Linnæus University
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Master Thesis

# Reverse Logistics in the Setting of Industry 4.0: A Sustainability Perspective

Authors: Nils Linden, Dhannya Rejoice Maliackal, Sophie Persson

Examiner: Helena Forslund

Tutor: Hana Hulthén

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# Abstract

Circularity and sustainability, these are terms that are discussed in many different ways in current research due to the climate crisis. To face the challenges of the climate crisis and new consumer behaviour, the still emerging concept of Industry 4.0 is considered in different ways. When it comes to circularity, this thesis highlights and focuses on the circularity part of reverse logistics or in other words, the reverse flow of goods in a supply chain. These themes are interrelated but not seen as a whole by research so far. This thesis analyses which Industry 4.0 technologies can be used in reverse logistics, what economic, environmental and social effects they have and how they can be measured. Methodologically, we combine exploratory and explanatory research with a deductive way of reasoning, where we analyse data of 4 interviews and 2 surveys in at total 5 Swedish and German manufacturing companies out of the mining, construction equipment, electronics, fasteners and communication industry with a multi method qualitative approach. This is done with the help of literature related to Industry 4.0, reverse logistics as well as environmental, economical and social sustainability. Our results are that the most used Industry 4.0 technologies by manufacturing companies in reverse logistics are Big Data, CPS, IoT and AI. When it comes to sustainability effects and measurements, the companies mostly are focusing on economical and environmental sustainability, while social sustainability is not observed to a similar extent. Especially environmental effects are seen and measured as these figures are important and in demand at the market right now, while economical effects are more often measured with regular KPIs and social effects are not considered as much.

**Keywords**

Industry 4.0, Reverse Logistics, Sustainability, Three Pillars of Sustainability, Economical Sustainability, Environmental Sustainability, Social Sustainability, Sustainability Effects, Sustainability Measurements, Circularity, Manufacturing Companies

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# 1. Introduction

## 1.1 Background

### *1.1.1 What Industry 4.0 Technologies are related to Reverse Logistics*

With regard to Industry 4.0, the use of new technologies makes it feasible to connect resources, information, objects, and people for the first time ever to establish the Internet of Things and Services. This phenomenon will have an impact on industry as well. This technical evolution in the field of manufacturing is known as "Industry 4.0" or the fourth stage of industrialization (Kagermann et al., 2013).

Mechanization, electricity, and information technology all had a role in the first three industrial revolutions. A fourth industrial revolution is now being ushered in by the advent of the Internet of Things and Services into the manufacturing environment. Businesses will create worldwide networks in the future that include their production equipment, warehouse systems, and other infrastructure in the form of Cyber-Physical Systems (CPS). These Cyber-Physical Systems in the manufacturing environment include intelligent equipmlient, storage systems, and production facilities capable of independently exchanging information, triggering actions, and controlling one another (Kagermann et al., 2013).

Not only within the manufacturing environment, but also for reverse logistics, the potentials of Industry 4.0 for cost reduction and profit maximisation are vital. With investments in these new technologies more efficient and performant reverse logistics can be reached. A more decent focus on reverse logistics came with the shift from mass production to the concept of Just-in-Time (JIT). With mass production based on push demand, a lot of products were produced that were not consumed, which finally lead to high inventory costs and therefore to the introduction of the JIT-concept from Toyota. JIT is based on a pull idea, so it is produced on demand, which should lower inventory costs, but it missed the consideration of the disposal of good at the end of shelf life. This led to a significant amount of waste from old items, landfills being overflowing, and an issue with environmental degradation, pollution, and carbon footprint in addition to the depletion of basic materials. A solution for this waste problematic could be the usage of Industry 4.0 technologies, especially within reverse logistics, which are able to reduce the amount of waste produced (Shah et al., 2019).

Reverse logistics is concerned with recovering value from end-of-life (EOL) items and handling non-recyclables in the right way (Rogers & Tibben-Lembke, 2001). The idea of reverse logistics was initially proposed in the early 1990s to represent all pertinent operations and logistical flows from final consumers to various producers, recyclers, and other entities (Salema et al., 2007). The primary functions of a reverse logistics system include gathering EOL products from clients and end users, conducting the necessary inspection, sorting, pre-processing, and disassembly, distributing various products, parts, and components to the appropriate facilities for proper handling, planning and scheduling facility operations and transportation (Agrawal et al., 2015; Fleischmann et al., 1997; Sun et al., 2022).

