators for marketing reasons. The use of the indicators could be used for marketing circular products, which could in turn have a positive economic impact, but Plastipak never explicitly stated that they found the indicators interesting for economic gain.
The company made it clear that the method did interest them to make sure that a level playing field was created for companies when it came to measuring circularity, so the method does have the potential to help the plastic packaging industry improve their circularity. There were however hinders that had to be solved first. The data that was required to calculate the indicators could be very hard to collect, and that currently, the sector was not collecting this information at large. This should however not mean that indicators should not be integrated with a VSM at the present. It would however be preferable to begin selecting indicators that the companies could and are already, collecting data for. To make sure that the circularity could be improved as soon as possible, and not wait until it was possible for the industry to apply the indicators selected.

Another hinder was the company found it hard to relate to the different indicators since they were called the same but were not measuring the same concepts. This same problem applied to the variables required to calculate the indicators, the concepts were not defined well enough and at times the same concepts meant different things. Examples of this are the use of recycling rate and collection, as it depends on the definition what they measure. Even if the company could see the feasibility of the presented indicators, it could be hard to implement the indicators on an industry level given the complexity of definitions.

It is however important to consider that the indicators presented were supposed to be assessed for integration with VSM to be able to support circular improvements. This means that not all the indicators at the same time would be presented, which could make them easier to understand. The proposed method, of integrating the CE indicators with a VSM, could support the plastic packaging industry in becoming more circular, since there is a need in the industry to easily measure and compare the circularity of products and there is no current method for them to deploy to measure their circularity. It is however hard to assess the contribution of each individual indicator since it was not possible to calculate any of them.

7. Conclusion and Recommendations

Today, the plastic packaging industry is facing increasing pressure from politicians and consumers to improve their environmental performance to be able to take part in a modern, environmentally friendly society, while at the same time keep up economic returns and contributions to society. For them to be able to achieve this goal they require tools and methods to be able to measure and improve their processes. The goal of the thesis was to provide the industry with a tool to be able to measure their current performance by taking advantage of their current practices and internal information. The newly proposed method of integrating CE indicators with VSM was seen as a promising method to achieve this goal. This study contributed with an exploratory method of integrating existing CE indicators with a VSM based on a real industrial case and provides insights and guidelines on how to approach this integration to be able to measure circularity on a product level.

The literature review made it clear that the main problem with CE indicators is the lack of holistic approach, both when it came to the definition of the concept of CE and regarding the three dimensions of sustainable development, and when it came to the alignment of what to measure with CE indicators. Despite focusing on indicators that measure material circularity, it was easy to understand what the indicators were measuring. Some indicators attempted to measure the entire CE performance of a product, while others only focused on the material circularity. This created complications when involving the company, since the different use of the same concept led to misunderstandings and confusion. Another problem that turned up during the company involvement was the data availability, despite that the indicators chosen were quite commonly cited in literature and had been proven to be calculable, it was complicated for the company to gather the data. When selecting indicators for future collaboration with industry, it is important to make sure that the data availability in industry is comparable with the data requirements of the indicators. The industry is open and ready for the use of the indicators but based on the results of this study, the indicators are not compatible with what the industry can provide.

The VSM integration was supposed to make use of the current practices in industry and apply CE indicators that are supposed to capture, in an easy and simple way, the circularity of a product. The problem of the mapping method is that the results are case specific, making the method unreliable for comparisons, which was what the company saw as the method's greatest potential. The ISO standard for VSM requires the same information to be gathered at every process, this could mean that the ISO standard does not fit circularity VSM and might have to be edited to allow for circularity measurements. But as the ISO standard is today, future integration methods should strive for following the ISO standard, similar to the other proposed CE indicators and VSM integration methods.

The integration of CE indicators and VSM is interesting to the industry, who is looking for ways to measure their circularity, both for internal improvements as well as for marketing and advertisement reasons. The method takes advantage of what the industry is already doing, measuring performance and using VSM, so what is required now, is to find the right CE indicators that fit the available information and fit with the VSM ISO standard. Thus, future research should focus on contributing to a holistic use of the concept of CE, develop and improve current CE indicators to make sure that they are simple to understand, integrable with VSM and make use of information that the industry has readily available.

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Appendix

Appendix A

Table of all the CE indicators found in the literature review with year of publishing and system level according to each article.

