Circular Economy Innovation at Tetra Pak through use of PLM System

- An Approach using Product Lifecycle Management (PLM) and Governance Model to Integrate Business Strategies, Technology and Product Innovation to Support Circular Economy Principles

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Preface

This master thesis is the final project of a Master of Science within Industrial Engineering and Management on advanced level. It is written at the department of Production Management at the Faculty of Engineering at Lund University. The thesis is done in collaboration with Tetra Pak.

During the period of the master thesis project, I have had the opportunity to meet many experienced people which I am very grateful for. People who are experts on what they are doing and happy to share their knowledge and experience.

Firstly, I would like to express my gratitude towards my supervisor Bertil I Nilsson at Lund University for all the support when I needed guidance and help to structure my thoughts to keep me on track. He has been great support when I needed discussions to move forward. With his previous experience and knowledge within this field, his guidance was very valuable for my project.

Secondly, I would like to express my gratitude towards the company representatives, my supervisors, Lars Sickert and Peter Lundgren at Tetra Pak, who have been very supporting and helpful throughout this project. They have supported me with valuable guidance and insight within the PLM field. I am also so grateful for the warm welcome at the office in Lund.

Finally, I am so grateful for these five years as a student at the Faculty of Engineering at Lund University and now I am curious about what the future has to offer.

Lund, June 2024

Julia Svegerud

Abstract

Title
Circular Economy Innovation at Tetra Pak through use of PLM System - An Approach using Product Lifecycle Management (PLM) and Governance Model to Integrate Business Strategies, Technology and Product Innovation to Support Circular Economy Principles

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Problem description
An increased importance of data management in organization is emerging. (Desai et al., 2022) Sharing and managing product data, information and knowledge are key aspects of Product Lifecycle Management (PLM). (Terzi et al., 2010) It is both a technological and strategic challenge to implement a PLM system strategy in a company. (Gehrke et al., 2020) There also exists barriers companies need to overcome to have a successful circular economy (CE) implementation, such as a major systematic change. (Cantú et al., 2021) Implementing CE into PLM will require the different phases of the product lifecycle to be modified. (Villamil Velasquez et al., 2020) New mandatory sustainability reporting regulations such as Corporate Sustainability Reporting Directive (CSRD) requires improved corporate transparency with its precise standards, and to provide relevant information regarding sustainable business activities. (Birkmann et al., 2024) Growing concerns regarding sustainability issues, and the emergence of the circular economy paradigm, in combination with new technological changes, press a need to redefine the PLM approach from a mass production paradigm to a new more on demand, customer-driven and knowledge-based production paradigm. (de Oliveira & Soares, 2017)

Purpose
The purpose of the thesis is to answer the problem statement regarding exploring the current state of the PLM system at Tetra Pak and how it can be adapted to better support the circular economy principles, including product reuse, remanufacturing, and recycling, to drive sustainable product innovation. Research questions are formulated into three categories to answer

the problem statement, including what has been implemented, current state, and future state.

Method
The research strategy of the thesis is both an explorative case study research with data collected through qualitative interviews and a literature review on the theoretical background on the topic. This resulted in a current state analysis of the case company, a benchmarking approach with other companies to broaden the perspective of the context of the thesis and leading to a roadmap approach.

Conclusion
The thesis proposes a unique strategic navigation presented in a roadmap, proposing how Tetra Pak can adapt the PLM system to better support the circular economy principles to drive sustainable product innovation. Important aspects to consider are proposed to be the technological approach, the change work approach and the stakeholders involved. Barriers exists to reach the aim with the roadmap in the identified areas such as technological, businesswise, CE implementation, change work, and the low emphasize at research institutions.

Key words: *Product Lifecycle Management (PLM) system, Closed loop PLM, Circular Economy, Reverse Logistics process, Organizational Change Management, Corporate Sustainability Reporting Directive (CSRD), Artificial Intelligence.*

List of abbreviations

AI	Artificial Intelligence
BOL	Beginning-of-Life
CE	Circular Economy
CSRD	Corporate Sustainability Reporting Directive
DPP	Digital Product Passport
EIS	Enterprise Information System
EOL	End-of-Life
ERP	Enterprise Resource Planning
ESRS	European Sustainability Reporting Standards
GHG	Greenhouse Gas
I4.0	Industry 4.0
ICT	Information and Communications Technologies
IoT	Internet of Things
MOL	Middle-of-Life
NFRD	Non-Financial Reporting Directive
PLM	Product Lifecycle Management

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1 Introduction

Chapter 1 aims to present concepts and the context of the study, the purpose of the study, ending with describing the delimitations.

1.1 Concepts and notions

Concepts and notions will be described in this section to provide an understanding of the most important theoretical descriptions needed moving forward with the report.

1.1.1 Product Lifecycle Management

During 2001, the start of the Product Lifecycle Management (PLM) paradigm took place, a paradigm which thereafter emerged. Previously, the paradigm of management of a company's data was on a departmental level, based on mainly four departments (Stark 2022-a, p. 2):

- The Marketing Department
- The Engineering Department
- The Manufacturing Department
- The After-Sales Department

During most of the twentieth century, the departmental paradigm was both generally a shared and agreed management approach. (Stark 2022-a, p. 2) Over the last 50 years, concepts and approaches has developed regarding operations planning and control. Information and communication technologies (ICT) have been enablers for facilitating the improvements of computer-based systems used for planning of operations and control. Systems for manufacturing planning and control, such as Enterprise Resource Planning (ERP) systems, and Material Requirements Planning (MRP) systems, have existed before the PLM system concept developed. (Olhager, 2012)

PLM has been widely adopted and defined differently by different communities. Generally, PLM can be defined as a product centric, lifecycle-oriented, business model, supported by ICT, where product data is shared among actors, processes, and organizations throughout the different lifecycle phases of a product. This concept enables to achieve desired performances and sustainability for the product and related services. (Terzi et al., 2010; Stark 2022-a, p. 1) In Figure 1, the PLM system is fundamentally illustrated.

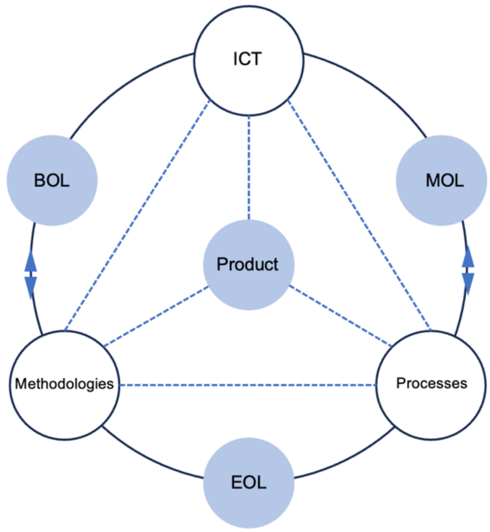

Figure 1: Fundamental illustration of the PLM System. (Terzi et al., 2010)

The scope of PLM operations covers the three main phases of a products lifecycle (Terzi et al., 2010):

Beginning-of-Life

Beginning-of-Life (BOL) includes the design and manufacturing phases of the product lifecycle. The design level includes product, process, and plant design. The design action has multiple sub-actions, such as identifying requirements, defining reference concepts, and performing tests. The manufacturing phase consists of the production of the artefacts and internal plant logistics needed. During this phase the product concept is generated and thereafter physically realized. The BOL phase includes a use of many tools, techniques, and methodologies, to enable designers, planners, and engineers to develop the design of the product and the production process, planning the production facilities and managing the manufacturing of the products with combination of a diverse selection of suppliers. To manage the manufacturing of the products with diverse suppliers, an ERP system is often used to support the information sharing. (Terzi et al., 2010)

Middle-of-Life

Middle-of-Life (MOL) includes the actions distribution, use and support. The support consists of the repair and maintenance of the product. During the MOL phase, the product has reached the end customer, e.g. product user/consumer and/or the service providers. The history of the product is often collected to enable an up-to-date report regarding the status of the product. (Terzi et al., 2010)

End-of-Life

End-of-Life (EOL) is the phase where the products are retired. The product often gets recollected by the company, to enable recycling, including disassembling, remanufacturing, reusing, etc. (Terzi et al., 2010) Reverse logistics is the term that normally summarizes the processes in the EOL phase of PLM. The concept can be reflected as a reverse supply chain, where the retired product either is transported into a new lifecycle or is going through the disposal process. (Hribernik et al., 2011) The phase begins when the product no longer is satisfying its user. Some of the useful information from the EOL is about the valuable parts and materials and other knowledge valuable for material reuse manners that should reach the recyclers and reuse actors. This enables to obtain accurate information about the status of the product. (Terzi et al., 2010)

1.1.2 PLM methodologies

Methodologies in a PLM context is defined as a system of principles, practices, and procedures. Depending on the different needs required from the different phases of the product lifecycle, different methodologies are used in the PLM system. Information and product data provided by a PLM system and human knowledge are required to be able to apply and use the methodologies. (Terzi et al., 2010)

The methodologies are grouped into four typologies (Terzi et al., 2010):

Procedures and techniques are used to support the designers and engineers during the development phase of a product solution. Examples of these methodologies are: Theory for inventing problem solving (TRIZ), Quality Function Deployment (QFD), Value Analysis and Engineering (VA&E), Design to Cost (DTC) and Target Cost Management (TCM).

Rules and procedures, which are based on past experiences, imply to the users how to consider needs and constraints existing in the product lifecycle phases. Examples of rules and procedures are: design for X (where X can be e.g., manufacturing, assembly, maintenance, environment, etc.), robust design, process capability, modular design and platform design, design for variety, variety reduction program, cluster design, etc.

Techniques for the evaluation, which evaluates the responsiveness of the product regarding the needs occurring in the different phases. Examples of methodologies are: Lifecycle Analysis Engineering and Assessment (LCA), risk analysis and Failure Modes Effects Analysis (FMEA) and Failure Modes Effects and Critically Analysis (FMECA), Fault Tree Analysis (FTA) and fishbone/Ishikawa diagram.

Management approaches and rules, aims to support continuous improvement in an enterprise. Some examples: Just In Time (JIT), lean manufacturing and thinking, Six Sigma, total quality management, and total productive maintenance.

The PLM System also includes a certain amount of ICT tools, platforms, and systems. ICT tools are mostly used during the BOL phase, with a large variety of tools, while in the MOL and EOL phases it is less used. New technologies and customer needs, for instance intelligent products and an improved traceability of the products, enables an increased relevance for ICT in these later phases of the lifecycle as well. In Figure 2, is a map of different ICT tools and to what phase of the lifecycle they are used. (Terzi et al., 2010)

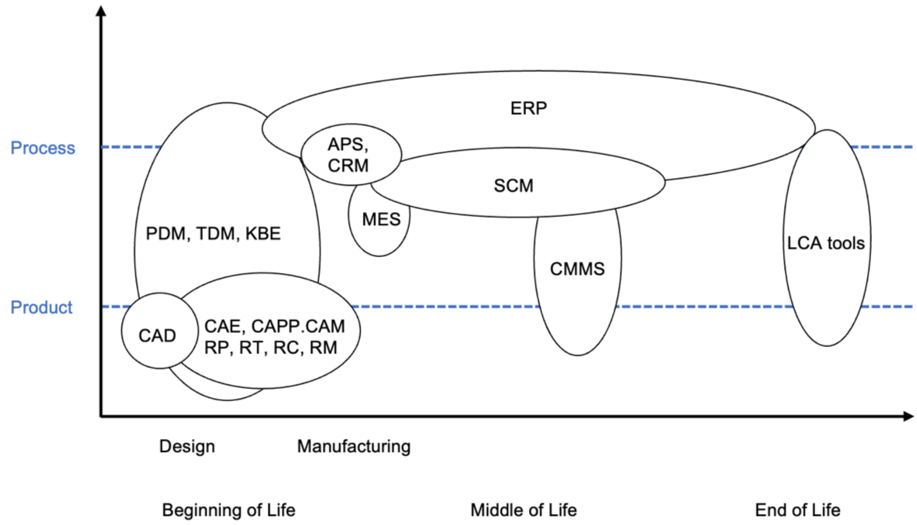

Figure 2: ICT tools across the product lifecycle. (Terzi et al., 2010)

1.1.3 Circular economy

In March 2020, the European Commission adopted the New Circular Economy Action Plan (NCEAP), which is one of the main building blocks occurring in the European Green Deal. The transitioning plan to a circular economy in the EU will lead to reduced pressure on natural resources, and creation of sustainable growth and jobs. (European Commission, n.d.-c)

The current transition, occurring in many companies in lots of sectors where the use of Circular Economy (CE) concepts plays a key role to capture more value from resources providing customers with better experiences, can be referred to as a paradigm shift. (McKinsey & Company, 2016)

Since the industrial revolution, the value creation has been based on a linear model of value creation, beginning with extraction, and ending with EOL disposal. Resources acquired, such as the energy and labor, have been exposed as wasteful by contemporary trends, which have led to trends making it practical to conserve assets and materials to maximize the value that can be derived from them. An increased will, from both people and companies, have emerged to use durable goods. (McKinsey & Company, 2016)

A circular economy maintains the value of products, materials and resources as long as possible. This approach results in minimization of waste. (European Commission, n.d.-d). CE aims to extend the product lifecycle by slowing, narrowing, and closing the resource loop with support from biological, technical, and information cycles. (Acerbi, 2021)

1.1.4 Sustainability reporting

The Non-Financial Reporting Directive (NFRD) directive made large public interest entities obliged to provide information at a management and control level regarding aspects such as environment, social issues, corruption prevention and diversity measures. The directive was designed in a way allowing the concerned companies a certain level of freedom in implementation and design of the directive. (Birkmann et al., 2024)

In April 2021 the European Commission presented its proposals on CSRD, with background from 2018's call from the European Parliament to revise the NFRD. The NFRD had some shortcomings, and the directive was perceived as largely insufficient and unreliable. Therefore, CSRD was made more detailed regarding reporting requirements on companies' impact on the environment, human rights and social standards. (European Parliament, 2022)

As a part of the European Green Deal, EU's strategy to be the first climate neutral continent, the continent to reach net-zero 2050 (European Commission, n.d.-a), CSRD strengthens the rules regarding social and environmental information required to be reported by companies. The directive will ensure stakeholders and investors having access to the information needed to make an assessment of companies' impact on people and environment. Investors will also be provided with the financial information needed to assess financial risks and opportunities related to climate change and sustainability issues. The companies who are required to report to the CSRD also must report to the European Sustainability Reporting Standards (ESRS). ESRS are standards developed in a draft by EFRAG, before known as European Financial Reporting Advisory Group. The group is independent body with the task to bring various stakeholders together. (European Commission, n.d.-b)

1.1.5 Artificial Intelligence

Recently, Artificial Intelligence (AI) has emerged and become one of the driving forces as well as a transformative technology, opening opportunities and challenges over the scope of different domains of applications. (Turi 2024, p. 3)

AI is the ability of a machine's capacity to perform the cognitive functions that can be associated with the human mind, with functions such as perceiving, reasoning, learning, interacting with an environment, problem solving, and exercising. When applying AI to real-world problems it has an extensive impact for the business world. When using AI, companies both have the opportunity to make business more efficient and profitable. (Turi 2024, p. 4; McKinsey & Company, 2023)

It is also important that companies are aware of how they choose to use the AI system to assist humans, as well as their ability to explain to shareholders and the public regarding the AI systems functionalities. When companies succeed with these aspects the AI makes the most value and it builds and earns trust among the shareholders and the public. (McKinsey & Company, 2023)

1.2 Problem description

It has become more important within companies to manage data regarding their products, and most companies currently struggle to use data management's full potential. (Desai et al., 2022) Sharing and managing product data, information and knowledge are key aspects of Product Lifecycle Management (PLM). (Terzi et al., 2010) It is both a technological and strategic challenge to implement a PLM system strategy in a company. (Gehrke et al., 2020) There also exists barriers companies need to overcome, such as a major systematic change, to have a successful circular economy implementation. (Cantú et al., 2021) Implementing CE into PLM will require the different stages of the product lifecycle to be modified. (Villamil Velasquez et al., 2020)

Currently, companies and organizations also stand in front of the challenge to give more detailed reports regarding their information to give investors and stakeholders the correct information to assess the impact of companies on people, environment, in line with the newly enforced directive, CSRD. (Council of the EU, 2022; European Commission, n.d.-b) The more detailed reporting will contribute to ending greenwashing, strengthen the EU's social market economy, and build the foundation for the sustainability reporting on a global level. (European Parliament, 2022)

This aspect is one of many arrangements, with roots in the growing concerns with sustainability issues and the emergence of the circular economy paradigm, in combination with new technological changes and a continuous competition. All these challenges press a need to redefine the PLM approach from a mass production paradigm to a new more personalized, on demand, customer-driven and knowledge-based production paradigm. Currently, the PLM approach is partially missing the incorporation of aspects enabling the shift, such as an enhanced collection and evaluation of information collected from production processes, distribution, retail, and customers. (de Oliveira & Soares, 2017)

The increase of complexity among products has created an enterprise unbundling, where companies mostly focus on the core activities and outsourcing support activities, which creates a value chain distribution including several organizations. This decentralized environment, with collaborations between stakeholders involved in most steps of the product lifecycle activities challenges the current PLM approach and it is in need of technologies such as Internet of Things (IoT) and Big Data. The growing sustainability concerns and an increased importance of CE concepts are developing, which creates requirements regarding improved products with longer usage time, and with multiple lifecycles. (de Oliveira & Soares, 2017)

1.3 Thesis description

The overall objective with the master thesis is to provide the case company, Tetra Pak, with further insight into the opportunities with integrating circular economy principles with the PLM system at the company, and how this strategically can be improved and managed in the future, based on a literature review, and internal and external information collection.

The study will explore the topic of the thesis and apply it to one of Tetra Pak's product segments, a general filling machine. The filling machines are the equipment that produces the packages by forming, filling and sealing them.

The thesis will analyze the current state of the PLM system at Tetra Pak, based on a current state analysis model to investigate potential weaknesses, strengths, opportunities, and threats that potentially can impact the circumstances of the context. Moreover, a benchmarking approach with two external companies will provide an external perspective to measure against. Lastly, the analysis will address a unique potential future strategic navigation forward.

1.4 Purpose of the thesis

The purpose of the study is to explore the current state of the PLM system at Tetra Pak regarding how it can be adapted to better support the circular economy principles. Both by applying it to a real case study and analyzing the theoretical background on the topic.

1.4.1 Problem Statement

The aim of the thesis is to answer the following problem statement:

How can Tetra Pak´s PLM systems be adapted to better support circular economy principles, including product reuse, remanufacturing, and recycling, to drive sustainable product innovation?

1.4.2 Research questions

The thesis is structured with seven research questions (RQ's) with the aim to fulfill to answer the problem statement. The questions are divided into three categories: *What has been implemented*, *Current state*, and *Future state*.

What has been implemented

RQ1: How does the current management of product data work at Tetra Pak with help from their PLM system?

RQ2: Does the company currently work with the circular economy principles? If yes, what type of company data is this work based on?

RQ3: How does the current management of product data work in relation to the circular economy principles regarding their product segment, the filling machine?

Current state

RQ4: Based on the current situation, what type of data is managed/needs to be managed from Tetra Pak's PLM system to support the work with the circular economy principles regarding their product segment, the filling machine?

RQ5: How is this/will this be managed strategically regarding the specific product segment? Who is in charge/will be in charge of managing the data? How will Tetra Pak support this data managing process?

Future state

RQ6: Will there be a benefit for the business to improve the support of the PLM system regarding the circular economy principles at Tetra Pak based on the study of the product segment, the filling machine? Are there any metrics, KPIs, that could be used to demonstrate that there will be improvements at Tetra Pak with this collaboration between the PLM system and the principles of the circular economy?

RQ7: Are there any possibilities to use new AI technology to make the data managing more efficient at Tetra Pak?

1.5 Target audience

The target audience for this master thesis project is primarily a student in Industrial Engineering and Management who is studying the last years of their engineering education. Furthermore, the thesis can also target industry professionals within the PLM industry to provide further insight and strategic navigation in the context of the problem statement.

1.6 Focus and delimitations

The thesis will focus on the whole Tetra Pak's current situation regarding their PLM system and investigate the opportunities for the whole organization in the context of the problem statement.

The thesis will be limited to analyze one product segment at Tetra Pak, a general filling machine, to narrow the scope of the thesis.

The product lifecycle phases also have been limited to focus on the end-of-life phase where the product is retired and reaches the reverse logistics stage.

Furthermore, regarding Corporate Sustainability Reporting Directive (CSRD), the scope is limited to explore one of the requirements of the directive, the scope 3 emissions. Both to have a general overview and specifically investigate the downstream emission category, end-of-life treatment of sold products.

To broaden the perspective, two interviews was conducted with two external companies to gain an understanding of how this work looks in other organizations and how far they have come. One interview with a PLM system supplier was conducted, to get an understanding regarding how PLM systems are defined and evolving. The external companies are not working in the same but in similar industries as Tetra Pak.

The timeframe of the thesis was a limiting factor regarding the number of internal interviews and external companies that could be included in the study.

1.7 Report outline

Table 1 presents the chapters included in the report to give an overview.

Table 1: A brief overview of the report outline.

CHAPTER	OVERVIEW
1. Introduction	Chapter 1 gives a summary of the context of the study. Starting with concepts, moving into the thesis description, presenting the research questions and ending with the focus and delimitations of the study.
2. Methodology	Chapter 2 provides a description of the methodology used to perform the study. The research strategy is introduced and its components. Ending with discussing the research quality.
3. Theoretical background	Chapter 3 introduces the collected theoretical background from the literature review of the study required to perform the analysis.
4. Empirics	Chapter 4 aims to present the collected data from the internal and external interviews with the case company and the benchmarking companies.
5. Analysis	Chapter 5 presents the analysis of the collected data from the theoretical background and the empirical findings. Resulting in a proposed strategic navigation forward for the case company.
6. Conclusion	Chapter 6 concludes the report and answers the research questions. The chapter ends with discussing future research regarding the topic.
References	References provides the sources used in the study.
Appendices	The appendices provide additional descriptions and the interview guides used in the study are placed there.

2 Methodology

Chapter 2 presents and motivates the research strategy and the methodology used in the research. Furthermore, the data collection and analysis methodologies are discussed. The chapter ends with a discussion regarding the trustworthiness of the study.

2.1 Research method

By a comparison between the four major research methodologies, according to Runeson and Höst (2009), the case study was the most appealing alternative. It also became the most natural and suitable option for the thesis purpose, when it was decided to write the thesis in collaboration with a company. Also, when the problem statement includes an examination of contemporary events in connection to its real-life context the case study is the most favorable alternative. The case study is of the character of an exploratory research due to the studies purpose of seeking for answers to what is happening and insights as well as providing ideas for new research.

This thesis project is based on one major case study with Tetra Pak as the state of art. To give a broader perspective, two minor complementary case studies have been conducted with two companies in similar industries. A minor study of a PLM system supplier, to provide further insight on the topic has also been conducted.

There are different purposes served by different research methodologies, and there does not exist one type of research methodology that fits all the kinds of purposes. (Runeson & Höst, 2009) Therefore, the decision regarding what research method to use becomes crucial, to provide the right results to the chosen thesis purpose.