Reverse logistics is first driven by two different factors (Fleischmann et al., 1997). Reverse logistics can increase the exploitation of various materials and, as a result, assist to address the issues associated with the depletion of natural resources worldwide. Additionally, it could give businesses the chance to increase their cost-cutting and profitability through product recovery. Furthermore, incorrect recycling practises might have a harmful influence on the environment and society even though reverse logistics has been viewed as a crucial component of sustainable development and the circular economy (Julianelli et al., 2020). For instance, the significant export volume of waste electrical and electronic equipment (WEEE) from developed nations, such as the United States, the European Union, and Japan, to developing nations in southeast Asia not only increases greenhouse gas (GHG) emissions related to maritime transportation, but also poses serious risks to the environment and workers due to the low-tech and antiquated recycling techniques used. As a result, reverse logistics that are well-designed will encourage more environmentally friendly methods of doing various tasks (Sun et al., 2022).

### *1.1.2 The Economic, Environmental & Social Effects of using Industry 4.0 Technologies in Reverse Logistics*

The current technological improvement and development of Industry 4.0 has created more opportunities for businesses to attain value creation and projects that focus on fulfilling the individual customer needs (Sun et al., 2022). Industry 4.0 technologies play a significant role in in enhancing sustainability of manufacturing activities, purchase choices, and establishing plans on resources. The technologies are essential in enhancing the flow of commodities and information necessary for processing raw materials. Also, the technologies influence the abilities or dynamic remanufacturing and green production through enhancing sustainability (Sun et al., 2022). The improvements in technologies including IoT (Internet of Things), Big Data Analysis, Artificial Intelligence (AI), Augmented Reality (AR), as well as Cyber-Physical Systems (CPS) and Blockchain Technology have raised the capability of supply chain structures in attaining the sustainability objectives (Srhir et al., 2023; Krstić et al., 2022).

The reason why a transition to Industry 4.0 technologies is important is because companies need to get away from traditional production systems that create bad ecological imbalances such as higher resource consumption, contribute to global warming and higher environmental pollution. Moreover, the world faces various social challenges such as poverty, inequalities and prosperity. Ultimately, the various technologies of the Fourth Industrial Revolution will improve many of these constraints translating into long-term organizational competitiveness and other economically beneficial consequences. This will in turn create a more sustainable future (Bai et al., 2020).

### *1.1.3 Measuring the Economic, Environmental & Social Effects of using Industry 4.0 Technologies in Reverse Logistics*

The term "sustainability" is one that is thrown around a lot, especially nowadays, and is open to a lot of interpretation. This idea of sustainability is frequently used to explain how people or businesses interact with different natural resources and ecosystems. These include things like social fairness, stability, and access to resources like clean water, clean air, and fertile land (Borglund et al., 2017). The UN report "Our Common Future" is frequently mentioned when a definition of sustainability is required. According to this research, " meeting the needs of the present without compromising the ability of future generations to meet their needs " is the definition of sustainable development (Brundtland et al., 1987, p.8). The notion of sustainability provided by Rockström et al., (2009) who study planetary limits, is also quite intriguing. Due to restrictions placed on how the Earth System functions, this definition is far more precise than the one provided by the UN. Climate change, ocean acidification, stratospheric ozone, global P and N cycles, atmospheric aerosol loading, freshwater consumption, land use change, biodiversity loss, and chemical pollution are the nine planetary limits that has been identified (Rockström et al., 2009).

Efthymiou & Ponis (2021) argued that there is a connection between Industry 4.0 technologies and improvements in operational efficiency in logistics activities. Parhi et al., (2022) found that Industry 4.0 technologies are vital in promoting sustainability in logistic activities. Industry 4.0 has transformed supply chain processes through promoting sustainability. The technologies enhance the design of the supply chain structure, making it more sustainable (Grzybowska & Awasthi, 2020). Industry 4.0 technologies have transformed supply chain systems across industries through enhancing sustainability. The Industry 4.0 assist corporations to attain the sustainability by improving technologies such as Blockchain and IoT that promotes efficient logistic operations (Parhi et al., 2022; Efthymiou & Ponis 2021; Srhir et al., 2023; Grzybowska & Awasthi, 2020). Researchers also have argued Industry 4.0 technologies increase the sustainability of supply chain systems through improving remanufacturing and green manufacturing (Sun et al., 2021).

In general, Industry 4.0 technologies have the ability to reduce labour and material costs, increase production flexibility and productivity, and create an improved customization in terms of economic metrics. Industry 4.0 technologies can also measure, for example, carbon emissions through data-centric and traceable carbon footprint analysis or have products disassembled into sub-components for reuse, recycling or remanufacturing, helping companies measure environmental aspects. Smart and autonomous production systems benefit the health and safety of employees as it can replace monotonous and repetitive tasks which in turn leads to higher employee satisfaction and stimulation which are social sustainability dimensions that Industry 4.0 technologies create (Bai et al., 2020).