Reference	Year	Indicators	Level
Fu-Siang Syu, Adarsh Vasudevan, Mélanie Despeisse, Arpita Chari, Ebru Turanoglu Bekar, Maria M. Gonçalves, Marco A. Estrela	2022	Material Reutilization Score	Micro
		Circular Economic Value	Micro
		Product-Level Circularity Metric	Micro
		Mass Recovery Index	Micro
		Material Circularity Indicator	Micro
Roos Lindgreen E., Mondello G., Salomone R., Lanuzza F., Saija G.	2021	Circular Economy Toolkit	Micro
		Material Reutilization Score	Micro
		Material Circularity Indicator	Micro
		Circularity Check	Micro
		Circular Transition Indicators	Micro
		Circulytics (CYTICS)	Micro
Trollman H., Colwill J., Jagtap S.	2021	A Circularity Indicator Tool for Measuring the Ecological Embeddedness of Manufacturing	Undefined
Boyer R.H.W., Mellquist A.-C., Williander M., Fallahi S., Nyström T., Linder M., Algurén P., Vanacore E., Hunka A.D., Rex E., Whalen K.A.	2021	Better Effect Index	Undefined
		RISE Research Institutes of Sweden have developed and tested a metric that focuses specifically on material recirculation, "C"	Undefined
		Ease of Disassembly Metric	Undefined
		Market entropy (ME) metric	Undefined
Harris S., Martin M., Diener D.	2021	Circular Economy Index	Micro
		Reuse Potential Indicator	Micro
		Circular Economy Indicator Prototype	Micro
		Circular Economy Toolkit	Micro
		Material Circularity Indicator	Micro
Baumer-Cardoso M.I., Campos L.M.S., Ashton W.	2021	Material Circularity Indicator	Micro
		Circular Transition Indicators	Micro
		Circulytics (CYTICS)	Micro
		Sustainable Circular Index	Micro
		Expanded Zero Waste	Micro
		Circularity Measurement Toolkit	Micro
		Indicators for Organizations considering Sustainability and Business Models	Micro
		Circularity Facts	Micro

Reference	Year	Indicators	Level
Mesa J., González-Quiroga A., Maury H.	2020	Material Circularity Indicator	Undefined
		Circular Economy (Performance) Indicator	Undefined
		Circularity Index	Undefined
		Value-based Resource Efficiency	Undefined
		Global Resource Indicator	Undefined
		Recycling input Rate	Undefined
		Old Scrap Rate	Undefined
		Recycling Rate	Undefined
		Material Durability Indicator	Undefined
		Product Level Circularity Metric	Undefined
		Eco-costs	Undefined
		Resource Duration	Undefined
		Displacement rate	Undefined
		Material Reutilization part–Cradle to Cradle	Undefined
		End of Life Recycling Rate	Undefined
		Number of Times of Use of a Material	Undefined
Rossi E., Bertassini A.C., Ferreira C.D.S., Neves do Amaral W.A., Ometto A.R.	2020	Circular Economy Toolkit	Micro
		Material Circularity Indicator	Micro
		Circular Economy Index	Micro
		Circularity Index	Micro
		Circular Economy Indicator Prototype	Micro
		Sustainable Circular Index	Micro
		Eco-efficient Value Ratio	Micro
		Ease of Disassembly Metric	Micro
		Recycling Rate	Micro
		End of Life Recycling Rate	Micro
		BIM-based Whole-life Performance Estimator	Micro
		Building Circularity Indicators	Micro
		Circular Economy Measurement Scale	Micro
		Circular Pathfinder	Micro
		Circularity Calculator	Micro
		Circularity Potential Index	Micro
		Economic-Environmental Indicators	Micro
		Economic-environmental remanufacturing	Micro
		Input-Output Balance Sheet	Micro
		Longevity and Circularity	Micro
		Material Reutilization Part	Micro
		Multidimensional Indicator Set	Micro
		Product-Level circularity Metric	Micro
		Recycling Indices	Micro
		Resource Duration Indicator	Micro
		Reuse Potential Indicator	Micro
		Set of Indicators to Assess Sustainability	Micro
		Sustainability Indicators	Micro