There exist four major research methodologies according to Runeson and Höst (2009):

- *Case Study*, with the purpose to investigate an empirical topic supported by following a set of prespecified procedures. A case study is often used when the research is aiming to answer questions such as "How?" and "Why?" and is also a preferred method when examining contemporary events within its real-life context, which can be especially useful when there are no clear boundaries between phenomenon and a context. Commonly, case studies are used in contexts like phycology, sociology, political science, social work, business, and community planning.

- *Survey* includes a collection of standardized information from a chosen population, or from one sample. The data collection could be conducted by a questionnaire or interview.

- *Experiment*, also called controlled experiment, includes measuring the effects of manipulating one variable on another variable as well as the subjects are assigned to treatments by a random approach. Similar to controlled experiments are quasi-experiments, which differs by the fact that subjects are not assigned to treatments randomly.

- *Action* research is a research methodology with a close relation to the case study, where the purpose is to influence or change aspects of the focus research. Action research is more focused and involved in the change process.

According to Runeson and Höst (2009) there exists four purposes for research which can be categorized as *exploratory*, *descriptive*, *explanatory* and *improving*. The *exploratory* aims to find out what is happening and to seek after new insight and to generate ideas for new research. The purpose of the *descriptive* research is to portray a situation or a phenomenon. The *explanatory* purpose is to find an explanation to a situation, while the *improving* purpose is to find an improvement of a specific aspect of the researched phenomenon.

2.2 Research strategy

The research strategy of this master thesis is inspired by Yin's (1994) version of a case study research strategy with some adjustments. His strategy worked well with how the research strategy was outlined and performed in this thesis. Yin is also one of the foundational methodologists (Yazan, 2015). The research strategy used in this thesis is illustrated in Figure 3 and it is an iterative process, with linear guidelines. The illustration is divided into three steps, the planning phase, the data collection phase, and the analysis phase.

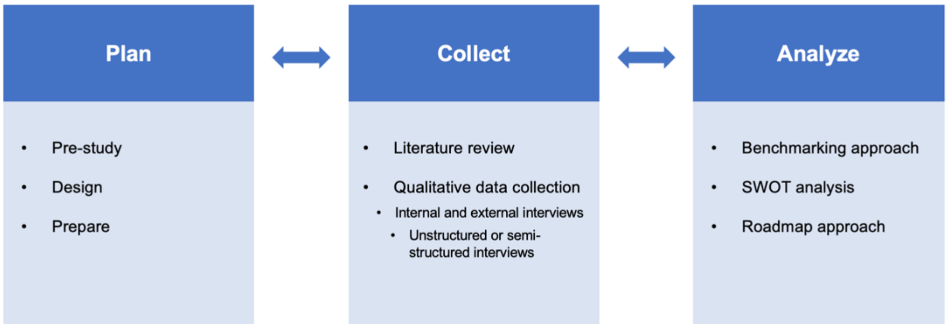

Figure 3: An inspired and adjusted version of Yin (1994) description of a case study research strategy.

Each step of the research strategy will be described and motivated further in this chapter. The chapter will end with discussing the quality of the research.

2.3 Planning, designing and preparing

The planning stage of the research began during late-autumn 2023 and ended in the beginning of January 2024. Based on a discussion at Tetra Pak and the PLM department, the PLM team suggested a problem statement and an agreement was confirmed. The problem statement was finalized during November 2023, based on a suggestion by Tetra Pak and approved by the researcher.

The context of the problem was briefly investigated to become familiar with the problem area. The next step included, developing the research questions and arranging them into three different categories. Based on the research questions a target document was formulated and approved by all parts included. The target document, later on became the base of the project plan for the thesis, finalized in late December 2023. The thesis began according to plan during January 2024, progressing according to the agreed upon project plan.

When a research strategy is chosen, the design and planning stage begins. (Yin 1994, p.18) All empirical studies have a research design of some kind.

The design of a research can be interpreted as the action plan where the sequence connects the empirical data with the initial research questions and conclusions. The steps in the design action plan can be interpreted as the collection and analysis of relevant data. (Yin 1994, p.19) The preparation step before a case study means developing the skills of the investigator, where training can be used to develop more skills for the case study research. (Yin 1994, p.54)

2.4 Data collection methods

The thesis data collection has been supported by three data collection methods. Firstly, a pre-study, enabling to define the goals and frames the thesis aims to reach. Secondly, a literature review, providing the secondary data according to available theory on the topic of the thesis. Lastly, the case study method, interviews, providing primary data from professionals and experts in the field.

2.4.1 Pre-study

To be able to define the thesis objective, scope, goals and the frames, a pre-study was conducted to analyze the existing literature on the context and in other areas around the topic. To create a general comprehensive picture of the thesis context the researched literature was wide and more general.

The findings from the pre-study later resulted in the target document and the project plan which established the research questions that has been described earlier in the thesis. The pre-study also supported the development of the interview guides for the case study.

2.4.2 Literature review method

A literature review has been conducted through internal documentation at the case company, and existing theory, research, and directives on the topic available in databases. Three databases have been used to perform the literature review: LUBsearch Discovery, Scopus, and Google Scholars. Also, Tetra Pak's intranet, has been used and few sources are from other organizations webpages. The literature review has been continuously developed and adjusted during the project.

Reviewing literature is an essential part of a research to demonstrate the awareness of the current state of knowledge regarding the subject of a study. Moreover, to demonstrate the subject's limitations as well as the wider context in relation to the research. Usually, the literature search is performed early in the research, but essentially it can be under continuous development during the whole project. The literature review often begins with defining parameters and key words in relation to your subject when conducting the literature collection. Furthermore, the parameters can be redefined and more specific leading to conduct a more precise literature collection. (Saunders et al. 2007, pp. 55-56)

2.4.3 Case study method

The chosen methodology for the data collection is favorable for a qualitative data collection approach and was decided to be in depth interviews. The qualitative interviews were of the character of an unstructured or semi-structured interview. The script for the unstructured or semi-structured interviews was incomplete and made beforehand, giving room for the interviews to become improvised from time to time. The script followed the minimum guidelines provided by Myers & Newman (2007). The interviews have been conducted internally at Tetra Pak with relevant people in the PLM team and Sustainability team to support the information and data collection regarding the project. Interviews with two companies beyond Tetra Pak and one with a PLM system supplier have been conducted to broaden the perspective of the thesis. The interviews have followed the guidelines introduced by Myers & Newman (2007). If the circumstances allowed, the interviews have been conducted in person, but in some cases via Teams because of the travel distance.

The empirical data may be collected through either a quantitative or qualitative data collection approach, but can also be mixed, which provides a better understanding of the subject studied. Quantitative data is referred to as data involving numbers and classes, while on the other hand the qualitative approach is involving words, descriptions, pictures, diagrams etc. Case studies are mostly based on qualitative data and provide richer and deeper descriptions of characteristics. (Runeson & Höst, 2009)

The qualitative interviews can be seen as one of the most important tools used to collect data, when a qualitative research approach is conducted. The qualitative interviews can be used in many different contexts of a qualitative research. Examples of different contexts of qualitative research where qualitative interviews can be used are in case studies, action research, grounded theory studies and ethnographies. (Myers & Newman, 2007)

Qualitative interviews appear in various types and the Myers & Newman (2007) lists three of them:

1. *Structured interview*. This qualitative interview type has the characteristic as an interview using a complete script which is prepared beforehand. This fully completed version of the script helps hinder the interview from becoming improvised. Often, this form of interview is used in surveys, and commonly they are not conducted by the researcher.

2. *Unstructured or semi-structured interviews*. In this type of interview an incomplete script is used when the interview is conducted. When interviews are done this way, it enables the interviewer to improvise when needed. There are always some questions prepared beforehand by the researcher but not as completed as in the structured interviews.

3. *Group interviews*. During a group interview, two or more persons are being interviewed at the same time, which could be conducted by one or more interviewers. Group interviews can be conducted using either structured or unstructured interview approaches.

Myers & Newman (2007) introduces minimum guidelines for an interview script:

- Preparation of an opening, giving the interviewer the opportunity to do an introduction.
- Preparation of an introduction, where an explanation is provided regarding the purpose of the interview.
- Preparation of the main questions that will be discussed during the interview.
- Preparation of the closing remarks, where permission to ask additional questions could be included as well as leaving room for the interviewee to leave recommendations to other candidates suitable for an interview.

2.4.4 Selection of respondents

The respondents selected for the internal interviews was a selection from both the PLM team and the Sustainability team at Tetra Pak in Lund to collect data aligned with the scope of the research. The chosen respondents were selected based on their expertise in the areas and on different levels in the company. It was important that the respondent had the knowledge needed to answer the questions formulated in the interview guides to provide data coverage.

The respondents for the external interviews were selected to give a broader perspective to the topic. Therefore, two companies in related industries working with PLM were selected. It was also interesting to analyze the perspective of the PLM system supplier perspective in the context of the study.

The aim with a case study is to provide an analytical generalization where the analyzed cases have common characteristics giving relevant findings, resulting in external validity. (Runeson & Höst, 2009)

2.5 Analysis method

Three major analysis method frameworks have been used to answer the research questions in this study, a benchmarking approach, a SWOT analysis, and a roadmap approach.

The analysis part of the case study is about examining, categorizing, tabulating resulting in addressing propositions of a study. It is the most difficult part of a case study, because of the absence of well-defined strategies and techniques in the past. (Yin 1994, p.102) Different strategies exist to perform an analysis but they are not one-size fits all and needs to be applied uniquely depending on the study. (Yin 1994, p.125)

2.5.1 Benchmarking approach

To develop a broader perspective to the study interviews with two external organizations was conducted. Based on the theoretical and empirical findings attributes were selected to benchmark among the three companies.

Benchmarking is defined as a tool used for improvement, provided by comparing organizations in a specific area. The tool enables an external focus to achieve competitive advantages and provides break-through thinking. It is interpreted as a process continuously measuring and comparing business process against each other resulting in providing information regarding improvement areas. (Bhutta & Huq, 1999)

2.5.2 SWOT analysis

The SWOT analysis was uniquely performed in three stages in this study which resulted in the current state analysis of this thesis, the final stage, according to Figure 4. Stage 1 is the initial stage of the SWOT based on the internal interview perspective. Stage 2 is the strategic stage including the completed literature review, and the internal and external interviews. Lastly, stage 3 is the final stage providing the current state analysis in the SWOT framework with the contributions to Tetra Pak.

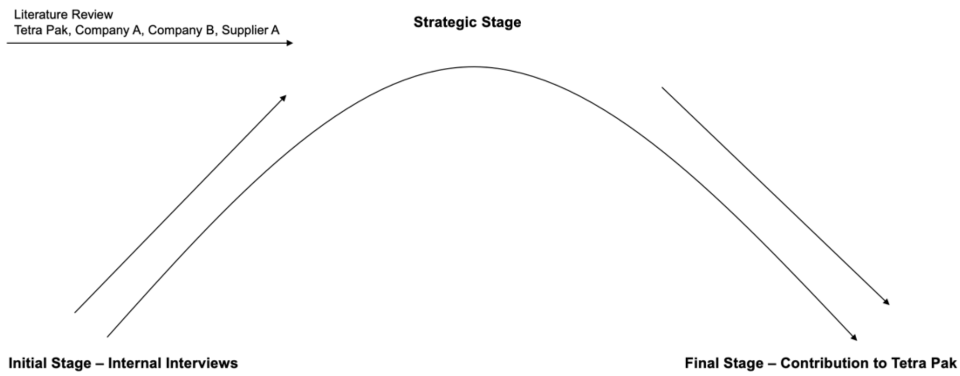

Figure 4: Illustration of the SWOT analysis approach used in this study.

The current state analysis was performed by using the SWOT framework, which is one commonly used tool for strategic planning. Internal strengths and weaknesses and external opportunities and threats are placed in four quadrants. The analysis provides planners with a better understanding of the strengths capabilities to leverage new opportunities and understanding for the weaknesses capabilities to slow down progress or strengthen threats. The framework also has the potential to provide future strategies to overcome weaknesses and threats which foster decision-making. (Helms & Nixon, 2010)

2.5.3 Roadmap approach

The benchmarking approach and the current state analysis was the foundation together with the theoretical background for the proposed strategic navigation forward for the company, presented in a roadmap. The roadmap was developed over time and was the last part of the analysis.

The roadmap approach is a simple, flexible, and useful process presenting a structured system thinking, visual methods addressing challenges and opportunities within organizations, which supports the communication and alignment regarding strategic planning and innovation management. (Vinayavekhin et al., 2021) The roadmap provides a structured framework addressing three questions: Where do we want to go?, Where are we now?, and How can we get there? (Phaal & Muller, 2007).

2.6 Research quality

The research quality is an important aspect when conducting a research study, this was a key aspect when the data collection methodology proceeded in this study. Key points from Runeson and Höst (2009), regarding the validity and reliability, have been considered and evaluated continuously during the thesis project.

It is necessary to understand the level of quality the chosen interview method provides and its disadvantages and difficulties. (Myers & Newman, 2007) According to Runeson and Höst (2009) validity is a metric determining the trustworthiness of the result. It assesses to what extent the results are true or biased by the researcher who has its own subject point of view. The validity must be considered before the analysis takes place, during the beginning of the case study.

Runeson and Höst (2009) mentions four classifications of validity:

- *Construct validity*: Assesses the operational measurements regarding what is studied in relation to the purpose investigated according to the chosen research questions by the researcher.

- *Internal validity*: Takes into account the causal relations, that can occur when factors are investigated and their level of impact on one other.

- *External validity*: This category considers the generalization of the findings and to what extent it is possible to generalize. It analyses the findings' relevance to other cases.

- *Reliability*: The dependency between the specific researcher and the data and the analysis is an important aspect as well when investigating the validity. In a hypothetical way of thinking, the results should be the same if another researcher conducted the same study.

The validity can be improved if for instance triangulation is performed (Runeson & Höst, 2009; Carter et al., 2014). Triangulation means that the qualitative research strategy is investigated by convergence of information taken from different sources (Carter et al., 2014).

3 Theoretical background

Chapter 3 presents the results from the literature review. This chapter will cover the findings from the literature review to support the analysis, proposals, and contribution of the thesis.

3.1 Closed loop PLM system

In this section the theory behind the concept closed loop PLM will be described. In addition, the theory regarding the benefits and challenges with closed loop PLM will also be presented.

3.1.1 Definition of closed loop PLM

Data, information and knowledge are created in the BOL, MOL, EOL phases of a products lifecycle, see Figure 5 for a visualization of the three lifecycle phases of a PLM system. In the BOL and MOL phase the product has support from intelligent systems such as CAD/CAM/CAE and other simulation software. (Kiritsis, 2011) Product Data Management (PDM) means the use of software helping organizations to both connect and communicate product information globally during product lifecycle stages where product development tools are used. (PTC, n.d.) The use of PDM can be performed effectively and efficiently during the BOL and MOL phases, but when transitioning to the EOL phase the use become less effective, frequent, and complete. (Kiritsis, 2011)

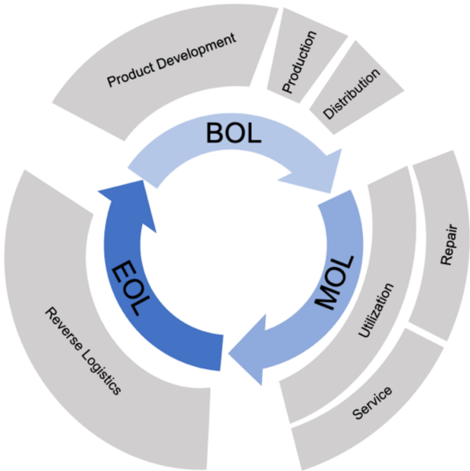

Figure 5: The three phases of the product lifecycle. (Hribernik et al., 2011)

To gain competitive advantages in the society of today and the future the focus needs to be on innovation to be able to provide the customers a holistic satisfaction from the product. In today's changing business environment companies are therefore looking for new innovative ways to provide maximized value to the customers as well as gain competitive advantages. In order to succeed in the modern society, a need of stronger focus of product design and the product lifecycle management phases can be seen as critical areas. This development of value characteristics therefore emphasizes a need for companies to shift focus to the design, BOL and EOL phases instead of the manufacturing phase. In the past investments have focused on just in time, quality management, and total productive maintenance to improve product cost, quality, and time to market. Focusing on issues such as environment, risk, lifecycle cost and service quality are also important factors to invest in. (Terzi et al., 2010)

The most traditional IT solutions used in the PLM system mostly support and address the initial phases of the product lifecycle and product variants rather than individual items. The tools offer solutions such as document, workflow, and project management functions. The way the system operates impacts how it can manage the MOL and EOL phases. The system's way of operating limits its potential to improve the reverse logistics processes existing in the EOL phase. The system is limited because of its abilities to seamlessly have availability to data, information knowledge from an entire lifecycle perspective, including the MOL and EOL phases. (Hribernik et al., 2011)

The main goal with PLM is to be able to manage the products data and information across the whole product lifecycle phases. The information flows are in most cases interrupted when the product is sold to the customer which is preventing the company to access the feedback consisting of data, information, and knowledge that occur under activities during service, maintenance, and recycling (Kiritsis, 2011). See Figure 6 for a visualization of a more specified version of the EOL phase. A general desire among many stakeholders in the supply and value chain has occurred, a desire to have a seamless flow, tracing and updating of information about a product after product delivery reaching the EOL phase and where this information also comes back to the designers and producers. (Terzi et al., 2010)

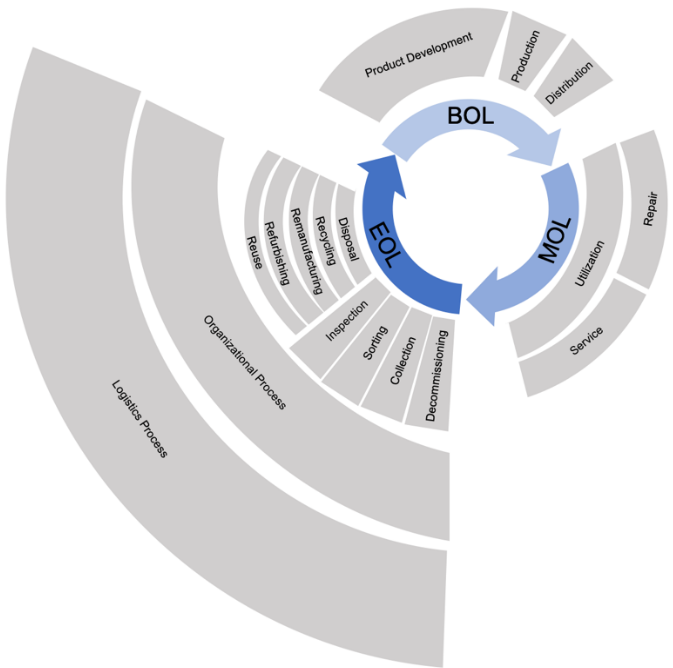

Figure 6: Reverse logistics specified in EOL. (Hribernik et al., 2011)

Approaches to address the reverse logistics processes can both be technical and non-technical. One approach that have significant attention is the concept of closed loop PLM. (Hribernik et al., 2011) The closed loop PLM can be described as an ecosystem which enables all stakeholders to a product to have access and control over product information in any product lifecycle phase. (von Stietencron et al., 2017; Kiritsis, 2011) The system has the aim to have availability of relevant product information at any phase of the product lifecycle. The concept also focuses on closing the information loops existing between the different layers of IT, including data acquisition, middleware, and knowledge transformation to the business application. Furthermore, the concept therefore has proposed different methods recommending applying information technology to be able to solve the information gap challenge. (Hribernik et al., 2011)

3.1.2 Actors and processes in the reverse logistics

According to Hribernik's et al. (2011) research paper, based on use cases and a literature review, a generic view of the EOL processes and actors has been achieved. The generic identification of the EOL processes and actors is a high-level view and designed to be applied to lots of different products.

A general representation of the processes in the reverse logistics phase of the product lifecycle are illustrated in Figure 6 where the core EOL processes are presented. The preparatory process includes decommissioning, collection, sorting and inspection. The preparatory process often then leads to one of five options: disposal, recycling, remanufacturing, refurbishment, or reuse. Lastly, the reverse logistics phase ends with an organizational process leading to the logistics process. (Hribernik et al., 2011)

A general identification of actors in the reverse logistics was made. The identified actors were: product owner, product user, executive officer of the plant operator, worker at the plant, vendor of the plant operator, executive officer of the logistics company, worker at the logistics company, product manufacturer, product distributor, municipality, legislator. These identified actors across the reverse logistics phase of the lifecycle generally consequently participate in the identified preparatory processes, with some exceptions, see Table 2. In Table 2 the blue boxes represent processes the actors usually participate in, the white boxes represent actions the actors commonly do not participate in, and the grey boxes represents that the actors usually participates indirectly in the process, with some exceptions. The EOL phase can be different depending on the type of product. The way a refurbished product is returned to the market might look different from case to case, where one option could be returning the product to the original owner, and another could be reselling the product in retail. (Hribernik et al., 2011)

During the last steps of the closed loop logistics process, the organizational and logistics process, the information management strategies are commonly less developed in comparison to other fields of logistics. The complexity regarding the different actors identified in the reverse logistics phase and different levels of participation in the reverse logistics process also contributes to worsen the circumstance. The absence of a proper information management approach results in an inefficient EOL process as well as overlooking the value the information sources can provide other processes in the PLM phases. (Hribernik et al., 2011)

Table 2: The actors in the reverse logistics phase and their involvement. (Hribernik et al., 2011)

	Decommissioning	Collection	Sorting	Inspection	Reuse	Refurbishing	Remanufacturing	Recycling	Disposal	Organisational Process	Logistics Processes
Product Owner	■	■	■	■							■
Product User	■	■	■	■							■
Executive Officer of the Plant Operator		■	■	■	■	■	■	■	■	■	
Worker at the plant		■	■	■	■	■	■	■	■		
Vendor of the Plant Operator					■	■	■	■	■	■	
Executive Officer of the Logistics Company		■								■	■
Worker at the Logistics Company		■									■
Product Manufacturer	–	–	–	–	–	–	–	–	–	–	–
Product Distributor	■	■	■	■							
Municipality	■									■	
Legislator	–	–	–	–	–	–	–	–	–	■	–

3.1.3 Benefits with closed loop PLM system

The outcome of closing the information loops will have positive consequences when shifting from a BOL and MOL focused system to embed the EOL areas. This approach will open the opportunity for all the actors playing a role across the product lifecycle to track, manage, control the product information at any phase of the lifecycle. (Terzi et al., 2010; Jun et al., 2007)

Closing the information loops can lead to following consequences (Terzi et al., 2010):

- Provide the producers with complete product data about usage, retirement conditions, and disposal of the product.

- Assist experts working with service, maintenance, and recycling with a complete and up-to-date report regarding the product status, and real-time assistance and advice.

- The designers will be provided with expertise from more players throughout the product lifecycle phases when improving product design.

- Experts working with recycling and reuse will be provided with accurate information regarding the value of the materials which arrives from the EOL.

According to Jun et al. (2007), Closed Loop PLM makes it possible to help with the decision-making process regarding a variety of operational problems that are connected over the whole lifecycle due to its possibility to collect information in real-time.