## 1.2 Problem Discussion

### *1.2.1 What Industry 4.0 Technologies are related in Reverse Logistics*

Today's focus on waste management, recycling, recovery of components or products has broadly emerged and can be explained by the fact of the world's increasing population and diminishing natural resources (Krstić et al., 2022). This could be a contributing reason why companies are taking a step away from the linear economic model of "take, make and dispose" in industrial processes. Instead, the spotlight is on reverse logistics' responsibility to deplete products with the vision of minimizing the consumption of resources and raw materials (Khan et al., 2022). In the reverse logistics process, collected used or end-of-life products are examined and then disposed of for further processing. This handling is an important decision for its efficient operational performance (Agrawal & Singh. 2019). The importance of preserving goods, components and materials with the highest level of usability has created a requirement for the reverse logistics process to work properly (Krstić et al., 2022).

By using Industry 4.0 technology, real-time data is gathered from operations and activities which assist the business in tracking, observing, and making decisions about product recycling (Khan et al., 2021). Industry 4.0 technologies that are associated in reverse logistics are the Internet of Things, Big Data, Blockchain and Advanced Robotics to name a few (Krstić et al., 2022). Krstić et al., (2022) goes on to say that using Industry 4.0 technologies give companies a competitive advantage because the work can be done much more efficiently. The article "ReAgendan" highlights how Internet of Things can create visibility and business opportunities on how materials and products are used. This will enable better track material flows to encourage recycling and reuse. Industry 4.0 technology has a great potential for producing industrial value creation that is sustainable in all three areas of social, economic, and environmental life, by improving resource efficiency. Because the relationship between sustainability and Industry 4.0 technologies requires a more systematic approach to managing change, the current growth of sustainability calls for a transformation from "doing things better" to "doing better things" (Khan et al., 2021).

However, only few studies examine Industry 4.0 technologies in reverse logistics, Krstić et al., (2022) analyses the importance of different Industry 4.0 technologies in the reverse logistics field to identify the most useful. By identifying which Industry

4.0 technologies are important for reverse logistics, the conditions will exist to create the greatest opportunity for success, broad application and most positive impact (Krstić et al., 2022). Moreover, the study excludes the sustainable effects the technologies create in reverse logistics. Therefore, the purpose of our study is not only to identify which Industry 4.0 technologies are used in reverse logistics, but also to address the effects of Industry 4.0 technologies in sustainable terms.

The Industry 4.0 technologies in this paper are selected based on the conceptualization of Industry 4.0 technologies on reverse logistics by Sun et al. (2022), as well as Krstić et al., (2022).

### *1.2.2 The Economic, Environmental & Social Effects of using Industry 4.0 Technologies in Reverse Logistics*

Necessary changes still need to be made to reduce impacts on climate, the environment and human well-being (ReSource, 2021). The importance of improving sustainability means that companies should take greater social responsibility, relate to legal pressures and environmental considerations and which should be part of their operations (Agrawal et al., 2016). One approach to achieving improvements is to introduce new technological solutions that consider how the value of the product can be optimized and used for longer (ReSource, 2021). This perspective is also given special attention in Goal 12 of the overall Sustainable Development Goals of the UN Agenda 2030 (ReSource, 2021). Goal 12 of the Agenda for Action covers the transition to a sustainable society for people, planet and prosperity (Regeringen, 2020). One driver for Industry 4.0 technologies is considered to be sustainability. With the real-time information extracted by the technology will help managers track, monitor and make sustainable decisions on the recycling of consumed products. This will benefit organizations in social, economic and environmental values as the technology creates sustainable longevity and efficiency (Khan et al., 2021).

**Economic Effects**

Industry 4.0 technologies have significant implications for reverse logistics (Rajput & Singh, 2021). The economic effects created are increased competitiveness, higher productivity and income (Birkel & Müller, 2021). The technologies provide real-time information and data analytics that can quantify cost reductions and long-term growth (Barreto et al., 2017; Rajput & Singh, 2021).

**Environmental Effects**

The environmental effects of Industry 4.0 technologies are increased quality and thereby durability of products, which in turn increases their lifespan and leads to lower material use (Oláh et al., 2020). Thanks to a more planned process, Industry 4.0 technologies result in reduced resource consumption (Birkel & Müller, 2021).

**Social Effects**

The social dimension aims to create and develop the working life of employees, thereby enriching their health and well-being in society (Maheswari et al., 2020). Reducing stress and reducing monotonous and dangerous tasks is what Industry 4.0 technologies such as new assistance systems provide (Birkel & Müller, 2021).

There is no doubt that the importance of identifying economic, social and environmental effects in reverse logistics together with Industry 4.0 technologies is strong and highly relevant in today's context. Birkel & Müller (2021) summarizes the literature on the potential of Industry 4.0 in the triple bottom line with respect to supply chain management. However, the study does not consider reverse logistics alone in its context. ReSource also points out that to achieve sustainable use referred to Goal 12 as mentioned earlier, more research is needed, including on digitalization as a tool to achieve circular material flows and a focus on reverse logistics (ReSource, 2021).