Reference	Year	Indicators	Level
Kristensen H.S., Mosgaard M.A.	2020	Circular Economy Toolkit	Micro
		Material Reutilization Score	Micro
		Material Circularity Indicator	Micro
		Circular Economy Indicator Prototype	Micro
		Reuse Potentail Indicator	Micro
		Value-based Resource Efficiency	Micro
		Eco-efficient Value Ratio	Micro
		Circular Economy Index	Micro
		Ease of Disassembly Metric	Micro
		Product Level Circularity Metric	Micro
		Circularity Calculator	Micro
		Recycling Indices	Micro
		Resource Duration Indicator	Micro
		Disassembly Effort Index	Micro
		Remanufacturing Product Profiles	Micro
		End-of-life Index	Micro
		Longivity Indicator	Micro
		Material Reutilization Score (C2C certification framework)	Micro
		Eco-efficient Value Creation	Micro
		End-of-life Indices (Design Methodology)	Micro
		Model of Expanded Zero Waste Practice	Micro
		Circularity Design Guidelines	Micro
		Combination Matrix	Micro
		Decision Support Tool for Remanufacturing	Micro
		Effective Disassembly Time	Micro
		Product Recovery Multi-criteria Decision Tool	Micro
		Sustainability Indicators in CE	Micro
		Design Method for End-of-use Product Value Recovery	Micro
		Multi-criteria Decision Analysis Combining Material Circularity Indicators&Life-cyclebased Indicators	Micro
		Mathematical Model to Assess Sustainable Design and End-of-life Options	Micro
		Typology for Quality Properties	Micro

Reference	Year	Indicators	Level
Corona B., Shen L., Reike D., Rosales Carreón J., Worrell E.	2019	Material Circularity Indicator	Micro
		Circular Economy (Performance) Indicator	Undefined
		New Product-Level Circularity Metric	Micro
		Circ(T) or Cumulative Service Index	Undefined
		Circularity Index	Undefined
		Global Circularity metric	Undefined
		Circular Economy Indicator Prototype	Micro
		Circular Economic Value	Micro
		Reuse Potentail Indicator	Undefined
		Value-based Resource Efficiency	Undefined
		Longevity Indicator	Undefined
		Sustainable Circular Index	Undefined
		Eco-efficiency index	Undefined
		Eco-efficient Value Ratio	Undefined
		Global Resource Indicator	Undefined
		Circularity degree	Undefined
		Circular Economy Index	Undefined
Haupt M., Hellweg S.	2019	Retained environmental value	Undefined
Moraga G., Huysveld S., Mathieux F., Blengini G.A., Alaerts L., Van Acker K., de Meester S., Dewulf J.	2019	Material Circularity Indicator	Micro
		Circular Economy (Performance) Indicator	Micro
		New Product-Level Circularity Metric	Micro
		Value-based Resource Efficiency	Micro
		Longevity Indicator	Micro
		Sustainable Circular Index	Micro
		Eco-efficient Value Ratio	Micro
		Global Resource Indicator	Micro
		Circular Economy Index	Micro
		Ease of Disassembly Metric	Micro
		Old scrap Collection Rate	Micro
		Recycling process efficiency Rate	Micro
		End of Life Recycling Rate	Micro
		Recycling input Rate	Micro
		Old Scrap Rate	Mircro
		Number of Times of Use of a Material	Micro
		Total Restored Products	Micro
		Lifetime of Materials on Anthroposphere	Micro
		Displacement	Micro