3.1.4 How will the information loops be closed?

The closed loop PLM concept proposes different methods recommended to apply information technology to be able to solve the information gap challenge. (Hribernik et al., 2011; Terzi et al., 2010) The concept creates a need of IT concepts and infrastructure which can acquire, transmit, and manage information for individual products across the entire lifecycle. Furthermore, a technological tool is needed to integrate the different actors and respective information system throughout all lifecycle phases. (Hribernik et al., 2011)

The common denominator between the products stakeholders is in many cases the product or component. From a technological perspective, intelligent products are therefore a concept that can be used to address this challenge and become the main enabler for closed loop PLM. (Holler et al., 2016; Främling et al., 2013; Hribernik et al., 2011)

Intelligent products can be described as physical items that may be transported, processed or used. Product Embedded Information Devices (PEID) is an example of an intelligent product, where Radio Frequency Identification Devices (RFID) is one type PEID. (Hribernik et al., 2011)

In relation with Hribernik et al. (2011), to improve service quality and design of products, according to Terzi et al. (2010), a need of development of identification technologies exists. RFID is an example of an identification technology, with the ability to enable products to have embedded information devices, RFID tags, and onboard computers, which opens the possibility to provide product information during the entire lifecycle and have access to the information at any time. This technology will be able to solve the gap of information after the product is delivered to the customer and until the last stages of EOL without the mentioned limitations. This technology solution opens the opportunity for designers and engineers to have easier access to the MOL and EOL information and therefore give improved BOL decisions. (Terzi et al., 2010)

Generally, the concept of closed loop PLM has become a fact among various industrial sectors and businesses. The concept usually works best with already integrated systems which includes software and systems which uses PEID. Furthermore, these technologies can provide real-time information to information management systems which are on a higher level. (Terzi et al., 2010)

Currently and under the coming years, Internet-of-things (IoT) technologies will play an important role regarding a wide perspective of applications through generalized tagging of products. This transformation will inevitably include consumers and users to improve the information exchange with the actors in the BOL, MOL, and EOL phases and therefore system development leading to improved interactions with the EOL actors. (Terzi et al., 2010)

The closed loop PLM can become to be called the “system of systems”. This change will work as a catalyst for improving and finding new efficient and effective processes, more sustainable manufacturing as well as opportunities for new business models. (Terzi et al., 2010)

3.1.5 Challenges with closed loop PLM

According to Terzi et al. (2010), to reach a closed loop PLM and improve the current described context of closed loop PLM, research and development will need to find solution to following challenges:

- A solution is needed to have a seamless link between the consumers and designers of products providing information in real-time, also considering the context when maintenance experts are involved in the lifecycle.

- An important aspect to consider is the social consequences of a relationship between consumers, designers, and service providers. This relationship might contribute to developing a new paradigm, sustainable production and consumption.

- The business models supporting this transformation is also important to start thinking of.

According to Gehrke et al. (2020), cross-divisional collaborations, renewing PLM strategies in changing conditions, creating a closed loop information flow where it is critical the find a way to link field data with IoT platforms. Capability building is an important requirement to achieve these challenges.

Furthermore, Jun et al. (2007) describes that the closed loop PLM approach can provide support and opportunities at a strategic and operative level, but it alone does not have the ability to solve the ineffectiveness of operations in the product lifecycle. Issues have been defined by Jun et al. (2007) in the three lifecycle phases BOL, MOL and EOL.

Issues in BOL

There are two main issues in the BOL phase of the closed loop PLM, because of its possibility to provide design and production with valuable feedback from the MOL and BOL phases to improve the products.

Firstly, the *conceptual product design considering lifecycle factors*, meaning that the design of a product should consider both the basic product functionality as well as required factors like assembly, manufacturability, reusability, maintainability, and environment. The BOL phase is the only phase where it is possible to make changes at a minimal cost. Quality function deployment (QFD) is the common systematical method to use when integrating customer requirements with the product concept. (Jun et al., 2007)

The traditional QFD does not consider product lifecycle factors in the conceptual design of a product, but some research publications have integrated the lifecycle factors into the method, considering the environmental requirements as well. For instance, Green QFD (GQFD) has been developed and where LCA and QFD are combined. Despite the research publications on the area of integrating environmental factors with QFD clear methods are missing enabling analyzing the lifecycle requirement with engineering characteristics. It is a difficult task for the designers to assess the interactions between design aims, and lifecycle requirements from the MOL and EOL phase, and therefore it is required an improved ability by a systematic method for analyzing and assessing this. (Jun et al., 2007)

Secondly, *the real-time production planning and scheduling* are production operation problems all manufacturing companies have. Therefore, the objection is to improve the production efficiency solve the issue with creating a long-term resource requirement plan for production as well as a short-term approach of controlling production-related objects. Regardless of attempts and research publications in the area focusing on intelligent products as a solution, there still exists limitations. (Jun et al., 2007)

Issues in MOL

There is one main issue in the MOL phase of the closed loop PLM, since this phase focus on distribution, used, maintained, and serviced. With support from the intelligent product, PEID, the product history in this phase can be logged. IoT or wireless mobile technology can be used to assist obtaining information to provide up-to-date reports about product status. (Jun et al., 2007)

During the MOL phase, *the predictive maintenance of the products* is a challenging issue, focusing on prediction of degradation process of a product. This is based on the assumption that the occurring does not happen instant for almost all abnormalities, and therefore there is usually a process of degradation when the product goes from the normal to abnormal state. There are four ways the predictive maintenance can be accomplished. Firstly, it can be done through a real-time diagnosis of a product status. Secondly, an estimation of a products deterioration level can be done. Thirdly, a prediction of the product abnormality duration. Lastly, maintenance, upgrade, and disposal actions can be executed. Furthermore, there are limitations of previous research presenting that PEID technologies can be combined with predictive maintenance. (Jun et al., 2007)

Issues in EOL

In the EOL phase one main challenge was identified, *EOL optimization*, where the used products are collected, disassembled, refurbished, reassembled, recycled, reused, or disposed. During the EOL phase the products are going through the reverse logistics processes, see Figure 7. The importance of improved EOL activities has increased since the increased return rate of products due to online purchasing, shorter product lifecycles, increased environmental responsibility regulations and profit maximizing EOL products value.

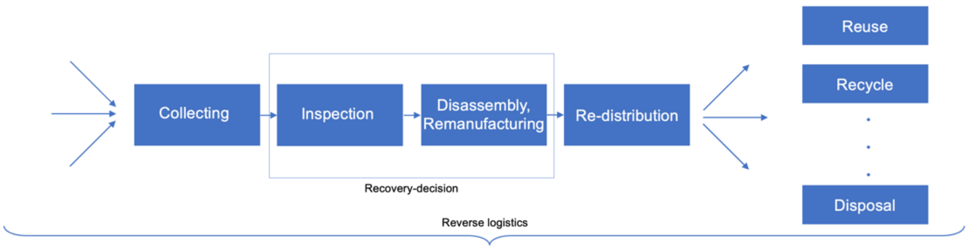

Figure 7: Reverse logistics process including the recovery decision-making process. (Jun et al., 2007)

For that reason, a recovery option needs to be decided, it is essential to develop a recovery decision-making method determining the best recovery option suited for the situation, see Figure 7. Despite research and attention to the subject, limitations exist. To implement EOL optimization it is required to have clear visibility over the whole product lifecycle. The more accurate information that can be collected the more optimized reverse logistics and product recovery decisions can become. One of the main challenges is therefore a need of developing a framework for EOL information management in the concept of closed loop PLM. (Jun et al., 2007)

The concept of closed loop PLM has the possibility to maximize the way lifecycle operations are performed. There are still many technological challenges with integrating PEID technologies into PLM systems needed to be resolved. Information is also required to be shared beyond the borders of a company. To be able to share the product information in an efficient way, it is therefore necessary to develop a standard for the PEID technology and how it can operate in PLM. (Jun et al., 2007)

3.2 Circular Economy

The concept of circular economy will be defined and described in this section. Furthermore, how it can be implemented and the challenges and enablers regarding having a successful circular economy implementation in an organization.

3.2.1 Definition of circular economy

`The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended´ (European Parliament, 2023). Circular economy can be defined differently, and this is how the European Parliament (2023) defined it.

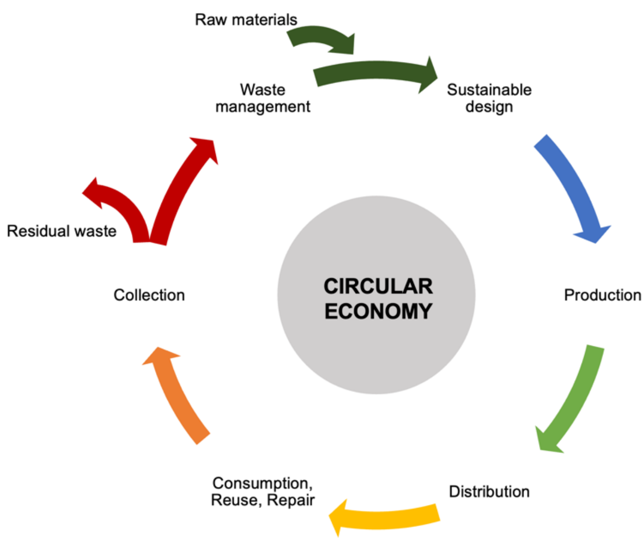

Figure 8: The circular economy model. (European Parliament, 2023)

The aim with CE in practice is to reduce waste to a minimum. Figure 8 visualizes the circular economy model according to European Parliament's (2023) illustration, where less material, less waste and fewer emissions describe the model. When it comes to the EOL phase of a product, recycling makes it possible to keep the materials within the economy. To create further value, the materials are often effectively reused again and again. (European Parliament, 2023)

The traditional economic model is the linear economic model, which strategy has a pattern of take-make-consume-throw away. This model associates with large quantities of cheap, easily accessible materials and energy. (European Parliament, 2023)

3.2.2 Benefits with a transition to a circular economy?

Firstly, to protect the environment by reuse and recycle products it opens the possibility to reduce the use of natural resources, reduce landscape and habitat disruption as well as limit biodiversity loss. It will also help to reduce the total annual greenhouse gas emissions. Secondly, the circular economy will help to reduce the raw material dependence. The demand for raw materials is limited and therefore it becomes important to reduce the raw material dependencies. Some of the EU countries are also dependent on other countries for raw materials because of the finite supplies. To put into context, the EU imports about half of the raw materials it consumes. Lastly, a transition to an improved circular economy will create increased competitiveness opportunities, innovation opportunities and boost the economic growth and create jobs. (European Parliament, 2023)

3.2.3 CE implementation

When implementing CE approaches in a company it can be introduced by a top-down or bottom-up strategy. When implemented through a top-down strategy, the policymakers play a key role, while during a bottom-up strategy the individuals, firms, and organizations is first acting through innovation. (Cantú et al., 2021)

The top-down implementation involves actions such as develop conditions to support infrastructure, adequate legislation and policy, and social awareness. These actions can all in combination contribute to leveraging CE implementation in a specific context. When it comes to these cases the company's implementing CE are supported by the host institutions, legal arrangements, or the market itself. (Cantú et al., 2021)

The bottom-up strategy instead refers to the industrial efforts with the aim to reduce their impact on the environment as well as adopt to the circular economy principles. This bottom-up approach can be achieved through actions such as product lifecycle management, collaborative business models, and circular product design among others. (Cantú et al., 2021)

3.2.4 CE implementation barriers and enablers for SMEs

Often, the CE implementation has been considered as a straightforward process, which provides the emerging economies best practices to implement from the developed countries. Despite that, to have a successful CE implementation it requires a major systemic change. (Cantú et al., 2021)

The question that can be asked is why the adoption to circular economy do not happen faster? At the same time a range of potential benefits, clearer regulations, policies, and an urgency are presented. The European small and medium-sized enterprises (SMEs) that engage in circular economy activities describes complexity, cost of administration, regulatory compliance, and the lack of human resources as the major challenges. (Walden et al., 2021)

According to the research by Cantú et al. (2021), barriers and enablers have been identified for SMEs firms face when they implement CE initiatives. Based on the literature review, external barriers was identified and placed into five categories and internal barriers were placed in four categories. The external categories refer to factors that occurs outside of a firm, while the internal factors refer to factors occurring and creates pressure within a company.

Barriers for CE implementation

The external barriers categories were *user's behavior*, *regulatory*, *infrastructure*, *economy and competitive markets, and supply chain*. *User's behaviors* such as their budget, preferences and demand, as well as understanding and perception regarding circular economy in general were identified as barriers to overcome. The *regulatory aspect* refers to an absence of CE implementation laws, incentives such as lack of CE funding, the political landscape, promotion and awareness regarding CE, and a lack of regulations regarding CE. The *infrastructure* barrier is about infrastructure irregularities and the lack of CE technology that exists today. Regarding the *economy and competitive markets* areas that are seen as barriers are lack of access to capital and financing tools, the market competition taking place in an uneven marketplace with a poor demand for circular products. The *supply chain* barrier refers to the availability regarding an existing green suitable supply chain, the cooperation between the parties participating in the supply chain lack information sharing and data transparency. The logistic barrier emphasizes the global geography, and difficulties with product traceability, collection and storage, and a lacking reverse logistics. (Cantú et al., 2021)

The four identified internal barriers were *knowledge*, *financial*, *organizational*, and *product and material characteristics*. The knowledge barrier is about the *communication* of asymmetrical information among employees, the lack of information access and awareness within companies with insufficient information management systems lacking access to real data. Companies also lack clear information regarding CE guidelines, performance indicators, and reference points. The *financial* barrier refers to the large investment costs, the revenue model and cost structure, and the financial risks with an CE implementation. The *organizational* barrier cover areas such as corporate governance, culture, management, organizational capabilities, organizational resources, and strategies. Lastly, the *product and material characteristics* identified as an internal barrier refers to design of the product regarding material, product complexity, and design constraints. (Cantú et al., 2021)

Enablers for CE implementation

Cantú et al. (2021) also identified enablers for SMEs to implement CE initiatives. Also divided in the same categories as the barriers.

External enablers, starting with the *user's behavior* enablers refer to budget and the willingness to pay surplus for CE products, the preference and demand regarding cultural acceptance of CE models and understanding and perception with a high environmental literacy and awareness. The *regulatory* enablers were implementation with government incentives and developing the infrastructure that is needed, incentives regarding government funding for CE initiatives, as well as promotion and awareness promoting the use strategies regarding sustainability and circularity and spreading information of the CE concept. Also establishing laws and policies regarding sustainability and CE. *Infrastructure* emphasizes effective ways to collect and treat waste, as well as the available CE technologies. Regarding *economy and competitive markets,* it is about access to the financial tools, and responding to the emerging market regarding sustainable business growth. The *supply chain* enablers are about leadership focusing on change agents, cooperation regarding the actors among the supply chain, developing a business case that is acceptable for all actors, and information exchange among the stakeholders. The incentives to suppliers where providing training and knowledge about CE are seen as enablers. The *logistics* that will enable CE implementation is the use of tools that will facilitate product traceability in the supply chain and implement a reverse supply chain specifically for the returning resources. (Cantú et al., 2021)

The identified internal enablers were also categorized the same way as the internal barriers. The enablers' regarding *knowledge* was identified as the available communication technologies, information and awareness regarding CE by developing knowledge, and having clear communication on the CE concept. *Financial* enablers were described as financial support such as contractual agreements, and access to finance, as well as risks were conducting pilot programs to minimize risks were described as an enabler. *Organizational* wise, regarding corporate governance, creation of a new business unit for cultural adaption as well as sustainability principles. The culture is also an aspect where internal collaborations and the company culture regarding environmental awareness are key players. The management enabling aspect emphasizes support as well as commitment from the top managers, a strategic leadership for CE, system's thinking approach enabling CE implementation, as well as acknowledging the existing problems of the scarce of resources and pollution. The organizational capabilities are seen as arranging specific training to develop new CE associated capabilities and skill, and also develop crow-functional capabilities through integrating all functions and employees. Organizational resources are also an important aspect regarding time and human. To set a strategy is also a key enabler, regarding integrating CE/sustainability strategy, mission, vision, goals and KPIs, and incent participation among all employees. The enabler category, *product and material characteristics*, emphasizes key enablers such as redesign material for recycling, reuse, and upgradability, and reduce the impact of product obsolescence. (Cantú et al., 2021)

3.3 The CSRD regulation and scope 3 emissions

The Corporate Sustainability Reporting Directive will be introduced in this section. The background, the requirement of scope 3 emissions and the challenges with complying to the directive and how to overcome these will be described.

3.3.1 The Corporate Sustainability Reporting Directive

The new EU directive presented in 2021, the Corporate Sustainability Reporting Directive (CSRD), will place higher requirements on companies' documentation and reporting regarding total emissions and the quality of data regarding social and environmental information. (Council of the EU, 2022; European Commission, n.d.-b). The CSRD obliges large companies and SMEs to comply with the reporting of more detailed and standardized sustainability aspects. Furthermore, an important acknowledgment with the directive is its mandatory integration into the management report, which position the sustainability reporting on an equal level with financial reporting. (Birkmann et al., 2024)

Furthermore, the directive will improve the public accountability for businesses when they are obliged to continuously disclose the societal and environmental impact created by the businesses. Therefore, the CSRD will contribute to ending greenwashing, strengthen the EU's social market economy, and build the foundation for the sustainability reporting on a global level. (European Parliament, 2022)

The directive was enforced in the EU in January 2023, and it ensures that both investors and stakeholders will have the access to the right information to be able to assess the impact of companies on people, and environment. For the investors information is needed to assess financial risks and opportunities that are on the rise regarding climate change and other sustainability issues. (European Commission, n.d.-b) The companies that are first to enforce the directive will start the financial year 2024 for the reports published 2025. (European Commission, n.d.-b)

The directive essentially changes the previous practices of sustainability reporting. The directive intends to contribute to more corporate transparency with its precise standards, also to provide relevant information regarding sustainable business activities making them comparable among external stakeholders. Among other things, information from the three sustainability categories, environment, social, and governance (ESG) are going to be published when complying with the directive. (Birkmann et al., 2024)

The NFRD directive made large public interest entities obliged to provide information at a management and control level regarding aspects such as environment, social issues, corruption prevention and diversity measures. The NFRD directive was designed in a way that allowed the concerned companies a certain level of freedom in implementation and design of the directive. (Birkmann et al., 2024) In April 2021 the European Commission presented its proposals on CSRD, with background from 2018's call from the European Parliament to revise the NFRD. The NFRD had some shortcomings, and the directive was perceived as largely insufficient and unreliable. Therefore, CSRD was made more detailed regarding reporting requirements on companies' impact on the environment, human rights and social standards, all based on common criteria's in EU's climate goals. (European Parliament, 2022)

3.3.2 Scope 3 Emissions

During the late 1990's, the Greenhouse Gas (GHG) Protocol was developed because an international standard for corporate GHG reporting and accounting was needed. The World Business Council for Sustainable Development and the World Resource Institute were the developers of the GHG protocol. The GHG protocol provides global standardized frameworks enabling to measure and manage the greenhouse gas emissions created by both the private and public sector operations, value chains and mitigation actions. (Greenhouse Gas Protocol, n.d.)

According to the GHG protocol the emissions created by companies from various sources can be grouped into three categories, so called scopes (WRI & WBCS, 2013), see Figure 9 for a visualization:

- Scope 1: Covers the direct emissions coming from sources owned or controlled by the organization.

- Scope 2: Includes the indirect emissions coming from the generation of purchased electricity, steam, heating and cooling which are consumed by the organization that reports.

- Scope 3: Covers all the indirect emissions from sources of an organizations value chain, which includes the upstream and downstream activities.

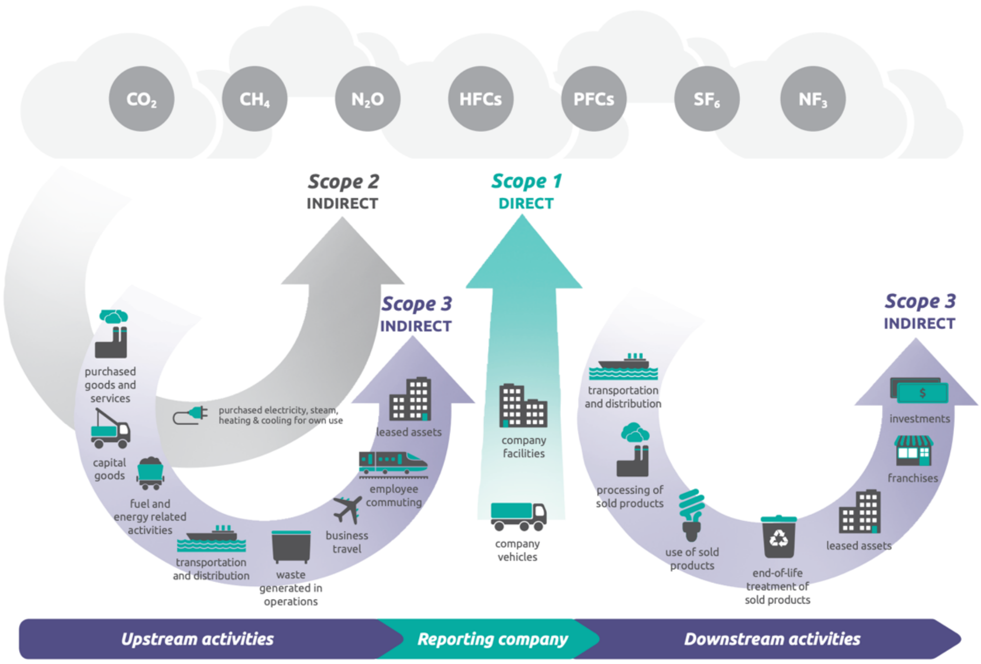

Figure 9: Visualization of the three scopes. (WRI & WBCS, 2013)

One of the environmental reporting requirements in the directive is that companies must report their scope 3 emissions to comply with the CRSD directive. Therefore, there is a need for companies to start mapping their scope 3 emissions, specifically their GHG emissions equal CO2 emissions. (Schmidt & Farbstein, 2024; Munthe Nilsson & Nilsson, 2023; PWC, n.d.-a) Until recently, companies have been focused on measuring scope 1 and scope 2 emissions, which includes measuring companies' emissions from their own operations and the consumption of electricity (Greenhouse Gas Protocol, n.d.).

Scope 3 emissions can be defined as all the indirect emissions having their source in the value chain within an organization, resulting from its upstream and downstream activities. (Schmidt & Farbstein, 2024) Lots of companies are experiencing challenges with mapping and understanding the size of the scope 3 emissions, because the emissions are occurring outside of companies own direct control and business. For instance, the scope 3 emissions can come from suppliers or the use of products, and this can correspond to 65-95 percent of the total climate impact from the company. (PWC, n.d.-a) The process of measuring the scope 3 emissions is therefore a difficult process, and a process companies must begin with to ensure to comply with the CSRD. (Schmidt & Farbstein, 2024)

The GHG protocol is the most globally used framework for greenhouse gas accounting standards (Greenhouse gas protocol, n.d.). The guidance document, *Technical Guidance for Calculating Scope 3 Emissions*, provides information such as methods for calculating GHG emissions in scope 3, data sources, and worked examples. The scope 3 emissions have been divided into 15 categories in the guidance document for the emissions occurring across a company's value chain, both in the upstream and downstream activities, see Table 3. The activities were divided into 15 categories to help companies avoid double counting emissions among them. (WRI & WBCSD, 2013)

Table 3: The 15 categories for scope 3 emissions. (WRI & WBCS, 2013)

Categories for upstream emissions	Categories for downstream emissions
1. Purchased goods and services	9. Downstream transportation and distribution
2. Capital goods	10. Processing of sold products
3. Fuel- and energy-related activities (not included in scope 1 or scope 2)	11. Use of sold products
4. Upstream transportation and distribution	12. End-of-life treatment of sold products
5. Waste generated in operations	13. Downstream leased assets
6. Business travel	14. Franchises
7. Employee commuting	15. Investments
8. Upstream leased assets	

3.3.3 Challenges companies face complying to CSRD

According to an article recently published in February 2024, in ESG Today, most of the large companies are improving their ESG data and reporting capabilities by for the next years planning on investing in sustainability software, and the capabilities within in the workforce. According to a survey released by KPMG US, there is a belief among the companies, of being ahead of the curve in this area, but in fact, around half of them are still using spreadsheets when managing their ESG data. Furthermore, because of the regulatory pressure regarding disclosing sustainability information increases, improved ESG capabilities is becoming a key factor to manage it. (Segal, 2024)

In addition, as mentioned earlier, lots of companies are experiencing challenges with mapping and understanding the size of the scope 3 emissions, because the emissions are occurring outside of companies own direct control and business. For instance, the scope 3 emissions can come from suppliers or the use of products, and this can correspond to 65-95 percent of the total climate impact from the company. (PWC, n.d.-a)

According to Odobasa & Marosevic (2023), identified challenges in the application of CSRD, which could lead to slowing down the transition process to a sustainable Europe from an economical and societal perspective. Some of the mentioned observed challenges is the additional financial and personnel costs related to business as well as the collection and preparation of the reports, resistance arising within the business sector related to assessment of falling profit rates and the global competitiveness decreasing, the continuous changes happening in the standards of information and auditing, the relationship between financial and sustainability reports is not elaborated enough, the network of auditors is not developed enough, and the system of sanction is not clearly defined when low-quality reports or no reports are published.

3.3.4 Overcoming challenges

CSRD is one of the most important mandatory sustainability initiatives in the European Union. The directive is estimated to impact 50,000 companies who are doing business within the European Union under 2025. In addition, the CSRD is a solution to address the issue with a missing uniform reporting standard contributing to companies and investors measuring and reporting differently making it difficult to compare. Organizations are in urgent need of support to address the CSRD through a clear planning process, which helps to ensure consistency of its disclosing requirements with corporate governance. (Hristov & Searcy, 2024)

Hristov & Searcy (2024) therefore proposed a framework which support the integration of sustainability and corporate governance. The purpose of the framework is to provide companies how to implement CSRD with support from sustainability balanced scorecard (SBSC). Balanced scorecard (BSC) is a management system with the purpose to integrate non-financial measurements in a framework with strategic control capabilities, supporting organization’s value creating activities. Currently, the implementation of SBSC is in an initial stage, because of the limited studies regarding the insight of implementing and using corporate sustainability performance measurement. The framework can be considered a starting point needing further exploration of the corporate sustainability implementation. Regardless of the acknowledged need of integrating sustainability with strategic tools equivalent with corporate governance, a low number of studies exist providing specifically how it can be performed.

Currently, among others, the large global consultancy firm PWC supports organizations with strategies and guidance to comply with the new way to manage sustainability reporting. PWC has developed a five step action plan companies can take to navigate compliance, and secure long-term value, including the steps (PWC, n.d.-b):

1. Take a strategic approach to your reporting.
2. Ensure your whole organization is behind the reporting transformation.
3. Tackle the data challenge.
4. Consider materiality and report in what matters most.
5. View reporting as a way to drive business-wide value.

3.4 Digital Product Passport

In this section the framework, Digital Product Passport, included in the European Green Deal, will be described. In addition, its opportunities in the circular economy context will be presented.

3.4.1 The concept of DPP

The global adoption to circular economy strategies increases among governments and corporations to enable meeting the needs of decoupling growth as well as decrease the resource consumption. But it is important to mention that the world is far from being circular, where some explanations are lack of transparency, standardization, and data sharing. One way to support the transformation and overcome these challenges is to use digitalization. (Walden et al., 2021)

Currently, Europe is in the beginning phase of its transformation to a more circular economy with the aim to be the most sustainable region in the world. A new framework created by EU – The Ecodesign Sustainable Products

Regulation (ESPR), a part of the European Green Deal, includes the Digital Product Passport (DPP). (GS1, n.d.)

DPP can be described as a set of sustainability data which supports and make it possible to have circular products and business models, see Figure 10. In detail, each product will have a unique identity which then can be linked to a data source that collects information about the product. Therefore, DPP enables businesses and consumers to access the product information directly from the supplier. The technology therefore will be able to cover product data areas such as sustainability performance, origin, warranty, recycling and instructions for installation or repair. (GS1, n.d.)

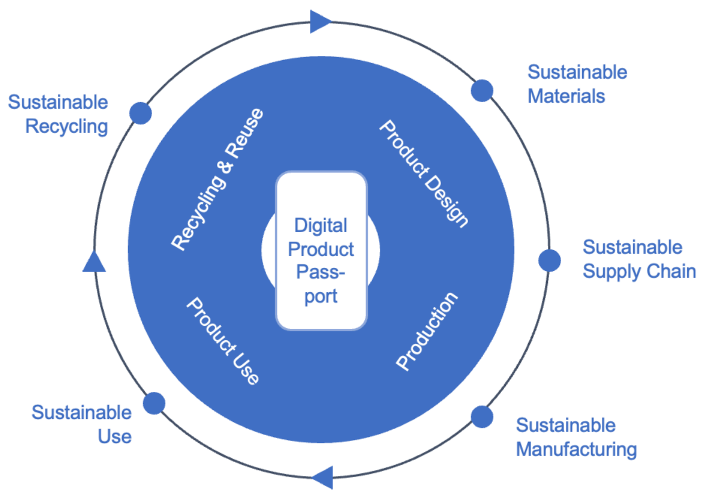

Figure 10: Visualization of DPP. (Walden et al., 2021)

3.4.2 Advantages with DPP

There are lots of advantages with the DPP technology, and some examples can be seen in Table 4. With consistent information management businesses will be able to have the necessary tools to achieve and monitor for instance sustainability goals and increase consumer interaction. (GS1, n.d.)

Table 4: Advantages with DPP. (GS1, n.d.)

Advantages	Description
Contributes to sustainability	The technology enables product data to be provided to consumers and buyers to support them to make more sustainable decisions.
Increased traceability	The technology enables unique identifiers and standardized data which creates a visibility over how all parties included in the supply chain can meet sustainability requirements.
More transparency	It creates an increased global visibility regarding the brand and towards consumers in relation to an improved openness over the sustainability data.
Consumer and product safety	When data is both reliable and verified it supports to protect products, consumers, and patients.
More efficient supply chain	The technology helps to avoid unnecessary manual administration and data management by the buyers and the producing companies.
Regulatory compliance	To ensure that brand owners comply with regulations and industry requirements, standardized information is one support which DPP can provide.

Although DPP is a promising solution with the potential to decrease and even remove the informational barriers to CE, there exists challenges. One important aspect is that there can be challenges finding a unified approach to DPP across industries. Today it is an unknown area regarding how the product passport will be able be kept up to date during the whole product lifecycle process. There are also unresolved factors that needs to be addressed regarding issues of confidentiality of business information and IP security which needs to be resolved before an industry adoption can take place. (Walden et al., 2021)

With clearer guidelines and directions, together with regulations and industry bodies, it might be possible to overcome these challenges. The EU Battery regulation is a best practice with a similar approach in a similar area, illustrating a potential roadmap for DPP. (Walden et al., 2021)

3.4.3 The EU battery regulation

The European Parliament has adopted new rules regarding batteries to support environmental, ethical, and social issues. In June 2023, the EU's battery directive was updated by the European Parliament with the purpose to ensure that batteries can adopt to the circular economy approach better by making it possible for them to be repurposed, remanufactured, or recycled when reaching the end-of-life phase. The directive has a link to the EU's circular economy action plan and the EU's industrial strategy, with the aim is to be able to cover the whole product life cycle and recycle into new products. (Guillot, 2023)

The functioning of the internal market for batteries is aimed to be improved, as well as safety, sustainability, and labelling requirements to ensure a fairer competition. To be able to reach these aims performance, durability, and safety criteria are key factors. There will also be restrictions for hazardous substances and the carbon footprint of batteries will be ruled by mandatory information. (Council of the EU, 2023)

Requirements regarding labelling and information on for instance battery's components and recycled content will also be introduced by the directive. To give member states and economic actors enough time for preparation the labelling requirements will apply by 2026. (Council of the EU, 2023)

The directive also introduces an electronic "battery passport" and a QR code which will apply by 2027. (Council of the EU, 2023) The battery passport is going to have a central role as a tool for sharing data on composition, material origin, and chain of custody providing information from the whole product lifecycle. (Walden et al., 2021; World Economic Forum 2019, p. 8)

3.5 Opportunity to integrate PLM with circular economy

Research describes various possibilities for integrating the circular economy with the PLM system. There are different approaches that use digitalization and technical solutions to integrate PLM with circular economy, which will be presented in this section.

3.5.1 Product Stewardship and Enterprise Information System

When it comes to sustainable manufacturing, besides the economical aspect, manufacturers also include the environmental and social aspects. The sustainable aspects are for instance, modelling and optimization, remanufacturing, sustainable supply chains, reverse logistics and closed loop supply chains. The concept Product Stewardship (PS) aims to minimize the environmental impact arising from products throughout their lifecycles and has a long history which definition has evolved throughout the years. (Jensen & Remmen, 2017) PS has developed from a focus on responsible management of hazardous waste to a broader perspective on how to conserve resources and recycling with a stronger connection to improve the efficiency of the industrial material flows. (Lane & Watson, 2012) Engaging in PS is one way of reaching and improve sustainable manufacturing. (Jensen & Remmen, 2017)

PS requires tools and systems to manage information to be able to exchange the information occurring throughout the entire product lifecycle. New technologies, such as digitalization as well as the end-to-end optimization, creates new opportunities such as support to automate work steps and decision support in areas like reverse logistics. There is a need for managing new data streams with support from central tools with functions to manage that information. PLM software or Enterprise Information System (EIS) are both information handling tools, which enables partners to share information and collaborate on various issues, for instance optimization of recycling of materials. (Jensen & Remmen, 2017)

Digitalization, in the form of EIS, can support PLM and such platforms to become the foundation for integrating environmental information, e.g. material composition of products improving the quality of recycling, or better reuse of components or products. Traditionally, the CE principles have not been a part of the EIS but have the potential to increase resource efficiency and PS by being integrated. A challenge to overcome is the ability to record data between all involved stakeholders in the product lifecycle. Mainly, challenges regarding information security as well as confidentiality emerges when transferring sensitive data between different stakeholders. (Jensen & Remmen, 2017)

An implementation of a digitalized system instead of a non-automated or even a paper-based system might generate new opportunities related to business value for stakeholders throughout the product lifecycle. It also opens opportunities improving the understanding of the products when information on material composition is integrated in the EIS. Furthermore, by automating the data collection phase provides the ability to making real-time lifecycle assessments which both improves the assessment as well as provides continuous improvement related to the product design phase of the lifecycle. (Jensen & Remmen, 2017)

3.5.2 Information and communication technologies integrate PLM and CE

For companies to move forward with a CE transition both PLM and ICT are crucial support components to make it possible. Based on the history from the past, there has been an issue with gathering customer feedback, but today's access to the ICT technologies have made it possible to provide data from the entire product lifecycle. Implementing CE into PLM will require the different stages of the product lifecycle to be modified. For instance, the redesign stage during the BOL phase, an improved way to provide service and maintenance in the MOL phase and assessing alternative options like remanufacturing instead of disposal during the EOL phase. Changes like this require a holistic perspective, collaboration between stakeholders, circularity of the information flow between stakeholders, and a PLM system supporting a transition to a circular economy. (Villamil Velasquez et al., 2020)

Villamil Velasquez et al. (2020) have studied and identified both opportunities and challenges of linking CE and PLM with the support from ICT. In the research paper the opportunities and challenges are categorized after the three lifecycle phases, BOL, MOL and EOL.

The opportunities can be summarized for the different phases. In the *BOL* phase possibilities such as a collaborative design where the customers are integrated in the design phase, economic benefits, ability to track suppliers for future business agreements, and decision-making information where simulation of scenarios will play a key role. In the *MOL* phase the opportunities were closing the information gap occurring when the products are sold, tracking service actions and product performance, and customized products services. In the *EOL* phase the possibilities were improved material knowledge facilitating EOL activities, optimizing the resource stock, extending the life of the products, resource recovery support as well as reducing waste.

The challenges with linking CE and PLM with support from ICT found in the research can also be summarized for each phase. In the *BOL* phase the research found challenges regarding the use of conflict or critical minerals in the manufacturing of ICT devices. In the *MOL* phase issues were the rebound effect meaning that it can result in product overuse, a gap of knowledge regarding the information when it comes to service-based business model. The issues in the *EOL* phase are the main focus on the EOL phase, and an increase of e-waste.

An aspect to consider regarding the CE being integrated in PLM supported by ICT tools is the passive or active perspective. Passive is defined as information that is collected but it is applied afterwards, meaning the current users will not be provided the changes and benefits that comes with it. While the active perspective, means that by support from ICT the products can be tracked and thereby help to improve performance, offer better services, expand the product lifecycle, and bring continuous change to match the customer needs. The current user will therefore be provided with these changes and its benefits. To comply with CE goals, ICT can be one solution, with its function to gather real time data, customer preferences and usage pattern data, and improved service and producing multiple life cycle products. (Villamil Velasquez et al., 2020)

From a system perspective, ICT is an enabler for transition to CE, but is not possible to integrate without a holistic perspective, where an understanding for the complete system is required. Various research on frameworks have been developed in the field, where the importance of high infrastructure and logistics are required for the ICT systems. Therefore, a deeper understanding of ICT is needed and a substantial plan regarding, design, manufacturing, supply chain and management are fundamental for a CE transition. (Villamil Velasquez et al., 2020)

The ICT devices also have advantages from a sustainability point of view. Mainly it will provide an improved energy and resource efficiency, support the decrease of emissions, and change the way consumers behave. Furthermore, it is important to acknowledge the impact of the environment production of ICT devices contribute with. The manufacturing process of the devices requires use of critical metals, which have its negative risks regarding resource scarcity among other things. It also contributes with more devices and infrastructure which increases the e-waste levels. It is important to acknowledge that the negative environmental impacts of ICT technologies might balance out the positive. Therefore, it becomes crucial to have a clear and defined purpose with sustainability regarding reduce environmental impact throughout the entire product lifecycle. (Villamil Velasquez et al., 2020)

The stakeholder's role in the field of CE, PLM supported by ICT is also a crucial aspect in the CE transition. There is an existing chasm between ICT and CE, which can be solved by co-creations, collaboration, and networking. One way ICT supports PLM is by enhancing collaboration between companies when recovering material from other companies, which requires communication, trust, and reciprocity. (Villamil Velasquez et al., 2020)

ICT enabling the link between CE and PLM is a new area, where more research is needed. There are both opportunities as well as barriers to overcome to reach a CE transition. (Villamil Velasquez et al., 2020)

3.5.3 Industry 4.0 - Supporting circular manufacturing

The industry 4.0 (I4.0) paradigm, is under development and during recent years one main area of technological innovations in the manufacturing system field has contributed to the fourth Industrial Revolution. Key elements and enablers to implement I4.0 consists of digital technologies and technological transformation. Furthermore, the main characteristic with I4.0 is to integrate the technology-based innovations in production systems, which will provide increased productivity and efficiency, contributing to economic growth and wealth. (Cannavacciuolo et al., 2023)

CE is seen as a solution to overcome the take-make-dispose paradigm, providing strategies for manufacturing companies related to their product design, circular industrial processes, and supply chains. (Spaltini et al., 2023)

I4.0 technologies are an advantage for companies that support them by improving financial performance and supply chains. Furthermore, a model merging CE and I4.0 considering the characteristics of a real manufacturing company is still missing. I4.0 technologies can be interpreted to represent a key factor to enable more circular business models, with their capabilities to support overcoming barriers related to CE implementation. (Spaltini et al., 2023)

Spaltini et al. (2023) developed a systematic literature review to provide a better understanding regarding how I4.0 and CE are related. Some of the key findings from the literature review was that IT-solutions are providing most of the contribution to achieving circularity in the manufacturing industry. The review resulted in three main areas of application of the I4.0 technologies were:

- Virtualization of processes, for instance by using simulations.

- Optimization and resource reduction, provided by AI-based decision-making.

- Virtualization of resources, provided by cloud-solutions.

The review also resulted in IoT being one of the most mentioned technologies achieving support with CE implementation. Furthermore, to be able to monitor in real-time and using condition-based or predictive maintenance, application of sensors onto products is an essential solution. IoT is a technology that have the capability to provide support for developing new business models, based on its function to share mobility which enables to increase the total usage of assets during their lifecycles. A solution to optimize the sustainability performance in companies is by combining the data collected by IoT devices and then elaborate it with help from Big Data Analytics models. These solutions supported by the I4.0 technologies are only some of the mentioned in the paper.

The I4.0 have the capability to both improve the economic performance and supply chains in companies, as well as support to overcome the CE adoption barriers. Where I4.0 have potential to overcome most of the barriers that is preventing companies from adapting faster to CE. For future studies on the topic a need to analyze the opportunities for different manufacturing processes to define best practices for the specific CE barriers using the right technology. Furthermore, two gaps were observed when the literature review was developed. Firstly, when the assessment of the link between I4.0 and CE was made, a lack of research focus was observed regarding multi-product and multi-asset for instance machine and lines. Secondly, a need of research on quantitative evaluation of the impact occurring when I4.0 technologies are applied, and the advantages or disadvantages regarding the support of the CE transition. (Spaltini et al., 2023)

3.5.4 IIoT's potential to enable closed loop PLM

Gehrke et al. (2020) presents how Industrial Internet of Things (IIoT) can be a solution to enable closed loop PLM. IIoT is a technology helping to connect production and product data, but even with one of the most established PLM systems it is difficult to process these data in an efficient way. It is both a challenge technically and businesswise to have a successful PLM System implementation.

According to Gehrke et al. (2020) there only exists few research addressing companies' capabilities to pursue a PLM strategy or the ability to link it to the field of Industry 4.0. Furthermore, a few independent research papers are published, addressing approaches in practice to create the required capabilities to successfully implement PLM. Both practical exercises and teaching approaches from first-hand experience are needed to be able to close the knowledge gap that currently exists in this area. Moreover, instead of present and learning about the available tools for PLM a transformation is needed educating about the PLM strategy. Currently, the lack of knowledge in the industry contributes to PLM implementation failure and therefore it becomes important to have a close collaboration between the academia and the industry to create an understanding and educate about technological knowledge.

There exists an imbalance regarding the maturity of tools, maturity of processes and methods across industries, and there are different opinions of PLM capability relevance among IT and engineering respondents which all impact the implementation of PLM. An alignment is required between the investments in PLM capabilities and the business strategy. (Gehrke et al., 2020)

Based on a literature review, expert interviews, and a survey by Gehrke et al. (2020), the top three challenges for organizations PLM implementation for companies without PLM are:

1. Lack of understanding PLM capabilities.

2. PLM payback opportunities are not clearly understood.

3. Lack of strategic direction.

Furthermore, Gehrke et al. (2020) presents a capability building workshop concept has been derived based on the information collection, where participants will have the opportunity to experience benefits from a closed loop PLM system at the Digital Capability Center (DCC) Aachen. During the workshop a closed loop PLM system will be installed enabled by IIoT on DCC Aachens product line. The purpose of the installation was to introduce the added value of a consistent information flow throughout the product lifecycle. The fundamentals of the IT-architecture consisted of CAD, PLM, IIoT and AR solutions from PTC Inc. An additional solution was also connected, Thingworx Navigate, an IIoT platform consisting of a set of apps enabling the product data to become centrally accessible which facilitate the collaboration between different stakeholders. The technical set up introduces the relation between PLM and IoT strategies and it enables cross-collaboration, contributing to opportunities to access, share and update the product data.

The implementation of the IT-architecture consists of three steps, illustrated in Figure 11 (Gehrke et al., 2020):

1. Firstly, Windchill connects to Thingworx Navigate, facilitating the collaboration between stakeholders.
2. Secondly, the original product data is complemented with the field data through support from Thingsworx Navigate. The user is provided with insight of data from the product occurring from the products behavior in the field.
3. Thirdly, emphasizing the importance of CAD, PLM, and IoT data, for technologies such as AR. During the workshop it supported improved understanding among the participants of the increased opportunities that was created from consistent flow of information.

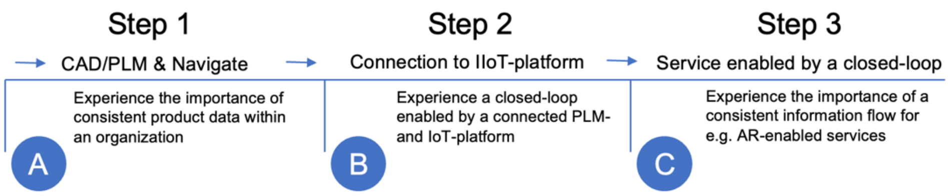

Figure 11: Example of the implementation steps of closed loop PLM system according to Gehrke et al. (2020).

3.5.5 Artificial intelligence in PLM system

An even newer technology is the fast-growing, Artificial Intelligence (AI) technology, which has potential to facilitate the data managing process (Spaltini et al., 2023; Desai et al., 2022; Wang et al., 2021). The information technologies, such as cloud computing, IoT, big data, and AI, are all under a rapid development and involved in the transformation of the paradigm of advanced manufacturing with an impact on all aspects of PLM. Both national manufacturing strategies and initiatives are promoting the next industrial revolution in the developed countries, with a similar vision of intelligent manufacturing, to make an in-depth integration of AI and advanced manufacturing. (Wang et al., 2021)

The application of AI for PLM in an advanced manufacturing context has its limitations in comparison with other fields. In the field of manufacturing there are high requirements for quality, reliability, accuracy, and cost-effectiveness, therefore small and medium-sized manufacturers (SMM) often are uncertain about adopting AI in PLM. But the advantages that come with adopting AI to PLM are immense. The ability of AI to replace humans with its repetitive operations, enables it to streamline a complex manufacturing process into a less labor-intensive state. AI also opens to the opportunity to make an expensive manufacturing process more cost-effective. The AI algorithms also have compatibility with the industrial big data, which opens the possibility to drive decision-making in the manufacturing context more data driven. One driving ability that enables the manufacturers adoption capability to change the industrial environment is the enhanced ability to handle a large scale of data and many of AI's applications are easy to adapt to existing industrial environments. (Wang et al., 2021)

3.5.6 Low emphasis at research institutions

According to Nobre and Tavares (2017), who made a bibliometric literature review from the Scopus database between the years 2006-2015 with the focus on the application of big data/IoT on the context CE, the number of research are low on the topic, environmental sustainability supported by information systems. Currently, the demand of scientific research is high and growing but the information is lacking in the field regarding the gap between the research and the practical actions taken to solve the environmental challenges. Furthermore, the growing global interest in CE principles where technologies such as big data and IoT are seen as enablers, more field studies are still required. Mainly, the found scientific research on the area was about conceptual models, ongoing projects, and pilots. The focus was more on possibilities based on theories rather than case studies on established programs to measure benefits. Moreover, there exists industry cases in this field that need to be scientifically explored by researchers. (Nobre & Tavares, 2017)

3.6 Change management in PLM context

This section will describe the importance of Organizational Change Management (OCM) in the context of implementation of change efforts provided by PLM initiatives in organizations. The section will also present a change work strategy by Kotter (2012), the dual operating system, an agile approach accelerating strategic change in organizations.