Reference	Year	Indicators	Level
Pauer E., Wohner B., Heinrich V., Tacker M.	2019	Recycled Conent	Undefined
		Reuse rate	Undefined
		Renewable conent	Undefined
		Recyclability	Undefined
		Recycling Rate	Undefined
		Recycling Output Rate	Undefined
		Downcycling factor	Undefined
		Compostability	Undefined
		Share of Renewable Energy	Undefined
Saidani M., Yannou B., Leroy Y., Cluzel F., Kendall A.	2019	Assessing Circular Trade-offs	Undefined
		Building Circularity Indicators	Undefined
		Material Reutilization Part	Undefined
		Circle Assessment	Undefined
		Circularity Assessment Tool	Undefined
		Circular Benefits Tool	Undefined
		Circularity Calculator	Micro
		Circular Economy Company Assessment Criteria	Undefined
		Circular Economy Index	Micro
		Circular Economy Indicators for India	Undefined
		Circular Economy Indicator Prototype	Micro
		Circular Economy Monitoring Framework	Undefined
		Circular Economy Performance Indicator	Micro
		Circular Economy Toolkit	Micro
		Circular Economy Toolbox US	Undefined
		Circular Economic Value	Meso
		Circularity Index	Micro
		Circular Impacts Project EU	Undefined
		Circularity Material Cycles	Undefined
		Closed Loop Calculator	Undefined
		Circular Pathfinder	Micro
		Circularity Potential Indicator	Undefined
		Super-efficiency Data Envelopment Analysis Model	Undefined
		Evaluation Indicator System of Circular Economy	Undefined
		Indicators for Material input for CE in Europe	Undefined
		End-of-Life Recycling Rates	Micro
		Environmental Protection Indicators (EPICE) in a context of CE	Undefined
		Evaluation of Regional Circular Economy	Undefined

Reference	Year	Indicators	Level
Saidani M., Yannou B., Leroy Y., Cluzel F., Kendall A.	2019	Economy-Wide Material Flow Analysis	Undefined
		Five Category Index Method	Undefined
		Hybrid LCA Model	Undefined
		Indicators for Consumption for CE in Europe	Undefined
		Circularity Indicator Project	Undefined
		Indicators for Eco-design for CE in Europe	Undefined
		Indicators of Economic Circularity in France	Undefined
		Integrative Evaluation on the Development of CE	Undefined
		Input-Output Balance Sheet	Micro
		Indicators for Production for CE in Europe	Undefined
		Industrial Park Circular Economy Indicator System	Undefined
		Material Circularity Indicator	Micro
		Measuring Regional CEeEco-Innovation	Undefined
		Product-Level Circularity Metric	Micro
		Resource Duration Indicator	Micro
		EU Resource Efficiency Scoreboard	Undefined
		Recycling Indices (RIs) for the CE	Micro
		Resource Productivity	Undefined
		Reuse Potential Indicator	Micro
		Recycling Rates	Micro
		Zero Waste Index	Undefined
		Sustainable Circular Index	Meso
		Value-based Resource Efficiency	Micro
Mesa J., Esparragoza I., Maury H.	2018	Circular Economy Toolkit	Undefined
		Material Circularity Indicator	Undefined
		Circular Economy (Performance) Indicator	Undefined
		Circular Economy Indicator Prototype	Undefined
		Circular Economy Index	Undefined
		Circularity Metric based on economic	Undefined
		Set of indicators forraw material, use,and end of lifestages	Undefined
		Recyclability Benefit rate	Undefined
		Resource Duration	Undefined
Figge F., Thorpe A.S., Givry P., Canning L., Franklin-Johnson E.	2018	Combined Longevity and Circularity indicator	Undefined
Brown P.J., Bajada C.	2018	Material Circularity Indicator	Micro
		Waste diversion rate	Undefined

Reference	Year	Indicators	Level
Milios L., Davani A.E., Yu Y.	2018	Greenhouse gas Emissions	Undefined
		Costs	Undefined
		Direct Jobs	Undefined
Iacovidou E., Velis C.A., Purnell P., Zwirner O., Brown A., Hahladakis J., Millward-Hopkins J., Williams P.T.	2017	Indirect or embodied carbon emissions	Undefined
		Direct carbon emissions	Undefined
		Avoided carbon emissions	Undefined
		Biogenic carbon emissions	Undefined
		Carbon Capture and Sequestration	Undefined
		Ozone Depletion Potential	Undefined
		Photochemical ozone formation potential	Undefined
		Acidification potential	Undefined
		Eutrophication potential	Undefined
		Human Toxicity Potential	Undefined
		Ecotoxicity Potential	Undefined
		Emerging organic contaminants	Undefined
		Black Carbon (BC) emissions	Undefined
		Waste heat losses	Undefined
		Nanoparticle emissions	Undefined
		Primary Energy Comsumption	Undefined
		Specific Energy Consumption	Undefined
		Cumulative Energy Demand	Undefined
		Gross Energy Requirement	Undefined
		Renewable Energy Generation	Undefined
		Exergy	Undefined
		Emergy	Undefined
		Water Consumption / Water Footprint / Blue Water Footpring	Undefined
		Water Quality	Undefined
		Material Intensity	Undefined
		Specific material Consumption	Undefined
		Critical raw materials use	Undefined
		Recycled/reused content	Undefined
		Feedstock renewability	Undefined
		Land Use	Undefined
		Energy Efficiency	Undefined
		Energy Efficiency index	Undefined
		R1 formula	Undefined
		Resource conservation efficiency	Undefined
		Upstream material efficiency	Undefined
		Downstream material efficiency	Undefined
		Recycled material fraction	Undefined
		Weight recovery (for product recovered)	Undefined
		Weight recovery (for product recycled)	Undefined
		Environmental space	Undefined
		Ecological footprint	Undefined