3.6.1 Organizational Change Management in PLM

Organizational change is defined as changes within a company when it changes from one organizational structure to another. Organizational Change Management (OCM) is defined as a structured approach which involves organizational change activities which supports the company during the implementation of a change. (Stark 2022-b, p. 423)

Usually, PLM initiative provides proposals of changes, which will impact the way people work if implemented. For instance, if an improved new product development process will be implemented, people in different areas in a company will be impacted and need to understand and adapt to the change. Among lots of people legitimate fears and concerns exists when it comes to change and therefore makes it difficult for both companies and people to change. Moreover, the objectives of the PLM initiatives will not be achieved if the changes do not occur. Furthermore, if OCM is in absence, a lot of PLM initiatives fail because the expected changes do not happen. (Stark 2022-b, p. 421)

Therefore, it becomes important to identify supporting activities for change implementation. To achieve a successful change effort application of “tools for change" are crucial, including learning, leadership, communication, and the correct reward system. (Stark 2022-b, p. 422)

The management aspect of change efforts is an important factor due to the fact change only can happen if the top management takes the lead. Top management can have an absence of the capabilities needed to lead a company through a period of change transformation. Especially in larger companies, change work lasts for a longer period of time, up to five years before the change results become visible. During these time-consuming change efforts, it is difficult for top management teams to maintain focus and involvement. (Stark 2022-b, p. 428)

3.6.2 Kotter's eight steps

Internationally, John P. Kotter is known as the foremost speaker in the field of leadership and change, where his area of expertise is to educate how companies achieve successful transformations. (Harvard Business School, n.d.)

Kotter has observed over 100 companies to transform into better competitors, through fundamental changes in the way a business is conducted, taking place before 1995 but the findings are still yet applicable. Only a few of the change efforts have been successful, where Kotter have identified general lessons learned from those. In order to have a successful change effort, it is required that the change process goes through a series of phases. If a phase is not performed the results will not become satisfying although it feels like the process runs faster. Critical mistakes occurring in any phase can make a devastating impact, slow down the pace of the change effort and lead to failure. (Harvard Business Review et al. 2011, pp. 1-2)

The eight-step model refers to eight phases of implementing a change effort in an organization (Harvard Business Review et al. 2011, pp. 1-2):

1. Establish a sense of urgency.
2. Form a powerful guiding coalition.
3. Create a vision.
4. Communicate the vision.
5. Empower others to act on the vision.
6. Plan for and create short-term wins.
7. Consolidate improvements and produce more change.

8. Institutionalize new approaches.

3.6.3 The dual operating system

The dual operating system originates from similar structures, practices and thinking, such as start-ups that commonly has a network organizational structure because of their creative thinking to find business opportunities. Mature companies can also be organized with informal networks including change agents, working unnoticed by the hierarchy. (Kotter, 2012)

Rapid change and complexity, creates challenges a hierarchical organizational structure can not manage. These situations would benefit from implementing a dual operating system. A dual operating system is a second operating system supporting the design and implementation of a strategy. The system uses an agile approach, has a network-like structure, and continuously assesses the business, the industry, and the organization. Rather than weighing down the hierarchy, the dual operating system works as a complement and contributes to an easier operating process in the organization and acceleration of the strategic change. (Kotter, 2012)

The dual operating system consists of five core principles (Kotter, 2012):

1. Requires a decent amount of change agents, to enable a faster change process, where the agents are volunteers.
2. The mindset is key and requires want to be a change agent.
3. Both a mental want and an emotional want is needed.
4. Requires leadership that is different from the hierarchy management, meaning operating with visions, opportunity, agility, action and celebration.
5. A constant information flow and activity between the network and the hierarchy is required.

The dual operating system comes with an updated version of the eight-step method to implement a change effort successfully. Instead, this new strategy system introduces the eight accelerators which it operates after, see Figure 12. The differences between the accelerators and the eight-step model are (Kotter, 2012):

1. Often, the eight-step model is performed in a rigid and sequential way, in effecting responding to episodic change, while the accelerators are concurrent and always working.
2. The eight-step model is controlled and operated by a smaller core group, while the accelerator strategy gathers a larger group by including volunteers throughout the organization.
3. The step model is based on functioning in a hierarchy. In addition, the accelerator model requires a network with flexibility and agility.

Today, companies are dependent on finding competitive advantage without letting the daily operations being impacted. The strategic system consisting of the network and the eight accelerators working as the activities enabling to inform the strategy and create the change. The eight accelerators can be interpreted as the processes enabling the strategy network to function. (Kotter, 2012)

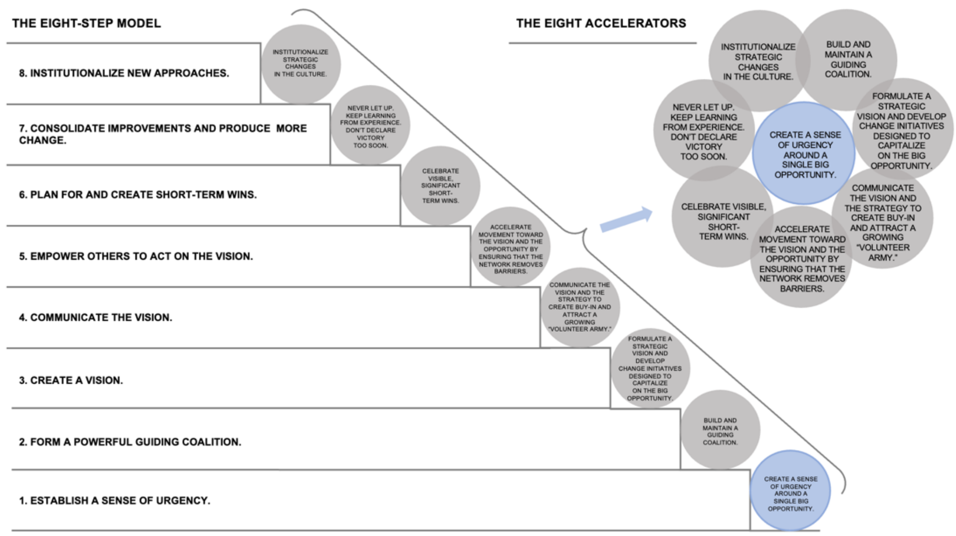

Figure 12: Kotter’s eight steps and Kotter’s eight accelerators. (Kotter, 2012; Harvard Business Review et al. 2011, pp. 1-2)

This section describes the importance of OCM in the context of PLM system implementation, where the dual operating system is one strategy that can accelerate the strategic change in an organization.

4 Empirics

Chapter 4 aims to present the facts and findings from the internal and external interviews that have been conducted in the study.

4.1 Overview

In total, ten interviews have been conducted both internally at Tetra Pak and externally with organizations beyond Tetra Pak, see Table 5 for a summarized overview of the conducted interviews. The interviews were conducted between February to March 2024, where six was conducted in person and four digitally over Teams. Four interviews were conducted in the PLM team and three interviews with the Sustainability team, internally at Tetra Pak. Three external interviews have also been conducted, two with the PLM team at two different companies and one interview with a PLM system supplier.

Four interview guides were used for performing the different interviews, chosen based on whom the interview was with, the internal or external PLM Team, the Sustainability Team, or the PLM System Supplier. All four interview guides can be found in Appendix B.

The interview candidates' experiences differs and the levels they currently are working at. There are candidates on expert level, manager/director level or Vice President level that has been interviewed which gives a wide spectrum of different experiences on the topic and how the topic can be interpreted on different levels in a company.

Table 5: Overview of summarized information regarding the ten conducted interviews.

Interview Candidate	Experience/ Industry	Date
Internal Interviews		
PLM Team		
Person A	Engineering Capability Expert	2024-02-13
Person B	PLM Capability Expert	2024-02-14
Person C	Manager PLM and Engineering Capability	2024-02-16
Person D	PLM Capability Expert	2024-02-19
Sustainability Team		
Person E	ESG Reporting Program Director	2024-02-15
Person F	Director Corporate Affairs, Circular Economy, and Packaging Policy	2024-02-22
Person G	Vice President Corporate Social Responsibility	2024-03-01
External Interviews		
Benchmarking companies		
Company A	Program Director PLM	2024-03-01
Company B	VP Life Cycle Services	2024-03-07
PLM System Supplier		
Supplier A	Associate Solutions Engineer	2024-03-18

4.2 The case company

The case company, Tetra Pak, will be introduced in this section and the ongoing PLM program at Tetra Pak will be described.

4.2.1 Tetra Pak

Figure 13: Tetra Pak's logotype.

From day one, Tetra Pak's major aim has been to help make food secure and available everywhere. And there is always a possibility to find a new and better way to do things which is one of the motivations behind the innovations. (Tetra Pak, n.d.-a) Tetra Pak's logotype can be found in Figure 13.

Tetra Pak is a world leading producer within the process and packaging solution industry for food. They provide custom made process and packaging solutions to their global customers and are available in 160 countries. The latest technology helps the companies' innovators, cooperation partners, and experts to find solutions to the challenges the global food and beverage industry meet. (Tetra Pak, n.d.-b)

The company's promise is `PROTECTS WHAT'S GOOD´ and is broken down into three brand pillars (Tetra Pak, n.d.-c):

- *Protecting food* is about helping people globally to have access to safe food of the highest quality. Where Tetra Pak has been in the forefront regarding innovative food processing and packaging.

- *Protecting people* is a strive for protecting the health and safety of people everywhere. With close cooperation with suppliers and partners, the goal is to enrich the lives and economies of the community where tetra Pak cooperate.

- *Protecting the planet* means that Tetra Pak together with its customers, suppliers, communities and others work on a mutual goal, to achieve the environmental sustainability goals.

4.2.2 The organizational structure

Tetra Laval Group is a private group that started in Sweden, which consists of three companies all together: Tetra Pak, DeLaval, and Sidel. The group has its headquarters in Switzerland. Tetra Pak's organizational structure can be seen in Figure 14. (Tetra Pak, n.d.-d)

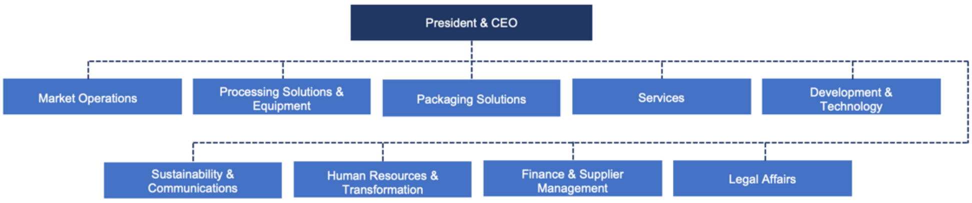

Figure 14: Organizational structure of Tetra Pak. (Tetra Pak, n.d.-d)

4.2.3 The ongoing PLM Program

The ongoing PLM Program at Tetra Pak prioritizes four business areas at the company:

- *Solution Configuration Management*
  The goal with solution configuration management is to provide reliable product data to sell quality solutions.

- *Integrated and Data Driven Solution Developmen*t
  Integrated and data driven solution development, aiming to integrate platforms for product and plant engineering.

- *Installed Base Traceability*
  Installed base traceability, covers the area of hardware and software component traceability.

- *E2E Data Flow*
  End-to-end data flow, where the focus is on system integration and digital ecosystem management.

4.3 What has been implemented and current state at Tetra Pak?

In this section the empirical findings from the internal interviews at Tetra Pak will be presented regarding what has been implemented and the current state of the PLM system. Moreover, the current state of the circular economy work and the ESG Reporting Program at Tetra Pak will be covered from the empirical findings.

4.3.1 The beginning of PLM at Tetra Pak

Person B describes that the PLM initiative has existed in the last twenty years at Tetra Pak and between that period there has existed a number of other PLM initiatives.

Person A describes a need for a more developed system within the company was discovered, and the company was mature enough regarding starting to improve the systematic way the company worked with PLM. The company was working well but the way they worked with PLM system was ineffective with lots of people involved. There was an opportunity to create a more effective way of managing data and work with databases having information at the right time with the right input.

Person B describes that the current existing system has missing pieces in the foundation and initiatives during the years have had the mission of trying to create a solid foundation. It is problematic to fix a car that is moving, and that is the situation the company faces every day. The team is working in a running business trying to build a PLM system which is a difficult mission.

According to Person C, Tetra Pak started a few years ago with creating a more defined PLM organization and that was the start of the PLM organization's current outlook. It was a more powerful acceleration of the PLM initiative, across Tetra Pak and across all lifecycles. Earlier initiatives have mostly focused on the engineering and development part of the lifecycle.

4.3.2 The current PLM system

Person B describes that depending on the definition of a PLM system it determines the current state of the system at Tetra Pak. If it is defined as a systematic work to integrate information to make it coherent then there is not a system yet, but it is currently under construction and it is moving forward.

Furthermore, Person B describes the other definition of the system as a way of managing the lifecycle of the product, lifecycle management, with help from people in homemade systems, where the data integration is through excel-files and a more manual interaction. Currently, the only place where the data management exists and where some form of data management occurs is under the mechanical design. The system that is under construction today has fantastic capabilities implemented into the system. Currently, the system has a few users, but it is in a theoretical state and under development and exercise. Proof of concepts has enabled capabilities in the system, and it is under development and construction.

Person B also explains a perspective of the current state of the PLM system, where the PLM system can be interpreted as building with different floor plans and all levels have different requirements to become complete. With this perspective in mind, Tetra Pak currently has missing pieces in the base of the house, and the base must be in place before the next floor plans can be built. The next floor plans symbolize the more niched PLM solutions that therefore will be implemented afterwards.

4.3.3 Data access in the different lifecycle phases

Person D describes a summarized version of the developments of the different PLM phases, BOL, MOL, and EOL. The different lifecycle stages of the PLM system and how far the company has access to data through the different phases in the product lifecycle. Regarding the BOL phase and its data access, the data is both manually and systematized. The longer in the beginning of life you go the more structure regarding how the data is managed, especially the work consists of BOMs and structures in the system. Regarding the MOL phase, when the product is in the usage phase, the company has a certain number of different service systems, where the company works with the installed base, which is the products Tetra Pak has installed. There are also systems for managing the defects.

According to Person A, there is minor access to data in the PLM system, when it comes to the EOL data. The data exists, but it is difficult to answer, if a paper version of the data exists there is a need to transform it to a digital format.

4.3.4 Future vision for PLM at Tetra Pak

According to Person C, the future aspiration is to become more PLM centric in relation to the current more ERP centric approach, which means a less customized ERP and for instance to manage variant and configuration management in the PLM system.

Person C explains that the company have just initiated an upgrade of SAP, because the current system is old and will not be supported by the software provider in the near future. This is a challenge and an opportunity for creating the future state for the PLM team. The next generation SAP can be interpreted both as an enabler and a complicating circumstance, because it will require better control of product data in order to succeed with the change, but it is at the same time a slightly complicating circumstance when it happens at the same time. The upgrade can be seen as both an accelerator and a brake pad, because you can partially follow along, but it requires a lot of resources, in particular IT resources, that can become a limiting factor.

According to Person D, another challenge is that there exist differences in how the company works, and how the new system will look. Therefore, there exists issues in the people part, where the risk is that we do not have synchronized plans for how the company want it to work between different organizations, while the system is straight forward.

4.3.5 Circular economy work

Tetra Pak leads the sustainability transformation with their development of recyclability of their carton packaging, action taking to mitigate climate change, and at the same time protecting and restoring nature. The sustainability work at the company is aligned with their brand promise to protect what's good, including protecting, food, people, and planet. The planet category has three different focus areas including, circularity, climate, and nature that the company currently is working on. (Tetra Pak, n.d.-e)

According to Person F, the company generally does lots of circular economy work regarding the packaging solutions. Tetra Pak has targets regarding increasing the share of fiber in the packages, introducing plastic and renewable plastic as an input. Work with ensuring packaging being designed for recycling is also on the agenda, and the company have for a long time already collaborated with different actors to increase the collection and recycling of the packaging globally.

4.3.6 CE activities regarding the filling machines

Regarding the filling machines, Person F explains that Tetra Pak does work with refurbishment, reuse, and remanufacturing of the filling machines. The company does not have any publicly disclosed targets for this.

According to Person F, Tetra Pak's refurbishment activities ensure to extend the lifecycle of the filling machines as long as possible. The activities are mostly services of maintaining the equipment at the customer ensuring it is done as quickly as possible. The company also do a secondhand business, delivering secondhand machines collected from another Tetra Pak customer.

Furthermore, Person F describes that the company is working with refurbishment activities, and currently Tetra Pak discusses issues such as the sustainability strategy for filling machines and how to consider the climate targets, water targets, and sustainability targets. Regarding the mentioned topics it would be important to set a clear strategy with targets, which enables the company to start measuring if it is moving into the right direction.

Person F explains that the work with recycling activities of the filling machines has the company more or less taken for granted, mainly because part of the material consists of stainless steel where in many countries this material is well recycled as well as the recycled input. Therefore, Tetra Pak has not had this as a focus area because of the knowledge that lots of countries' share of recycled input is already rather high for stainless steel. But this topic is under discussion and Person F believes there will be further work and definitions of this area in the near future.

4.3.7 The ESG Reporting Program

Person E describes that Tetra Pak has started a Program, The ESG Reporting Program, with the purpose to make sure that Tetra Pak complies to EU's CSRD directive based on the EFRAG ESRS standards. The director of the program's task is to make sure the program implements CSRD in those businesses that falls under the criteria for non-listed businesses. The Program manages, monitors, and handles Tetra Pak’s work with the CSRD directive. The CSRD will enhance the company’s current sustainability reporting work process, which will increase the quality of the reporting. Tetra Pak is regulated to report 2026 for the financial year of 2025.

Moreover, Person E explains to manage the directive and non-financial reporting in the future, the program therefore looks at what they call the ESG Service Delivery Model made for reporting. The reason behind the model is that every country's report needs to be audited by a third party. Within in the finance team at Tetra Pak a model called Finance Service Delivery Model is used to report the financial information. Therefore, the need of an ESG Service Delivery Model is a good way forward.

Furthermore, Person E describes that the reporting opens possibilities for new business opportunities using tools like AI and data mining, to develop innovations that do not exist today based on the improved data access.

4.3.8 Current data access of the scope 3 emission

Compared to recent reporting, Person E describes that the company needs to report a large number of data points, which the company has not needed to disclose before which is a new challenge.

According to Person F, regarding the data access connected to the EOL regarding the filling machines, the company can not concretely calculate the CO2 impact of the circular business models or solutions if the company can not capture the amount of reuse. To improve the circularity, the calculations and input is dependent on that data. Considering that the filling machine lines will sit a long time at the customers premises, it is important that the company understand and can track the information such as reuse, refurbishment, repair, and resell. There exists knowledge that it is not easy to track the circular economy standard work. Not all customers use Tetra Pak’s services, and instead use other companies’ services regarding repair and refurbish activities. Therefore, the company would benefit from better data.

4.4 The external perspective

In this section the empirical findings from the external interviews with Company A and Company B will be covered regarding their current state of their PLM systems. Furthermore, the empirical findings from the PLM system Supplier A will be covered.

4.4.1 Company A's PLM system

Company A is a world leading producer in the heavy industry, focusing on large-scale operations, in the marine, energy, food and water industry. The company is a component supplier.

According to Company A, the PLM initiative started at the company due to the investment in E-commerce and therefore realized the control of the product information was bad, which was going to be exposed to the partners or distributors. Company A describes this as the crucial factor starting the PLM initiative. Later, more reasons to why working with PLM occurred, where digitalization was the major contributing factor and master data. Master data is defined as a concept within information management, which is particularly important information about, among other things, customers, people, and products. Furthermore, there exists lots of different driving forces driving companies to start their PLM journey. In the end, it is about having the ability to serve the customers in an improved and cost-effective way.

Company A's current PLM system is quite competent. Important to emphasize is that it is not a system, meaning people talk about data process, people and systems. Systems comes at the bottom, so it is all the processes, and the roles people have in the processes and above all, the information that is created and the flows in the processes. Company A thus have a very comprehensive package regarding that perspective of PLM, where the company has focused mostly on new sales and currently invests in the after-market service. The system has not so much focus on the supply chain, and least focus on the product development and product engineering. This is Company A's PLM approach based on the companies' driving forces for their business.

Regarding future improving plans of the current state of the existing PLM package (system), the company has lots of work regarding the after-market, to be able to sell spare parts. Therefore, better control over what has been delivered, to what end customer, and the configurations compositions. This work is called, product instance journey, meaning enable to follow a product instance throughout its whole lifecycle. The groundwork needs to be done and DPP and CSRD reporting is the other area. Our products need to comply to many directives and regulations, which is an important part and is driven by the requirements.

According to Company A, when the products are sold to several customers there is a gap of information regarding the EOL phase. The company has limited access to the EOL-data. Regarding the service, there are a certain number of products the company do not serve, and there is products' never returning after delivery. Some products are connected, but it does not mean that the company have access to that data, which has to do with the company being a component supplier.

Regarding how far the company has come with closed loop PLM, Company A explains that the company has not come so far but has done a minor effort. But without proper access to the EOL data it makes it difficult. To improve the future plans it involves more people, and it is not the PLM initiatives decision.

4.4.2 Company B's PLM system

Company B is a global industrial group within tools and tools systems. The interview person represented one of the companies four divisions, the persons responsibility as VP Life Cycle Services, is the Life Cycle Services representing the product portfolio responsibility, marketing, pricing, technical support, training, and education.

The products weight between 20-150 tons with a life cycle of 10 to 30 years. The products are traditionally driven by a diesel combustion engine. Currently, the company works to an adjustment against electrification of the engines.

Currently, Company B do not have an integrated PLM system software, instead the company is working via local systems to manage the information and data. The company uses the ERP systems, but the product management is not in a system but is managed manually in excel, powerpoint etc.

Company B does not have any future plans to systematize the current system, because it is a limited number of products in the portfolio and therefore there is no current need to add an IT system. Today's system is manageable given the size of the portfolio.

Company B has the customer groups, the rental companies, the contractors and the end users. The rental company maintains the product when needed. When the product is at a certain stage of the lifecycle, the rental company either sells it to one of the end users or the product is scrapped. Since a few years ago Company B has added telematics to all products the company sends out, a transmitter and an antenna attached to the products that via a modem sends data back to Company B from the products. This technology enables the company to centrally follow where the product is located, number of operating hours, which services needed and how they are performed. Company B consider this data important to follow up, and collect the lessons learned to provide this information back to the designing phase of the products. Company B sees this feedback collected from the telematics as valuable for the company compared to the investment needed. The telematic technology also helps the company to measure the CO2 footprint, based on the data regarding the number of products that are operating, operating hours, diesel/ or electrical driven.

Company B is in the beginning journey of a closed loop PLM system, because the company have future plans to systematize the current manual calculations of CO2 footprints. Company B also emphasized that they were the first in the industry to replace diesel with HVO in their products. This has to do with the scope 1 and 2, because HVO reduces almost all the carbon dioxide combustion. This change is a standard when the products are delivered, they all are delivered as green with HVO in the tank.

4.4.3 PLM system Supplier A

Supplier A is a supplier of software solutions to manage data throughout the product lifecycle and is a global leader in product lifecycle management software industry. According to supplier A the organization provides sustainability PLM software and use cases among customers exists. The Supplier A describes that they offer closed loop PLM solutions. Supplier A believes AI can be future tool opening opportunities regarding the integration between the PLM system and circular economy principles. AI can be a tool for giving advice, recommendations, and best practices, but AI technology is still in an early development stage and therefore the future will tell.

4.5 The internal and external sustainability perspective

This section will describe the internal and external empirical findings regarding challenges with CSRD, the current state of sustainability data integration in the PLM system, and the current state of collaboration between the PLM team and sustainability team.

4.5.1 Challenges with CSRD

Identified challenges by the PLM team

The PLM team has similar views of the largest problems the company has regarding CSRD reporting of scope 3 emissions.

Person A and Person D both agrees on the challenge regarding the difficulty to identify emissions occurring across the supply chain involving external parties. Person D also believes that the company might have the data but how companies need to report to comply with the directive is something new.

Person A also believes that more data needs to be collected and synced and an agreement on universal measurements is needed.

Person B believes an attitude change in the relationship between the companies and the subcontractors needs to be more consistent.

Specifically, regarding the challenges that the PLM team identifies regarding the scope 3 emission, downstream end-of-life-treatment of sold products, were all very much in agreement.

Person A, and D identify the challenge of lack of knowledge when the equipment is sold to the customers because the company no longer owns the product. Person A also believes that carbon emissions are just one sustainability measurement, and in the long run the company needs to be prepared to measure more factors.

Identified challenges by the Sustainability team

The Sustainability team also has similar views of the largest problems the company has regarding CSRD reporting of scope 3 emissions.

Person G highlights that one of the major challenges in the new reporting requirements from CSRD/ESRS, is the scope 3 environmental data. Better traceability in the supply chain and more specific data from suppliers are needed. Person E and Person F also identify having access to high quality data as a challenge with the CSRD reporting of scope 3 emissions. Person F believes reliance to databases is another challenge.

Specifically, regarding the challenges that the Sustainability team identifies regarding the scope 3 emission, downstream end-of-life-treatment of sold products, Person F thinks access to data is a challenge. Person F explains that the data gaps lead to assumptions which makes it difficult to trace back and the data is not very accurate. Person F also believes it is difficult to show the sustainability value and communicate it effectively when there is no access to the specific data.

Identified challenges by the external companies

Company A identified some challenges regarding CSRD reporting of scope 3 emissions. The biggest challenge is to create a sense of urgency, because the reporting will require a lot of work, and the CSRD reporting is a new ticket to operate. There also exists an uncertainty in interpreting various directives, which creates difficulties to figure out what is okay or not to report. Specifically, regarding the scope 3 emission, downstream end-of-life-treatment of sold products, the challenge is that the company do not have access to the data.

Company B believes the biggest challenges of CSRD reporting of scope 3 emissions are finding enough data from subcontractors to make an accurate calculation, and having the access to data, which is dependent on the maturity of the subcontractors and how well order they have on their data. Specifically, regarding the scope 3 emission, downstream end-of-life-treatment of sold products, without having access to the needed data instead results in assumptions.

4.5.2 Lessons learned regarding CSRD

Person E emphasizes that the lessons learned so far regarding the CSRD reporting of scope 3 emissions is that the directive is more burdensome on the environmental part than the social and governance parts.

Person F have been looking at it from a circular economy standard point of view, and further work is needed before these standards can be brought together.

According to Person G, as the CSRD/ESRS reporting is new, there is not yet an established practice on how to apply standards or perform the reporting. This is new to all stakeholders and there is a need for joint learning and best practice building.

4.5.3 Sustainability data integration in the PLM system

According to Person A, there exists sustainability data in the PLM system, like weight, and the product apparency. According to Person B, the data exists but Person B is unsure about whether the information is available to the persons who needs it. Both Person B and Person C explain that the PLM team currently are working with getting the base of the PLM system in place. When the foundation of the system is in place more functions and attributes can easily be added such as sustainability data.

Both the PLM team and the Sustainability team have a common belief that the PLM system can provide support for the work with the circular economy.

The PLM team's perspective

The PLM team has a common belief that the PLM system can provide support for the work with the circular economy.

Person D describes that with a well working PLM setup makes it possible to have the control over the products, regarding what is and what has been produced. And the more developed PLM System and PLM thinking you have, the more information you have control over. If the system becomes scalable it is possible to include other information and documentation from subcontractors. This way, the sustainability related information can be integrated to the system.

The Sustainability team's perspective

Person E believes that the PLM system can provide support to the work with circular economy regarding material master. Material master is defined as all components needed to produce a product. Meaning information on master data principles, such as the weight of the components. Therefore, access of information on material master in the PLM system is crucial, resulting in the information being traceable to manage the reporting.

According to Person F, there is a believe that the support the PLM system can provide the work with circular economy principles is to provide support regarding tracking different products and components across their lifecycles and connect the input. This will enable the company to trace back what has been added to certain components before installed in a machine line and follow it at the customer side. Person F also believes that it could be extended to the EOL, and even following the material until the reverse logistics activities, such as recycling and remanufacturing. This will require customer consent and agreement allowing the company to track this data. The company do not have ownership of the filling machines when sold, which is an issue. Most advance companies have been moving towards leasing systems, where they offer a certain function as a service, and give ownership of the equipment to customers. Person F think this could solve the issue, which enables the company to have all the information and data and provide processing as a service to the customers. This would ensure that the company use the material and the value to the highest extent throughout the lifecycle.

The external companies' perspective

Company A describes that the company has sustainability data in their PLM package, such as weight and chemical compositions to a large extent. During this year the company will work with including carbon emissions as well.

Company A believes the PLM system can provide a large amount of support to the work with circular economy principles. Regarding reduce, such as reducing weight of the input material, it is important to have control over the weights, where the PLM system can provide support. It can also be about reducing carbon emissions, where comparison between different product lines and their different levels of emissions. Reuse is a classic PLM use case where the system has control over the product data so that the wheel does not have to be reinvented. If the company do not have control over the serial number or the product input, it can be difficult with the recycling. If the company do not know where their products end up it is difficult to control.

Company B describes that the company has sustainability data like weight and chemical composition in their ERP system. The company do not have the CO_2 footprint from the suppliers in the system but is something the company is working with improving currently. According to Company B, if the system was in place, the access to data would exists. Company B believes it is related to the business strategy of a company, where the strategy manages the situation more.

4.5.4 Collaboration between the PLM team and the Sustainability team

Tetra Pak

Person A and Person E expresses that an initial collaboration between the PLM team and the Sustainability team currently exists at Tetra Pak. Person A describes that the vision is that the collaboration will become part of the current strategy in the company.

PLM team

According to Person A, an understanding that the two teams need each other is required to improve the integration and collaboration between the PLM team and Sustainability team. Resources, improved tangibility, discussions, and expressed by top-management are other factors Person A believes is needed. Person C also believes involvement with the higher level management is needed, where both a bottom-up and top-down approach probably is needed. Person D describes that showing evidence of what PLM can contribute with as well as showing the organization that the product data can be managed in a structured way are aspects needed to improve the integration among the two teams.

Sustainability team

Person E believes the key to improve the integration and collaboration between the PLM team and the Sustainability team is that they need to merge more with the team working with the SAP upgrade.

According to Person F, a process involving all different internal stakeholders is needed to be able to manage an improvement regarding the integration between the PLM and Sustainability teams. This would help to align and ensure to create a clear vision and what contributions each internal stakeholder needs to provide.

External companies

Currently, Company A expresses that the company has developed a good collaboration between the PLM team and the Sustainability team. According to Company A, three teams need to collaborate, where the third team refer to those who create and maintain the data.

Company B explains that the company have a collaboration between the PLM team and the Sustainability team regarding what needs to be calculated, regulations regarding what data that needs to be reported, and in terms of sustainability we are also looking at what is developing going forward and how this is communicated externally. To be able to manage an improvement in the collaboration between the two teams, Company B believes communication and transparency are key factors.

4.6 AI and the business benefits

The empirical findings regarding the opportunities with AI will be covered in this section. Furthermore, the identified parameters to measure regarding an improved closed loop PLM system implementation to improve the circular economy aspects are covered.

4.6.1 AI and PLM system

The PLM team had a mutual view of the support opportunity AI can provide regarding the integration of the PLM system and the circular economy work. The interview persons also emphasized the importance of a proper system with structure and control of data before combining it with AI technology and it can provide support. Person E and Person F also believes AI can have a great potential to support the work. The external benchmarking companies also believes AI will make the data management process more efficient.

4.6.2 Business benefits

The interview candidates were asked during the interviews, given a sustainability perspective, what they believed important parameters to measure was, if a more improved closed loop PLM system was introduced to improve the circular economy aspects. Some of the aspects correctly connected to the question is collected in Table 6. The table identifies proposals to Key Performance Indicators (KPIs) to measure and present the success regarding the business benefits with an implementation as described. The KPIs are categorized in five groups, collaboration, communication, traceability, value creation and measurements of actions.

Table 6: Important parameters to measure, if a more improved closed loop PLM system was introduced to improve the circular economy aspects.

Category	KPI	Interview Candidate
Collaboration	Customer collaboration.	Person C
	Internal collaboration between PLM and Sustainability teams.	Person D
	Supplier collaboration.	
Communication	Communicate which sustainability parameters are needed in the system.	Person D
	Communicate the number of products refurbished/ remanufactured/ resold leading to market opportunities.	Person E
Traceability	Traceability over all circularity loops.	Person F
	PLM system support across the whole product lifecycle.	Company A
Value creation	Value creation from credible tracking.	Person F
	Becoming more fact based and having real-time data communicated to the company.	Company B
	Digitalization of the whole production will contribute to enabling simulation of the material flows and material impact of different materials.	Company A
Measurements of actions	Environmental benefits: raw materials, climate impact, nature impact, social impact.	Person F
	Number of operating hours.	Company A
	Water usage calculations.	
	Electricity usage calculations.	
	Number of servings with wearing parts.	
	Locate the final destination of the product.	
	Reuse of components.	

5 Analysis

Chapter 5 aims to link together the collected information from the literature review, and the internal and external interviews. The chapter will provide an analysis including a benchmark between the two external parties and Tetra Pak, a current state analysis of Tetra Pak's current strategical position according to the problem statement resulting into a proposed strategical navigation forward.

5.1 Introduction to analysis

The analysis will be approached to form a contribution to the main objective of this thesis, Tetra Pak. Therefore, it is important to have this perspective in mind when approaching this analysis, where the current state analysis provides information of specifically Tetra Pak's current state within this context.

Aspects covered in Chapter 3 and Chapter 4 are further analyzed and structured in this chapter. A benchmarking framework, a SWOT framework, and the dual operating system model are all frameworks enabling an analysis to be performed. The analysis ends with a proposed strategic roadmap framework based on the current state analysis for Tetra Pak moving towards an improved future stage.

5.2 Benchmarking with external companies

Based on the theoretical background and empirical findings of the PLM representatives from the Tetra Pak and the two benchmarking companies, Company A and Company B, an analysis comparing the companies could be performed.

Two perspectives were interesting to compare between the companies regarding the problem statement of the study and based on the collected information from the literature review and the interviews. According to the empirical findings an importance of the PLM systems technologically maturity level was an important factor to keep in mind before adding additional functions to the system. Furthermore, according to the literature, it is required to overcome technical and business wise barriers to enable a successful PLM system implementation.

Moreover, the number of research on the area of circular economy integration with PLM system enabled by intelligent products is also in an early stage in regard to research, and more research of case studies are required. Examples like ICT technologies enable a link between CE and PLM is a new era, with opportunities and barriers. Where mentioned barriers from a system point of view, are requirements such as a holistic perspective, and understanding for the complete system, high infrastructure, and logistics. The ICT technology contributes with functions such as, gathering real time data, gathering customer preferences and usage pattern data, improved service and producing multiple lifecycle products, which all are information needed to comply with CE goals.

Based on this motivation the companies PLM system maturity level and the PLM system sustainability data integration was chosen to be benchmarked in a coordinate system framework, illustrated in Figure 15. The PLM system maturity level is placed on the y-axis and the PLM system sustainability data integration is placed on the x-axis. The maturity level refers to the implementation level an organization is on related to the PLM system. The PLM system sustainability data integration refers to the level of sustainability data a company's PLM system are integrating at the moment in regard to the EOL-data integration of reverse logistics.

The axes are both displaced, the y-axis shifted to the left and the x-axis is shifted down. The displacement of the axes is illustrating the barriers needed to overcome, both to have a successful PLM implementation and integrating CE with PLM and also the existing knowledge gap mentioned.

The future stage can be defined as a mature PLM system which has integrated sustainability data into the foundation of the PLM system. To be able to integrate such additional technologies enabling suitability data integration, the foundation of the PLM system needs to be in place. The way to reach the future stage is not a straight line, illustrated with a solid, a longer dashed, and a shorter dashed curve. The S-curve, illustrated by the solid curve, illustrates the progress of a project over time. The S-curve is a common way to control projects throughout their execution phases. It is a valuable tool for project management in projects, both to report status and predict the future.

(Miskawi, 1989) The two exponential curves illustrate two other ways to reach the future stage, depending on what resources a company has regarding this type of project.

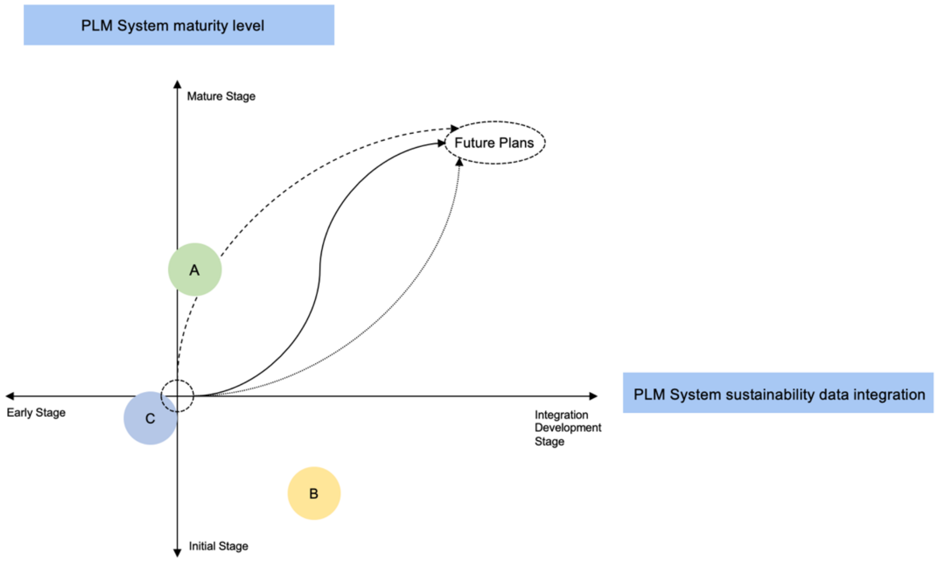

Figure 15: Benchmarking between Tetra Pak, C, and the two benchmarking companies, Company A, A, and Company B, B.

The placement of the different companies is based on the empirics of the thesis and translated to a non-scaled coordinate system. The motivation of the placement in the coordinate system are as following:

Tetra Pak, C

Tetra Pak's current PLM system is defined as being on an initial stage with a need to solve the gaps in the foundation to improve and become mature. But the company has shown improvements and are in a developing stage. Regarding the sustainability data integration in the system, there might be data already, but the current focus is to complete the foundation of the system, and future plans of what additional functions will be considered, such as sustainability data attributes. The ongoing work with the installed base traceability supports the sustainability integration. Therefore, there are no concrete plans regarding integrating sustainability data.

Company A, A

Company A's current PLM system, called PLM package, is defined as quite competent and very comprehensive. The focus is on new sales and investments in the after-market is under development. The company's investments in the after-market and the product instance journey enabling to follow the product instance throughout the whole lifecycle, aligned with DPP and CSRD. The collaboration between the sustainability team and PLM team is good. During this year the company will work with including carbon emissions as well.

Company B, B

The company do not have a system, more of a network with both ERP system and id. Currently, this systematic approach works, and therefore no future plans exist regarding becoming more systematic. Regarding the sustainability part of the systematic approach, the telematic technology enables the products to become connected and is key to collect sustainability data. Future plans on including CO2 footprint data also exists to make that process go from manual calculations to more systematic.

It is interesting how the PLM system approach is used differently in various companies as seen in the three described company cases. The explanation can be the drivers for PLM in different companies, where the business opportunities is a determining factor in the PLM system, as described by Company A and Company B.

Also, the products the company produces and to what volume can determine how the PLM system is implemented and to what extent. A smaller volume can result in a less systematic PLM approach.

An opportunity in the PLM system field is the sustainability data integration, motivated by the empirical findings.

5.3 Current state analysis

The starting point of the current state analysis links back to the problem statement of the study:

"How can Tetra Pak´s PLM systems be adapted to better support circular economy principles, including product reuse, remanufacturing, and recycling, to drive sustainable product innovation?"

As described in the internal interviews, the current PLM system at Tetra Pak needs to solve the issues in the foundation before adding additional technologies and systems to the foundation. When the foundation is in place other functions and attributes can be added supporting the company's business strategy regarding product lifecycle management to improve the efficiency level. Figure 16 illustrates the described situation.

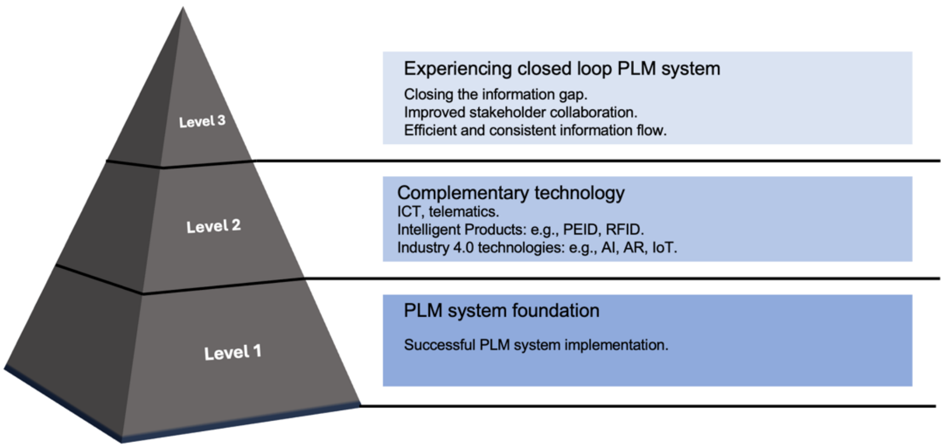

Figure 16: A pyramid illustration of the levels of implementing PLM based on data collection.

Based on the collected information in theoretical background and empirical findings, the SWOT framework could be applied. The internal strengths and weaknesses, and external opportunities and threats were identified related to the problem statement of the study. The identified aspects are presented in Table 7, where the identified aspects are placed in the SWOT framework without mutual ranking. The identified aspects are further described in Appendix A.

Table 7: SWOT analysis, identifying internal strengths and weaknesses, and external opportunities and threats.

Strengths (Internal)	**Weaknesses (Internal)**
• Driving factors for PLM • The foundation of the PLM system is in a developing and improving phase • Minor collaboration between the PLM team and Sustainability team • The ESG Reporting Program (CSRD) acknowledges the importance of access to data • The SAP upgrade	• Minor collaboration between the PLM team and Sustainability team • Need of collaboration with the third party involved • Information gap in EOL phase • The SAP upgrade • Low top-management commitment • Requires a sense of urgency and a clear strategic vision
Opportunities (External)	**Threats (External)**
• Improved existing PLM system • Closed loop PLM system • Technology enablers • Digital Product Passport (DPP) • Circular Economy (CE) implementation enablers • Challenges with complying to CSRD regarding scope 3 emissions • Dual Operating System	• Information gap when products are sold • Need of improved collaboration with EOL phase actors • Challenges with closed loop PLM • Circular Economy (CE) implementation barriers • Low emphasis at research institutions • Challenges with complying to CSRD regarding scope 3 emissions • Cyber security • Technology enablers

5.4 The stakeholder perspective

Stakeholders can be mapped in a stakeholder model, where the involved stakeholders in a certain context are identified. Stakeholders involved in the context of this study is based on the theoretical background regarding Hribernik's et al. (2011) identification of the actors and processes in the reverse logistic process of the EOL phase and the empirical findings regarding collaboration between internal actors at the company. Figure 17 displays a proposal of actors needed to be involved in the supporting process the PLM system can provide the work with circular economy. This is a proposal and a start on the actors needed, and more actors may need to be added to complete the process.

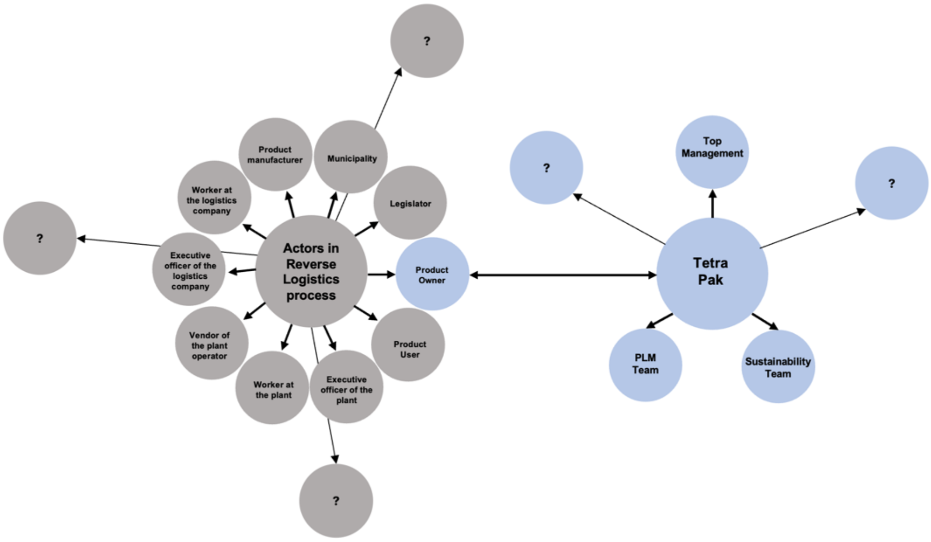

Figure 17: Illustration of actors needed in the integration of PLM and CE at Tetra Pak, based on Hribernik's et al. (2011) identified actors.