Reference	Year	Indicators	Level
Iacovidou E., Velis C.A., Purnell P., Zwirner O., Brown A., Hahladakis J., Millward-Hopkins J., Williams P.T.	2017	Environmentally weighted matreial consumption	Undefined
		Environmental impact recoverability indicator	Undefined
		Cleaner treament index	Undefined
		Material input per service unit	Undefined
		Material Recovery Indicator	Undefined
		Energy recovery indicator	Undefined
		MSW management self-sufficient indicator	Undefined
		Net Recovery index	Undefined
		Transport intensity index	Undefined
		Cost of raw materials and intermediates	Undefined
		Net sales	Undefined
		Net profit/loss	Undefined
		Net Present value	Undefined
		Capital cost	Undefined
		Operational & maintainance cost	Undefined
		Utilities costs	Undefined
		Non-energy costs	Undefined
		Revenue from secondary resource sale	Undefined
		Taxation	Undefined
		Susidiy and incentives	Undefined
		Healt costs	Undefined
		Ecosystem services	Undefined
		Economic spillover effects	Undefined
		Acceptability	Undefined
		Participation rate (in RRfW)	Undefined
		Participation (in decision making)	Undefined
		Social function and equity	Undefined
		Child labour	Undefined
		Working hours	Undefined
		Working hourly wage	Undefined
		Health and safety (of workers)	Undefined
		System safety	Undefined
		NIMBY syndrome	Undefined
		Job creation	Undefined
		Employment or job quality	Undefined
		Local deficiencies	Undefined
		Noise pollution	Undefined
		Odour	Undefined
		Reusability	Undefined
		Remanufacturability	Undefined

Reference	Year	Indicators	Level
Iacovidou E., Velis C.A., Purnell P., Zwirner O., Brown A., Hahladakis J., Millward-Hopkins J., Williams P.T.	2017	Mass recyclability	Undefined
		Technical recyclability	Undefined
		Mass recoverability	Undefined
		Energy recoverability	Undefined
		Lower heating value (LHV) or net calorificvalue	Undefined
		Technical recoverability of components and products	Undefined
		Technological advancement	Undefined
Saidani M., Yannou B., Leroy Y., Cluzel F.	2017	Circular Economy Indicator Prototype	Micro
		Material Circularity Indicator	Micro
		Circular Economy Toolkit	Micro
		Longevity Indicator	Micro
An X.-H., Cui Y.-M., Qi E.-S.	2011	Eco efficiency	Undefined

Appendix B

The structure of the data spreadsheet sent to the company. This example explains the indicator Circularity Index, its equation, and variables.

Name of Indicator:	**Circularity index**	
Explanation of indicator:	The tool Circularity Index is based on material circulation, but includes the notion of quality by the ratio of energy required for material recovery to energy required for primary production. This approach tries to avoid the risks of achieving resource circularity by increasing the energy use. The Circularity Index is the ratio between materials and energy inputs considering recycling and raw material extraction.	
Equation for calculation:	$Circularity\ index = \left(\frac{Recovered\ EoL\ Material}{Total\ Material\ Demand}\right) * \left(1 - \frac{Energy\ Required\ to\ Recover\ Material}{Energy\ Required\ for\ Primary\ Production}\right)$	
General Questions about the Indicator:	Do you see this indicator as useful?	
	Do you see the application of this indicator as generally feasible in the industry?	