As both the theoretical findings and the empirical findings shows evidence of, the absence exists of an integrated information management approach in the reverse logistics process. The lack of information management contributes to an ineffective process in the EOL phase, which also explains the information gap from the literature occurring in the EOL phase.

Furthermore, as identified, many stakeholders are involved in the EOL phase and therefore a proper systematic approach is needed to manage the valuable information occurring during the reverse logistic process. This information can be valuable for continuous development, innovation, research and development, and designers. If the information remains in the EOL phase it will never have the opportunity to reach the designers in the BOL phase.

5.5 The eight accelerators applied to the current state

Figure 18: The eight accelerators from Kotter (2012) applied to the current state analysis. Green circles represent a partly completed accelerator process, and grey represent that an accelerator process has not started.

Based on the empirical findings and the theoretical background on organizational change management in the process of implementing a PLM system change, change management becomes an important factor to take into consideration. In Figure 18 proposals of the accelerators are applied to the context regarding the current state analysis of Tetra Pak. The green circles represent partly fulfilled actions in the accelerator model, while the grey circles represent actions needed to be taken.

A start of a sense of urgency exists around the PLM importance, but the voice needs to become louder. The opportunities the PLM system can support the CE principles needs to become urgent especially because of the need of reporting and complying to the CSRD directive regarding scope 3 emissions.

A start of a guiding coalition exists but needs to involve more volunteer internal actors to be completed. Involving more people in the sustainability team, and other important actors in the company. This will end up creating the dual operating system supporting the implementation of the change effort.

A strategic vision for the PLM initiative has been developed but more clarity regarding what the vision is supposed to result in must become more specific. To be able to integrate the CE aspect to the PLM strategy a vision needs to integrate this aspect.

5.6 Roadmap moving forward

In this section the strategic navigation moving forward in the context of the problem statement of the thesis will be presented and described.

5.6.1 The roadmap

In order for Tetra Pak to be able to strategically navigate forward and reach a stage where the PLM system can support the work with circular economy regarding the filling machines in the reverse logistics phase in EOL and drive a sustainable innovation process at the company, a strategic roadmap has been created and can be interpreted as proposals for the company to move forward on the topic, see the illustration in Figure 19.

Related to the benchmarking approach and the two axes, PLM system maturity level and PLM system sustainability data integration, there are barriers to reach the future state, regarding the technological challenges and the businesswise issues. Implementation of a successful PLM strategy into an organization has challenges and barriers to overcome, technically, businesswise and in terms of organizational change management. CE implementation in organizations is not a straightforward process either, which has obstacles to overcome along the way. Literature refers to product lifecycle management being one of the enablers to implement CE into an SME organization.

The objective with the roadmap is to embrace an iterative and agile approach to reach a future stage with a closed loop PLM system enabled by additional technologies, such as I4.0, ICT and intelligent products. The technologies need to be evaluated and chosen based on what is best for the company. There exist many technologies introduced in the theoretical background, and it depends on what product and the unique use case.

The roadmap is based on the collected information from the theoretical background and empirical data, and is divided into five steps:

1. Set up a clear strategic plan moving forward.
2. Implement the foundation of the PLM system in the organization.
3. Implement additional technology to close the loop in EOL.
4. Experiencing closed loop PLM system.
5. Checkpoints: evaluate stepwise.

The steps include four categories, *the goal with the step*, *the technological approach*, *the change work approach,* and *the stakeholders involved*. All categories are required to be fulfilled to complete each strategic step in the roadmap. Between each step the checkpoints represent the follow-up process needed to evaluate stepwise and make improvements or adjustments to the strategic plan moving forward.

The different categories in the roadmap will be described and motivated further in the next sections regarding their placement on each of the four steps.

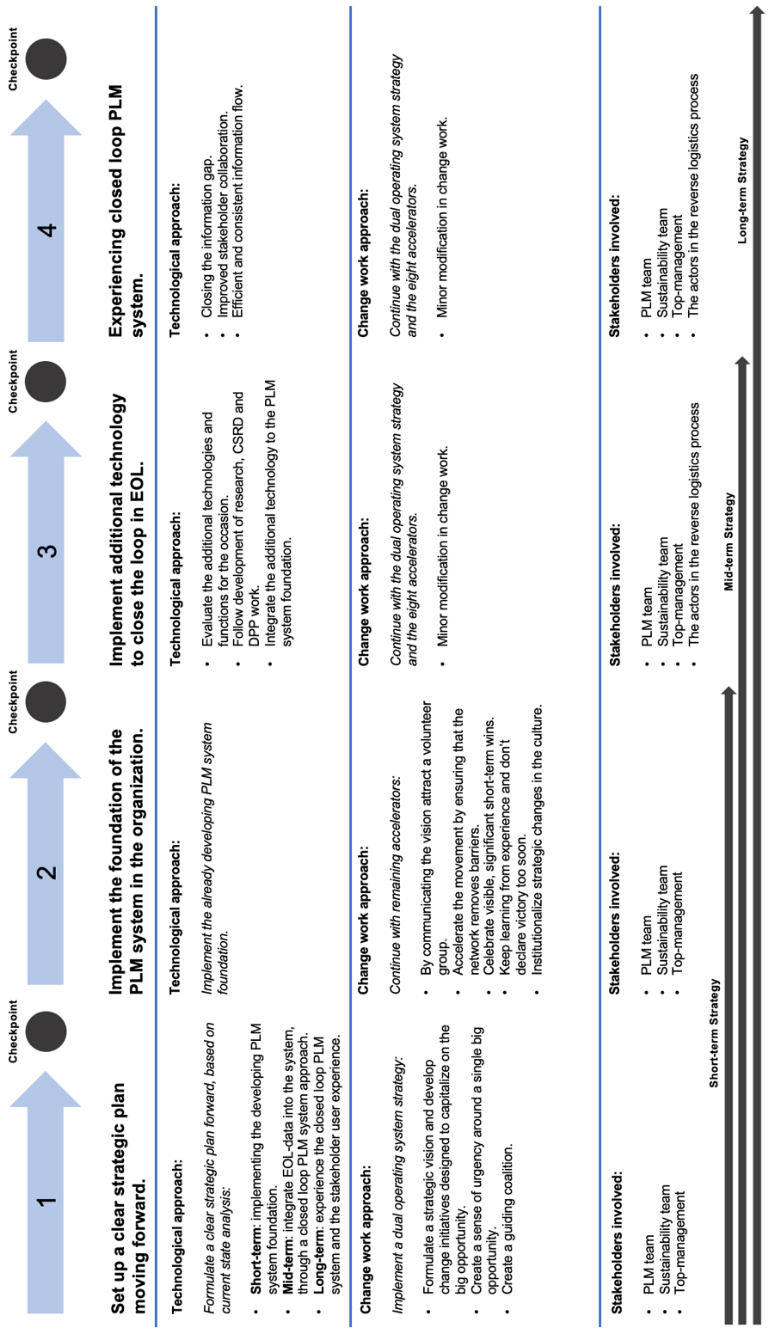

Figure 19: Proposed strategic navigation moving forward regarding how Tetra Pak's PLM system can be adapted to better support the circular economy principles regarding the filling machines, including product reuse, remanufacturing, and recycling, driving sustainable product innovation.

5.6.2 The technological approach

The technological approach is based on the theoretical background regarding closed loop PLM implementation, and the steps presented by Gehrke et al. (2020) as a general technological approach implementing additional technology, IIoT in Gehrke's example, enabling a closed loop PLM system.

Firstly, before the technological approach can be implemented a clear strategic vision in a format of a plan is required to be established. The strategic plan is proposed to be divided into three steps. The short-term strategy, including the implementation of the current developing PLM system foundation. The mid-term strategy is the implementation of additional technologies enabling a closed loop PLM system. The long-term strategy is the user experience among the stakeholders involved in the implementation of the closed loop PLM system. It is important to keep in mind the time perspective regarding the three different terms of strategy, because it is a process taking place over a long period of time, where technological development and regulatory development are happening parallelly.

Secondly, the next step in the roadmap is the implementation of the current developing PLM system foundation, which completes the short-term strategy.

The third step includes the mid-term strategy, which goal is to implement additional technology enabling closing the information loops in the EOL phase. During this phase an evaluation needs to be performed of what technology should be used to connect to the filling machines and integrate with the PLM system. The literature emphasized various technologies, but because of the current technological challenges more research in the field is needed to have a better understanding. CSRD and DPP are two important regulatory frameworks to follow regarding how the collection of data along the supply chain can be performed, where best practices will emerge over time.

The last step in the roadmap is the long-term strategy including the user experience by all involved stakeholders of the closed loop PLM system. The main goals are to close the existing information gap, improve the stakeholder collaboration, and provide an efficient and a consistent information flow throughout the entire product lifecycle.

5.6.3 The change work approach

The change work approach is based on the empirical findings regarding the current state, and the theoretical background mentioned by Stark (2022), Kotter (2012) and Harvard Business Review (2011). The dual operating system approach is proposed to be applied in the company regarding this topic. This strategy will improve the acceleration of the change effort the PLM team needs to provide a successful PLM system implementation. The system uses an agile approach, has a network-like structure, and continuously assesses the business, the industry, and the organization. Where the dual operating system will work as a complement to the hierarchical structure and contribute to an easier operating process in the organization and acceleration of the strategic change.

During the first step the implementation of the dual operating system is proposed to begin. Where continuing the already started work with the formulation of the strategic vision, the creation of a sense of urgency, and the creation of a guiding coalition. In relation to the current situation, it is proposed to continue scaling up the voluntary group of internal change agents in the company. In addition, it is proposed to present to the company a concrete use case regarding the work that the PLM system can contribute with regarding a more efficient work of data management. This will help to communicate the improvements to the organization, involving top management and scale up the change network.

The second step revolves around continuing to apply the remaining accelerators and improving the partly completed accelerators. By communicating the vision internally, the volunteer group will scale up and accelerate the movement and ensuring to remove barriers. The celebrations of short-term wins will become visible as the change effort progresses and will be more important. Learning from experience will also keep up the acceleration, if slowing down the change process too early the resistance to change will slowly take over. Therefore, the sense of urgency is important to be able to keep focus. To have a completed strategic change initiative the change needs to become a part of the organizations culture, where the PLM initiative's change effort and PLM understanding needs to become a part of the day-to-day activities.

During the last two steps related to the mid-term and long-term strategies it is important to continue with the dual operating system strategy. Minor modifications related to the change work approach can occur due to future circumstances.

5.6.4 Stakeholders involved

The identified stakeholders in the analysis are the internal actors, the PLM team, the sustainability team, the top management, and the external actors in the EOL-phase connected to the filling machines, the actors in the reverse logistics process. Considering, more actors might be added when navigating through the roadmap.

During the first two steps, the short-term strategy, the three internal actors are involved in the process. Where these actors create a guiding coalition, the network of change agents and volunteers in the company.

The actors in the reverse logistics process and the internal actors are all a part of the last two steps, the mid-term- and long-term strategies.

5.7 Future State

This section describes the analysis of the future state which is the main goal with the roadmap in Figure 19. This is also connected to the future plans in the benchmarking framework in Figure 15 and to level 3 in the pyramid model in Figure 16.

5.7.1 The business opportunity

The objective of the roadmap is to reach the future state connected to the benchmarking illustration in Figure 15, a closed loop PLM system enables to close the information gap occurring in the EOL-phase with a mature PLM system.

The empirical findings observed the need of the data to improve the sustainability reporting work regarding both circular economy matters, as well as CSRD reporting. Moreover, organizational business opportunities were identified. Where the theoretical background expresses the need of an improvement of collecting the EOL phase data. There exist sustainability regulatory and businesswise incentives to improve the EOL phase data collection and closing the information gap.

Businesswise, for companies to be willing to invest in improvements regarding data management in the EOL phase it has to become a business opportunity in regards to the empirical study. Having improved control of the EOL phase and the data can become a business opportunity with a second-hand market when refurbished products can be reused and resold.

Incentives of a business opportunity is within reach, when regulations become mandatory leading to end the era of greenwashing. The potential for companies to have best practices regarding sustainability reporting processes has the potential to become a business opportunity. Furthermore, because of the increased regulatory pressure regarding disclosing sustainability information, improved ESG reporting capabilities in organizations are becoming a key factor to manage the CSRD.

PLM drivers are different within various companies depending on their business strategy and what type of product or service the company provides. Factors which also are decisive regarding various business opportunities linked to PLM systems.

The identified KPIs in the empirical findings demonstrate the improvements when reaching a collaboration between the PLM system and the circular economy principles. These KPIs are proposed as a start of factors to measure to present success in the context of the problem statement, but more KPIs can become important.

5.7.2 Technological challenges

The absence of research that addresses the company's ability to drive a PLM strategy as well as the ability to connect it to the area of I4.0 are challenges that need to be resolved to enable an acceleration of a closed loop PLM system. Furthermore, there is a lack of research addressing approaches in practice to create the required capabilities to successfully implement PLM. The lack of knowledge in the industry can result in PLM implementation failure, which therefore requires a closer collaboration between academia and industry providing knowledge about PLM strategy.

According to the theoretical background the major challenges for organizations PLM implementation for companies without PLM are the lack of understanding of the PLM capabilities, the opportunity with PLM is not understood, and a lack of strategic direction. The lack of information management approach in the EOL phase, the reverse logistics process, is a common issue due to an absence of a technology closing the information gap providing a support for data sharing and stakeholder collaboration. Closing the loop will provide actors in the reverse logistics field such as producers, experts working in service, maintenance, recycling, and reuse with real-time data regarding product status and value of material. This type of data will provide these actors with the needed assistance to enable an effective and more sustainable EOL phase for products. All actors across the product lifecycle will be able to track, manage, control, the product information from any phase of the lifecycle.

The technologies such as intelligent products, I4.0 and ICT are key technologies supporting a closed loop PLM system. Currently, technological challenges still exist regarding integrating the technologies into the PLM system, such as PEID and IoT. A challenge to overcome this is the ability to share data between all involved stakeholders in the product lifecycle. To be able to share the product information in an efficient way, it is therefore necessary to develop a standard for the technologies and how they can operate in PLM system. Furthermore, challenges regarding information security as well as confidentiality emerges when transferring sensitive data between different stakeholders and this also needs to be resolved.

5.7.3 CSRD and DPP as catalysts

The current acknowledged challenges companies struggle with regarding complying with the mandatory directive, CSRD, and manage the scope 3 emission are emphasizing the absence of collaboration with external actors across the supply chain. The directive's aim to minimize and end greenwashing and place sustainability reporting and financial reporting on the same level, shows the importance of a well working process regarding collection of required sustainability data.

Currently, most companies do not have a process in place to efficiently collect the needed data, where assumptions are made, and calculations are performed manually in spreadsheets. Investments in sustainability software and capabilities within the workforce are on the agenda for the next years to come for the larger companies, due to the need to improve ESG data and reporting capabilities.

Therefore, an opportunity to follow and learn from this real-time use case, complying to CSRD can be an important aspect of driving the closed loop PLM implementation into reality. It might be possible to merge these problems together and PLM system can be one of the enablers to streamline the management of sustainability data.

DPP is also a regulatory framework important to follow, regarding its benefits such as increased traceability transparency and a more efficient supply chain.

There is a common connection where the data is owned and managed by actors in the supply chain that companies do not own and can not control. Thus, this cooperation between the actors is required for transparency and increased data sharing. With CSRD, all of this is put to the test when the reporting of scope 3 emissions becomes mandatory.

5.7.4 The change work required

The mentioned three major challenges with PLM implementation in companies without PLM, the lack of understanding of the PLM capabilities and their opportunities in organizations was related to change work. Additionally, the theoretical background explains the importance of organizational change management to successfully implement PLM in an organization. Therefore, the change work becomes an important factor, due to the absence of OCM often results in failing PLM initiatives.

6 Conclusion

Chapter 6 aims to give a summarized perspective of the results from the analysis and motivate the choice of methodology. Finally, the chapter ends with presenting the contribution to the academy and the suggestions for further research.

6.1 Conclusion of results

The analysis concludes with a uniquely proposed strategic navigation for the case company aiming to propose how the company can adapt the PLM system to better support the circular economy principles of product reuse, remanufacturing, and recycling to drive sustainable innovation work, which is presented in a roadmap framework. Important aspects to take into consideration can be the technological approach, the change work approach and the stakeholders involved. The technological goal is to reach a closed loop PLM system which have the benefits to solve the existing information gap. With a constant information flow of real-time data reaching involved stakeholders will have the possibility to give correct feedback to the designers in the beginning phase of the product lifecycle enabling a sustainable product innovation process.

Barriers exists to reach the aim with the roadmap in the identified areas such as technological, businesswise, CE implementation, change work, and the low emphasize at research institutions. To be able to reach the proposed aim these challenges must be taken into consideration and be evaluated. Regulations such as CSRD and DPP are steps in the right direction opening opportunities to improved stakeholder collaboration throughout the supply chain and therefore it becomes important areas to follow and look after the development in the future.

6.2 Connect results to the RQ's

This section connects back to the problem statement and the research questions of the thesis. Each question is answered in this section based on the findings of the study.

6.2.1 Answering the problem statement

How can Tetra Pak's PLM systems be adapted to better support circular economy principles, including product reuse, remanufacturing, and recycling, to drive sustainable product innovation?

Realizing how the PLM system is uniquely implemented and built in different companies to best suit their business strategies, the closed loop PLM system is the key to closing the information gap in the EOL phase where the reverse logistics process exists. If an improved stakeholder collaboration occurs in the reverse logistics process, based on a close loop system implementation, the system can provide a better information management approach in the complex stakeholder relationships. This data will be valuable feedback for the beginning of life phase to improve and innovate sustainable products.

6.2.2 Answering the RQ's

RQ1: How does the current management of product data work at Tetra Pak with help from their PLM System?

The current PLM system at the case company is under development, and the current data management process works but needs to be more efficient through digitalization and systematization supported by the developing PLM system.

RQ2: Does the company currently work with the circular economy principles? If yes, what type of company data is this work based on?

The company works with circular economy principles with most focus on the packaging material part. Regarding the filling machines there exists an information gap regarding the EOL phase of the end-of-life treatment of sold products. The data do not exist in the PLM system but might exist and because of the complex situation in the EOL phase regarding the reverse logistics process it makes it difficult to find.

RQ3: How does the current management of product data work in relation to the circular economy principles regarding their product segment, the filling machine?

Due to the data gap in the EOL-phase, regarding the filling machines, a bigger focus is therefore needed especially when complying to the CSRD. The EOL phase has been taken for granted by the users of the filling machines to take care of because the users become the owners when the products are sold. The company offers service, and refurbishment actions but it is up to the customer to decide how to dispose the machine when the product serves no value for them. The data do not exist in the PLM system but might exist and because of the complex situation in the EOL phase regarding the reverse logistics process it makes it difficult to find. The PLM program's work with the installed base traceability is an ongoing and supporting work. Therefore, a need is observed of a collaboration between the PLM team and Sustainability team.

RQ4: Based on the current situation, what type of data is managed/needs to be managed from Tetra Pak's PLM system to support the work with the circular economy principles regarding their product segment, the filling machine?

The data in the EOL phase, the reverse logistics process, are the targeted data needed to be managed to support the work with the circular economy principles, regarding product reuse, remanufacturing, and recycling. Currently, there exists an information gap regarding this data.

RQ5: How is this/will this be managed strategically regarding the specific product segment? Who is in charge/will be in charge of managing the data? How will Tetra Pak support this data managing process?

The roadmap proposes the strategical navigation moving forward including the technological approach, the change work approach and the stakeholders involved.

RQ6: Will there be a benefit for the business to improve the support of the PLM system regarding the circular economy principles at Tetra Pak based on the study of the product segment, the Filling Machine? Are there any metrics, KPIs, that could be used to demonstrate that there will be improvements at Tetra Pak with this collaboration between the PLM system and the principles of the circular economy?

The study shows evidence on the benefits of the support the PLM system can provide the circular economy work. A need is observed from the sustainability team of an improved data management process. And the theoretical background implies that PLM can be a solution enabling a circular economy implementation in companies. The empirical findings also propose KPIs to measure the benefits with such an implementation.

RQ7: Are there any possibilities to use new AI technology to make the data managing more efficient at Tetra Pak?

Possibilities exists regarding I4.0 and the AI technology. Both the theoretical background and the empirical findings has observed opportunities regarding integrating AI and the PLM system.

6.3 Effect of delimitation

The delimitation of the thesis impacts how the conclusion can be applied in a more general context. The thesis is from the case companies', Tetra Pak's, perspective and proposes a unique strategical navigation forward regarding the problem statement for the whole Tetra Pak.

The focus on the product segment filling machines also impacted the conclusions and proposals of the thesis. Different products impact how the PLM system can be adapted to support the circular economy principles.

The focus is on the EOL phase of the product lifecycle narrows the scope and affects the conclusions of the study as well. The proposals and recommendations become most applicable for the EOL actors and stakeholders.

With more time, the study could have been more comprehensive. More interviews could have been conducted and more benchmarking companies could have been included.

6.4 Impact of the chosen methodology

A case study method was a great option when choosing the research method, due to the collaboration with the case company. In addition, answers to the questions “How?” and “Why?” were needed and the study was an examination of a contemporary event within a real-life context. The interviews providing qualitative data is an appropriate method when doing case study research. It supports case study research with providing a deeper description of characteristics.

Alternative interview methods could have been used such as group interviews. Document studies analyzing what has been developed within Tetra Pak could also improve the thesis.

6.5 Contribution to academy

The case study with a benchmarking approach contributes to the academy in this field with its unique proposals to a real-time event.

The study emphasizes the requirements and specifications of how to fulfill the problem statement. It presents the current state of preparedness in organizations for PLM systems regarding including sustainability data. Ending with proposing a uniquely designed roadmap based on the current state analysis, to Tetra Pak, regarding opportunities to proceed on the topic within the organization based on the findings from the study.

The roadmap emphasizes a technological approach, a change work approach and stakeholders the company can focus on to accelerate the change effort within the organization. The study describes the importance of the needed change work in the context of PLM system implementation, where lack of PLM understanding is seen as one of the major challenges in organizations implementing PLM systems.

Contributions to the research regarding integrating the PLM system with circular economy has also been covered in this study, where PLM can be seen as an enabler for circular economy implementation in organizations.

The study also emphasizes the novelty of CSRD, and challenges companies are facing today regarding the mandatory reporting. The study acknowledges the similarity to the closed loop PLM concept regarding the absence of stakeholder collaboration.

6.6 Further research

Several areas are of interest to develop more knowledge and carry out further research about. Some of the important aspects of this study are covered on this section.

Based on the roadmap, further research regarding the details on each category is required, the technological approach, the change work approach and the involved stakeholders. Further research is needed regarding the details of how to create a preparedness within Tetra Pak and at the potential customers.

Especially, the information gap in the end-of-life-phase in the product lifecycle, despite the current level of knowledge, absence of a standard for technological solutions and how they can operate in the PLM system, causing barriers to share information among the stakeholders.