Name of Variable	**Explanation of variable**	**Suggested process for origin of data (According to VSM)**	*Do you have this data available?* **Write 1 for yes and 0 for no**	*If external to Plastipaks processes, do you recieve this information from your supplier?* **Write 1 for yes and 0 for no**	**If available, insert here**	**Unit [kg/ton/Liter/time etc.]**	**Comments**
Total Material Demand	The amount of PET required for the production of the product, measured by weight	Internal to Plastipaks processes (Preform Production)					
Recovered End of Life (EoL) Material	The amount of PET recovered from recycling of the product, measured by weight	External to Plastipaks processes (Collection & Sorting)					
Energy Required for Primary Production	The energy required for production of virgin PET, measured in MJ/kg	External to Plastipaks processes (Gathering of Virgin Resources)					
Energy Required to Recover material	The energy required to recover the PET from the recycling process, measured in MJ/kg	External to Plastipaks processes (Collection & Sorting)					

Appendix C

The meaning of the abbreviations for the five chosen indicators.

Indicator	Abbreviation	Meaning
Circularity Index	TMD	Total Material Demand
	REoLM	Recovered End of Life (EoL) Material
	ERPP	Energy Required for Primary Production
	ERRM	Energy Required to Recover material
Combined Longevity and Circularity	a	Percentage of bottles turned in for EoL treatment
	b	Percentage of bottles turned in for refurbishing
	c	Percentage of bottles that are recycled
	d	Percentage of each bottle that is possible to recycle
	α	Decrease in lifetime of a PET bottle through refurbishment
	n	Number of cycles a bottle is recycled and refurbished
	$L^\wedge A = Inital\ Lifetime$	How long a product is used for the first time before being discarded
Material Circularity Indicator	V	Virgin feedstock
	F_R	Recycled feedstock
	F_U	Reused feedstock
	F_S	Biological material feedstock
	M	Mass of final product
	W	Unrecoverable waste associated with the product
	C_R	Collection rate
	C_U	Reuse rate
	C_C	Composted waste
	C_E	Energy recovered waste
	E_C	Efficiency of the recycling process
	E_F	Efficiency of the recycling process to produce recycled feedstock
	L	Lifetime
	L_{av}	Lifetime average
	U	Frequently used
	U_{av}	Frequently used average
Material Reutilization Score	CRedM	% recycled or rapidly renewable product content
	CRleM	% of product recyclable or biodegradable or compostable
Recycling Rate	g	Closed-loop recycling
	h	Open-loop recycling
	b	Waste generated flows going to municipal solid waste incineration
	c	Waste generated flows sorted for separate collection

Appendix D

A summary of the transcription and questions asked during the second interview with the supply chain manager at Plastipak.

Question	Summary of quotes
How does the lack of agreed definition within this field affect the industry?	Non-academic people or even people from the industry with maybe less contact or less clue to the sustainability aspect of our industry, could be a little bit lost in seeing same concepts being used with different definitions. To avoid confusion in the industry, the same word should not have multiple definitions
How you could use the information from the CE indicators, and how will this be useful to you?	So you basically have the two extremes. Then you have a lot of duplication SKU which are between those two upper and lower limits. ...That is where you can have the set of data from extreme material, and then at least apply the model and still see if even the worst one still has potentially better performance from a circularity point of view vs. an alternative. The purpose is also to see how different applications and what are the element would deteriorate the circularity of a bottle
Do you think CE indicators measuring circularity, in general, could be interesting to someone who is performing VSM? Do you, as a leading company within the industry, visualizing to be using the integration in the future?	Yes, I do. In this sense, the market and the customers, are progressively looking at the packaging world with sustainable eyes. Then you need to be able to demonstrate, the industry does not want to have sentences, it wants to see facts, data, and numbers. So at some point, you need to be able to give a value to demonstrate that, compared to something else and based on a certain methodology, then this packaging compared to that packaging is better circularity which gives a lower impact on the environment. Clearly, yes, we see now customers willing to get facts and data to promote a different approach but also because behind this will drive strategic decisions at the company level. The question was raised last Friday by the director of this plant when we had the discussion on product circularity datasheet. How will the search reference all of the product? Give something which you can show with some kind of numbering, of percentage, of ratio really data because that is something which is important to compare. You need a value, not just a feeling because that makes no sense in the industry. Well, it might be a starting point, but then you need to be more scientific, and that is where these indicators should be able to give the answer to this