The security regarding sharing information among stakeholders beyond an organization becomes threatened when transparency and sharing data are the keys to closed loop PLM. Therefore, further research is needed on this topic to find a secure way to share data between different actors across the supply chain.

Research, best practices, case studies regarding the technological challenges of integrating technologies into the PLM system enabling a closed loop system is an area needed to be further investigated. The closed loop PLM concept has the potential to increase the efficiency level to the max regarding the performance of the operations.

The stakeholders involved mentioned in the study are a general perspective and uniquely designed for this studies objective. More actors can be important to involve depending on the context.

The organizational change management is a required approach to invest in to succeed with a successful PLM initiative change effort. Yet, the understanding of the PLM capabilities is one of the common challenges with implementing PLM in companies without it.

The newly enforced regulation, CSRD, can be interpreted as an accelerator because stakeholder collaboration and data sharing must be improved to enable measuring scope 3 emissions. Currently, companies are all struggling to comply with the directive, therefore best-practices on how to work with the directive need to be investigated further.

AI is a current fast-growing technology and under development which can be a tool to improve the efficiency of the data sharing work. This is a subject to investigate further in the future.

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Tables

Table 1: Made by the author

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Interview Candidates

Company A, 2024. Program Director PLM [Interview] (1 March 2024).

Company B, 2024. VP Life Cycle Services [Interview] (7 March 2024).

Person A, 2024. Engineering Capability Expert, Tetra Pak [Interview] (13 February 2024).

Person B, 2024. PLM Capability Expert, Tetra Pak [Interview] (14 February 2024).

Person C, 2024. Manager PLM and Engineering Capability, Tetra Pak [Interview] (16 February 2024).

Person D, 2024. PLM Capability Expert, Tetra Pak [Interview] (19 February 2024).

Person E, 2024. ESG Reporting Program Director, Tetra Pak [Interview] (15 February 2024).

Person F, 2024. Director Corporate Affairs, Circular Economy, and Packaging Policy, Tetra Pak [Interview] (22 February 2024).

Person G, 2024. Vice President Corporate Social Responsibility, Tetra Pak [Interview] (1 March 2024).

Supplier A, 2024. Associate Solutions Engineer [Interview] (18 March 2024).

Appendices

Appendix A – Explanations of the SWOT analysis

Strengths

The identified internal strengths regarding Tetra Pak's current state analysis with explanations are:

Driving factors for PLM

In Tetra Pak's case, the PLM system development is based on the efficiency of the current data management process and PLM approach at the company. And the current complex system of data points and many manual processes results in a long lead time to find the needed data. This aspect is therefore seen as a strength for reaching an improvement in the context of the problem statement.

The foundation of the PLM system is in a developing and improving phase

Another strength is the current developing and improving phase the PLM team is going through related to the developments occurring in the PLM system. This is an important step and represents level 1 in the pyramid, see Figure 16. When the foundation is in place the next levels can be developed, leading to an improved data integration of potential sustainability data.

Minor collaboration between the PLM team and Sustainability team

The minor collaboration existing is important to motivate the collaboration between the sustainability strategy of the PLM system. The sustainability team are experts regarding what sustainability data is needed to collect, while the PLM team can contribute with a more effective way of collecting and structuring the data making it available for stakeholders.

The ESG Reporting Program (CSRD) acknowledges the importance of access data

The work the company does regarding CSRD, The ESG Reporting Program, acknowledges the importance of access to upstream and downstream emissions data related to scope 3 emissions. This work can be interpreted as a catalyst of the importance of closed loop PLM. The importance of increased collaborations with actors across the supply chain is also an aspect that is being emphasized.

The SAP upgrade

The SAP upgrade project can be interpreted as an enabler according to the empirical data, because the circumstance will require the company to have improved control over the product data in order to succeed with the transformation.

Weaknesses

The identified internal weaknesses regarding Tetra Pak's current state analysis with explanations are:

Minor collaboration between the PLM team and Sustainability team

The minor collaboration can also be interpreted as a weakness because to be able to have an understanding, the two parties are in need of each other, according to the empirical study, and a stronger collaboration is required.

Need of collaboration with the third party involved

In this context, the third party involved in how the PLM system can be adapted to better support the circular economy principles product reuse, remanufacturing, and recycling, is the stakeholders and actors across the lifecycle especially in the reveres logistics process. Therefore, an improved collaboration with these actors becomes crucial.

Information gap in EOL phase

The identified gap of access to data in the EOL phase when the products, the filling machines, are sold is also identified as a weakness in this context. Without this data the PLM system probably can not be adapted to support the circular principles.

The SAP upgrade

According to the empirical data the SAP upgrade can also be interpreted as a complicating circumstance in this context. The upgrade can be seen as a brake pad because it requires a lot of resources, particularly IT resources, which can be a limiting factor.

Low top-management commitment

The empirical data explains the low top management commitment the PLM system initiative currently has. Related to the theoretical background about OCM, top management commitment is one important success factor to reach a successful change effort provided by the PLM initiative in an organization.

Requires a sense of urgency and clear strategic vision

According to the theoretical background regarding the OCM and the empirical findings, the importance of succeeding with the PLM system foundation implementation a sense of urgency and a clear vision is required.

Opportunities

The identified external opportunities regarding Tetra Pak's current state analysis with explanations are:

Improved existing PLM system

The existing PLM system has the opportunity to provide improved support to the circular economy principles by adding additional technologies and functions the system foundation. The theoretical background has presented the benefits with improving the system.

Closed loop PLM system

When the foundation of the existing PLM system is implemented, it could benefit from implementing additional technologies creating a closed loop PLM system. The benefits from a closed loop PLM system in the theoretical background can contribute to an ecosystem enabling stakeholders having access and control over product information in any product lifecycle phase. This leading to addressing the challenges with lack of information management in the reverse logistics process.

Technology enablers

One of the big opportunities from the literature review is adding intelligent products, such as PEID technologies, to the foundation of a successful implementation of a PLM system. These technologies are seen as main enablers for closed loop PLM.

Other technologies mentioned in the literature review is I4.0, ICT, IIoT and AI. I4.0 can create opportunities providing increased productivity and efficiency when integrated to production systems. ICT and technologies make it possible to provide data from the entire product life cycle. IIoT technologies connects production and product data. AI is an even newer, fast-growing technology, which has potential to facilitate the data managing process.

Digital Product Passport (DPP)

The DPP solution is a promising technology, which enables businesses and consumers to access the product information directly from the supplier. The technology will therefore be able to cover product data areas such as sustainability performance, origin, warranty, recycling and instructions for installation or repair. When the challenges with DPP are solved, it will be a promising solution in this context.

Circular Economy (CE) implementation enablers

According to the theoretical background enablers for CE implementation in SMEs exists. Product lifecycle management is seen as one way to implement CE in an organization. This provides proof from the CE perspective that PLM is needed to implement CE in organizations. The empirical data from the sustainability interviews also provides proof of PLM's capability as a needed tool to implement CE in the organizations.

Challenges with complying to CSRD regarding scope 3 emissions

Currently, companies face challenges regarding complying to CSRD and reporting scope 3 emissions. One of the experienced challenges is mapping and understanding the size of the scope 3 emissions, because the emissions are occurring outside of companies own direct control and business. Most of the large companies are improving their ESG data and reporting capabilities, by planning on investing in sustainability software, and the capabilities within in the workforce. CSRD can therefore be seen as a catalyst of improving the reporting capabilities. The acknowledgement, of challenges of mapping the scope 3 emissions can bring a sense of urgency to better track the data in the product lifecycle.

Dual Operating System

According to the empirical findings, evidence of what PLM can do for the company needs to be communicated, and the communication needs the top management levels in the organization. The theoretical background acknowledges the importance of OCM and change management being present to be able to succeed with PLM initiatives change efforts. Also, the dual operating system is seen as a more effective and accelerating change strategy to apply, where the change network and the hierarchy operates together as a dual operating system.

Threats

The identified external threats regarding Tetra Pak's current state analysis with explanations are:

Information gap when products are sold

The information gap at Tetra Pak when the filling machines are sold from the empirical findings, is something both the theoretical background on the topic explains and something occurring in other companies due to the benchmarking companies. It is a challenge because Tetra Pak do not own the filling machines when sold, and therefore that also contributes to the challenge. Furthermore, recommendations to apply intelligent products to be able to solve the information gap challenge is proposed.

Need of improved collaboration with EOL phase actors

The absence of collaboration with actors in the EOL phase is also a threat creating a barrier to improve the CE implementation and the PLM system support. In Tetra Pak's situation the collaboration with the customers owning the filling machines is crucial.

Challenges with closed loop PLM

Moreover, the theoretical background presents the unresolved challenges with closed loop PLM that needs to be addressed. There are still challenges research and development needs to find solutions regarding. Also, technological challenges with integrating PEID into PLM systems needs to be resolved. Information sharing barriers beyond the borders of an organization is also an issue, and a standard for the PEID technology is necessary and how it can operate in PLM. Furthermore, the concept of closed loop PLM has the possibility to maximize the way lifecycle operations are performed. The empirical findings regarding Company B, presented a case where telematics as a technology supported information collection in the EOL-phase in their organization.

Circular Economy (CE) implementation barriers

According to the theory, the CE implementation has been considered as a straightforward process, which provides the emerging economies best practices to implement from the developed countries. Despite that, to have a successful CE implementation it requires a major systemic change. There exist barriers to succeed with an CE implementation which affects the context for Tetra Pak.

Low emphasis at research institutions

The theoretical background presents that more research is required to succeed with closed loop PLM system, and generally regarding environmental sustainability supported by information systems. The research addressing companies' capabilities to pursue a PLM strategy or link it to the field of I4.0 are few. Only few research papers address approaches in practice to create required capabilities to successfully implement PLM. The absence of practical exercises and teaching approaches from first-hand experiences creates a knowledge gap required to be closed. A close collaboration between academia and the industry is needed due to the lack of knowledge contributing to PLM implementation failure.

Challenges with complying to CSRD regarding Scope 3 Emissions

The challenges currently experienced with complying with the CSRD are also barriers in the area. The barriers regarding reporting scope 3 emissions are due to lack of capabilities in companies to collect the data, data companies never had been required to report before. This also addresses the problem of low access to data across the supply chain, such as EOL data. The empirical findings describe the challenges with complying to CSRD is something all companies are impacted by, and they all learn together due to the absence of established best practices and lack of resources.

Cyber security

Furthermore, the threat regarding cyber security is a barrier regarding sharing data among stakeholders. The empirical findings describe, the current business model including selling the ownership of the filling machine to the customer leads to complications accessing the data where customer consent and agreements allowing the company to track data can be seen as a barrier. The theoretical background also explains the unresolved factors that needs to be addressed regarding issues of information security and confidentiality of business information when sensitive data is transferred between different stakeholders.

Technology enablers

The technology development is not in a state addressing companies' capabilities to pursue a PLM strategy and their ability to link it to I4.0. Therefore, literature refers to that more research is required because of the current low number.

Appendix B – Interview guides

Interview Guide PLM Team

Interview Guide - PLM Team (Internal interviews)

Date: [2024-xx-xx]

Interviewer: Julia Svegerud
Interviewee: [xx]

Introduction:

- Begin with showing gratitude for the interviewee for participating in the master thesis data collection method.
- A brief introduction of the interviewer and the purpose of the master thesis, with a prepared presentation.
- Give information regarding the timeframe of the interview, 1 hour.
- Ask for permission to record the interview.
    - Explain the purpose behind the recording permission. The recording will only be used for the data collection in the master thesis project and will be transcribed after the interview. After the transcription the audio file will be deleted.

Introduction of the Interviewee:

- Could you begin with briefly describing who you are, and your position and responsibilities at the company? Any positions before in other companies, with similar tasks?

Current state of the PLM System:

- Why and when did the PLM initiative start at Tetra Pak?
- What is the current state of Tetra Pak's PLM System today?
- What are your future plans regarding improving the current system's state?

- What access do you have to the data regarding the filling machines life cycle phases, BOL/MOL/EOL?
    - What access does the company have to the EOL-data?
- How far has the company come with the Closed Loop PLM System?
    - Are there any plans to improve this work?
- Do you have any sustainability data in your system today?
    - What kind of data?
    - Do you have any future plans on including (more) sustainability data in the PLM System?

CSRD Reporting of Scope 3 Emissions:

- Are you familiar with the CSRD directive and the reporting of Scope 3 Emissions, as mentioned in the introduction presentation?
- How does the company work with the newly enforced CSRD directive, regarding more detailed and higher quality of the reporting of Scope 3 Emissions?
    - Is this an area the PLM team is working on or are involved in?

Circular Economy Principles Integration with PLM System:

- Are you familiar with the Circular Economy Principles (product reuse, remanufacturing, recycling), as mentioned in the introduction presentation?
- What support do you think the PLM System can provide the work with Circular Economy Principles?
- Currently, is there a cooperation between the Sustainability Team and the PLM Team?
- How far have you come with this cooperation practically?
    - Is the integration currently a part of a strategy in the company?
- What aspects do you think are needed to be able to manage an improvement regarding the integration between the two teams?

Future Outlook:

- What do you see as the biggest challenges at the company regarding CSRD reporting of the Scope 3 Emissions?
    - Specifically, do you see any challenges regarding the Scope 3 Emission: downstream end-of-life-treatment of sold products, (product reuse, remanufacturing, recycling)?
    - Do you collaborate with other companies in the same situation?
    - Do you collaborate with external organizations etc.?
        - What about the Ellen MacArthur Foundation?
    - Have you looked into the SAP Sustainability Control Tower solution?
- Given a sustainability perspective, what do you see as important parameters to measure, if you introduce a more improved Closed Loop PLM System to improve the circular economy aspects?
- Do you see AI as a future tool opening opportunities regarding the integration between the PLM System and the Circular Economy principles?

Closing Remarks:

- Anything else you would like to add or questions regarding the master thesis project?
- Do you recommend someone else I might consider interviewing?
    - Do you know any other external contacts that can be useful for me?
- Is it okay if I reach out if additional questions need to be added?
- I would like to thank you very much for your participation in my master thesis project.

Interview Guide – PLM Team (External interviews)

Date: [2024-xx-xx]

Interviewer: Julia Svegerud
Interviewee: [xx]

Introduction:

- Begin with showing gratitude for the interviewee for participating in the master thesis data collection method.
- A brief introduction of the interviewer and the purpose of the master thesis, with a prepared presentation.
- Give information regarding the timeframe of the interview, 1 hour.
- Ask for permission to record the interview.
    - Explain the purpose behind the recording permission. The recording will only be used for the data collection in the master thesis project and will be transcribed after the interview. After the transcription the audio file will be deleted.

Introduction of the Interviewee:

- Could you begin with briefly describing who you are, and your position and responsibilities at the company? Any positions before in other companies, with similar tasks?

Current state of the PLM System:

- Why and when did the PLM initiative start at the company?
- What is the current state of the company's PLM System today?
- What are your future plans regarding improving the current system's state?
- What access do you have to the data regarding the life cycle phases, BOL/MOL/EOL?
    - What access does the company have to the EOL-data?
- How far has the company come with the Closed Loop PLM System?
    - Are there any plans to improve this work?
- Do you have any sustainability data in your system today?
    - What kind of data?

    - Do you have any future plans on including (more) sustainability data in the PLM System?

CSRD Reporting of Scope 3 Emissions:

- Are you familiar with the CSRD directive and the reporting of Scope 3 Emissions, as mentioned in the introduction presentation?
- How does the company work with the newly enforced CSRD directive, regarding more detailed and higher quality of the reporting of Scope 3 Emissions?
    - Is this an area the PLM team is working on or are involved in?

Circular Economy Principles Integration with PLM System:

- Are you familiar with the Circular Economy Principles (product reuse, remanufacturing, recycling), as mentioned in the introduction presentation?
- What support do you think the PLM System can provide the work with Circular Economy Principles?
- Currently, is there a cooperation between the Sustainability Team and the PLM Team?
- How far have you come with this cooperation practically?
    - Is the integration currently a part of a strategy in the company?
- What aspects do you think are needed to be able to manage an improvement regarding the integration between the two teams?

Future Outlook:

- What do you see as the biggest challenges at the company regarding CSRD reporting of the Scope 3 Emissions?
    - Specifically, do you see any challenges regarding the Scope 3 Emission: downstream end-of-life-treatment of sold products, (product reuse, remanufacturing, recycling)?
    - Do you collaborate with other companies in the same situation?
    - Do you collaborate with external organizations etc.?
        - What about the Ellen MacArthur Foundation?
    - Have you looked into the SAP Sustainability Control Tower solution?

- Given a sustainability perspective, what do you see as important parameters to measure, if you introduce a more improved Closed Loop PLM System to improve the circular economy aspects?
- Do you see AI as a future tool opening opportunities regarding the integration between the PLM System and the Circular Economy principles?

Closing Remarks:

- Anything else you would like to add or questions regarding the master thesis project?
- Do you recommend someone else I might consider interviewing?
    - Do you know any other external contacts that can be useful for me?
- Is it okay if I reach out if additional questions need to be added?
- I would like to thank you very much for your participation in my master thesis project.

Interview Guide Sustainability Team

Interview Guide - Sustainability Team

Date: [2024-xx-xx]

Interviewer: Julia Svegerud
Interviewee: [xx]

Introduction:

- Begin with showing gratitude for the interviewee for participating in the master thesis data collection method.
- A brief introduction of the interviewer and the purpose of the master thesis, with a prepared presentation.
- Give information regarding the timeframe of the interview, 1 hour.
- Ask for permission to record the interview.
    - Explain the purpose behind the recording permission. The recording will only be used for the data collection in the master thesis project and will be transcribed after the interview. After the transcription the audio file will be deleted.

Introduction of the Interviewee:

- Could you begin with briefly describing who you are, and your position and responsibilities at the company? Any positions before in other companies, with similar tasks?

Current State of the Sustainability & Circular Economy Work at the Company:

- What does the Sustainability Team mainly work with?
    - What is the size of the team?
    - Do you have a current sustainability strategy? Please describe it briefly and its main topics.
    - Are there any topics that are more urgent than others?
- What work does the company do for driving a circular economy?

    - How far have you come with the work regarding reuse, recycling, re-manufacturing and disposal at the company, mainly regarding the filling machines?
- What is the current circular economy strategy, regarding the three principles: product reuse, remanufacturing, recycling?
    - Is there a strategy that includes filling machines?
    - Do you work with all three principles: product reuse, remanufacturing, recycling?

CSRD Reporting of Scope 3 Emissions:

- Are you familiar with the CSRD directive and the reporting of Scope 3 Emissions, as mentioned in the introduction presentation?
    - Who manages/monitors the work?
    - What is the size of the team? Are there any other contacts involved in the project you would like to recommend interviewing?
    - Does the directive change how the company works with reporting?
    - How is the directive compared to the recent reporting work processes?
        - What more data do you need to report compared to recent reporting directives?
- Do you have all data access needed to report aligned with the directive regarding the Scope 3 Emissions?
- Specifically, what does the status regarding the data access connected to the end-of-lifecycle look like, mainly regarding the filling machines? (Waste management: Product reuse, re-manufacturing, and recycling).
- Are you working with any IT-tools to improve the efficiency of the reporting work?
    - What improvements does/ or could these tools provide?
- Lessons learned so far?

Circular Economy Principles Integration with Product Lifecycle Management (PLM) System:

- Are you familiar with the Circular Economy Principles (product reuse, remanufacturing, recycling) and Product Lifecycle

Management (PLM) System, as mentioned in the introduction presentation?

- What support do you believe the PLM-System can provide the work with circular economy principles?
- Currently, is there a cooperation between the Sustainability Team and the PLM Team?
- How far have you come with this cooperation practically?
    - Is the integration currently a part of a strategy in the company?
- What aspects do you think are needed to be able to manage an improvement regarding the integration between the two teams?

Future Outlook:

- What do you see as the biggest challenges at the company regarding CSRD reporting of the Scope 3 Emissions?
    - Specifically, do you see any challenges regarding the Scope 3 Emission: *downstream end-of-life-treatment of sold products*, (reduce, re-manufacturing, recycling)?
    - Do you collaborate with other companies in the same situation?
    - Do you collaborate with external organisations etc.?
        - What about the Ellen MacArthur Foundation?
    - Have you looked into the SAP Sustainability Control Tower solution?
- Given a sustainability perspective, what do you see as important parameters to measure, if you introduce a more improved Closed Loop PLM System to improve the circular economy aspects?
- Do you see AI as a future tool opening opportunities regarding the integration between the PLM System and the Circular Economy principles?

Closing Remarks:

- Anything else you would like to add or questions regarding the master thesis project?
- Do you recommend someone else I might consider interviewing?
    - Do you know any other external contacts that can be useful for me?
- Is it okay if I reach out if additional questions need to be added?
- I would like to thank you very much for your participation in my master thesis project.

Interview Guide PLM system Supplier

Interview Guide - PLM System Supplier
Date: [2024-xx-xx]
Time: [xx]

Interviewer: Julia Svegerud
Interviewee: [xx]

Introduction:

- Begin with showing gratitude for the interviewee for participating in the master thesis data collection method.
- A brief introduction of the interviewer and the purpose of the master thesis, with a prepared presentation.
- Give information regarding the timeframe of the interview, 1 hour.
- Ask for permission to record the interview.
    - Explain the purpose behind the recording permission. The recording will only be used for the data collection in the master thesis project and will be transcribed after the interview. After the transcription the audio file will be deleted.

Introduction of the Interviewee:

- Could you begin with briefly describing who you are, and your position and responsibilities at the company? Any positions before in other companies, with similar tasks?

Sustainability Support in PLM System:

- What support/services does the company offer when it comes to companies' sustainability work?
- Are you familiar with the Corporate Sustainability Reporting Directive, CSRD, newly enforced in the EU?
    - Does the company have support in its solutions for sustainability reporting directives?
- What support does the company have regarding efforts to reduce the environmental footprint of the customers' products?

- Any specific IT tools the company is using for this aspect of data structuring and collection?
- Do you have customers that work with your sustainability system solutions?

Circular Economy Principles Integration with PLM System:

- Are you familiar with the Circular Economy Principles (product reuse, remanufacturing, recycling), as mentioned in the introduction presentation?
- Do the provided sustainability solutions offer support regarding the end-of-life stages of the product lifecycle regarding remanufacturing, reuse and recycling of a product and its components?
- What support do you think the PLM system can provide the work with Circular Economy Principles?

Closed Loop PLM System:

- Are you familiar with the Closed Loop PLM System?
- Does the company work with Closed Loop PLM System solutions?
- Does the company have future plans on driving Closed Loop PLM solutions development?

AI Support in PLM System:

- Currently, does the company offer PLM System solutions with AI?
- Does the company have future plans integrating AI in the solutions they offer?
- Do you see AI as a future tool opening opportunities for how PLM Systems operate? With regards to CSRD and sustainability aspects?
    - What opportunities do you see?
- Do you see AI as a future tool opening opportunities regarding the integration between the PLM System and the Circular Economy principles?

Closing Remarks:

- Anything else you would like to add or questions regarding the master thesis project?
- Do you recommend someone else I might consider interviewing?
    - Do you know any other external contacts that can be useful for me?
- Is it okay if I reach out if additional questions need to be added?
- I would like to thank you very much for your participation in my master thesis project.