Do you think the more complex indicators would be more valuable?	At this stage I would say, if it is too complex, it will be hard for the industry to adopt them as a reference, because it is not easy to collect data. Once you have a set of indicators and a way to calculate them, then you need to have the data to be able to calculate them. If they are complex, there are difficulties to access the data, even your own data. To be able to calculate energy consumption for a preform, we have multi-generation injection machine which is consuming a totally different quantity of energy to produce the same preform depending on the platform on which you inject. .... Today, I am not able to say easily what is the energy delta if I produce on this machine vs. that machine. That aggregating numbers, we will lose a little bit of the element that could make a difference between preform A and preform B, and create, probably, a lot of complexity in calculating an indicator. If they are not too complex, it will better match what the industry is available to calculate on its own or the actor from the industry.
Do you have to be able to aggregate the data at some level to be able to get that reasonable figure for the indicator instead of being too specific?	Some elements will be very SKU-related information. Some elements to calculate, the SKU performance will require aggregated numbers because I do not have them at SKU level. ... We need to start with what we have today. ... If we wait until the industry is able to calculate everything and then we will put in place indicators, well it is a bit sad to wait. But we need to make sure that, what we want to calculate is calculable, because if you can't just get the data, indicators may be nice, but worthless.
Based on the information you do have available now and that you are measuring, do you think it is possible to measure circularity if you look at the indicators that are presented to you? In what detail do you think you would be able to measure?	I will make a split between two types of customers. Costumer with whom we work in closed loop. Mean that we inject material, we sell them and they will recover their own bottles. Then we buy the bales. We subcontract the washing, grinding, we recover the flakes, we re-extrude the flakes and we re-inject in a loop. There is probably one element in the grey zone where we are not owning the data directly, it is at the customer side. What is the rate of collection for their own bottles? For the rest of the loop, as we are really the owner of this closed loop process, we really have a lot of data. ... I could apply relatively more accurate information even for open loop based on what we know about the closed loop. Because at the end we know that the value of a clear PET bottle, will be sorted out, be valued, sold to recycler to make RPET or application mainly in the bottle industry. We could apply similar more accurate details that we know because we do have controlled almost on all the loop. That is where I think we can make a clear distinction based on the application we know the of the product.

Because the material or the product is so valuable at the end-of-life, it will most likely end up in a recycling loop where it will end up in a PET bottle again?	Yes, clearly. These indicators, to be honest, if you speak about the PET industry, the PET industry knows that they work with the monomer, which is the most recyclable worldwide. The PET industry will appreciate having these kinds of indicators to compare alternative packaging types. That's where the industry wants to differentiate itself from others and be able to scientifically say “I’m better than TetraPack® or I'm better than the paper bottle or I'm better than HDPE”. But that's where you will scientifically be able to demonstrate indicators. To ensure which packaging type will be best for a certain application. Because behind there is an existing recycling stream because this is material that you can reuse multiple time because it's a packaging that will guarantee longevity. I would say from a data point, this is where the proposed indicators becomes interesting, to evaluate and compare, but not comparing one preform to another PET preform we can do. Probably we can already do it from scratch. The application of each indicator is feasible in the packaging industry, as a whole, but only looking at the PET industry is too narrow. We need these indicators to be a source of comparison between alternative types of packaging. We need them to challenge ourselves and challenge our customers because when they have a requirement, that's where they would be used for the eco-design and contribution. But then also being able to challenge customers from their type of material usage in terms of designing the most environmental or sustainable, circular solution for packaging their goods. These indicators should be seen as element to stimulate the reflection between company and customers to challenge the requirement to challenge ourselves and product development center. It should also be an element that educate, not only customers, but consumers and consumers. Do not trust me because I'm working in the PET industry. Look, these are independent indicators. I think the plastic industry was hit by the plastic bashing. When we say plastic as a whole, there are so many different types of plastic with different degrees of recyclability and also a long way to go because in plastic association plastic Europe as confirm that they will be 30% recycled plastics in all types of packaging by 2030. This is a huge challenge for some of the plastic type packaging, where they are zero today. It's a question of technology, not just a dream. Huge investment. So the industry is really challenging itself probably beyond feasibility, based on today's knowledge. So that is where the academic world and fundamental research is required to help the industry because the industry on its own wants to be able to reach that. We need the research to contribute to this huge challenge for the industry, we need to support academia, but academia should not just work in the dark lab.