### *1.2.3 Measuring the Economic, Environmental & Social Effects of using Industry 4.0 Technologies in Reverse Logistics*

Materials and resources reused with the support of Industry 4.0 technology are highly relevant for companies to meet their sustainable development goals (Ocicka et al., 2022). To monitor the sustainable development among of many possible actions could be to expand performance measures to include not only economic but also social and environmental effects (Agrawal et al., 2016). Because companies today are considered to have a responsibility to the environment and society. Indicators allow companies to measure their environmental performance, such as reduced energy and material consumption, reduced air and water pollution, and minimisation or elimination of waste generation and use of toxic and harmful materials. Social performance can include management quality, health and safety issues, wages and benefits, equal opportunities policies, education, child labour, forced labour, freedom of association, and human rights and services. It refers to companies' commitments to social responsibility issues. When evaluating economic performance in reverse logistics, metrics such as recovery of value from products, reduction of inventory investment, improved profitability and labour productivity can be used. (Banihashemi et al., 2019). There is still uncertainty about how products should be disposed after use and what impact this has on sustainable performance (Agrawal & Singh. 2019).

Maheswari et al., (2020) focuses their study on informal e-waste enterprises and sustainable reverse logistics scorecards which means that it addresses a number of parameters and perspectives as performance measures for the enterprises. Our study differs in the way that it only considers the economic, social and environmental effects in terms of performance. Figure 1 illustrates the different subjects and parts of the study and provides an overview of the identified research gap. Therefore, a qualitative study in this context is needed to explore what Industry 4.0 technologies are relevant in a company's reverse logistic context and identify, in order to measure the social, economic and environmental effects of using Industry 4.0 technologies in reverse logistics. This would be important to make appropriate decisions in sustainability.

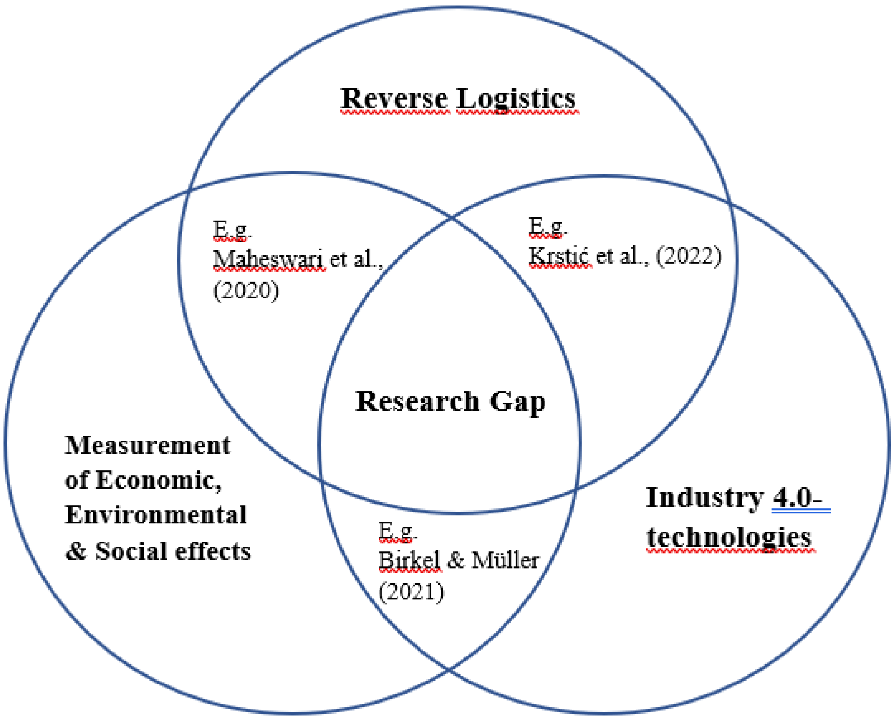


**Figure 1:** *Research Gap*

Above figure 1 which describes the research gap between the three studied fields can be seen. This paper is especially limited to manufacturing companies which have own reverse logistics e.g. in the form of remanufacturing or repair. No ranking or suggestion of the best suited technology is given, as this thesis focuses on the effects and measurements of these effects that Industry 4.0 technologies can have in reverse logistics on sustainability. Therefore, our research questions can be seen below.

**Research questions:**

1) What Industry 4.0 technologies are relevant for a manufacturing company's reverse logistics processes?

2) What are the economic, environmental & social effects of using Industry 4.0 technologies in a manufacturing company's reverse logistics?

3) How can the economic, environmental & social effects of using Industry 4.0 technologies in the reverse logistics be measured?

## 1.3 Thesis Deposition

**Chapter 1: Introduction**

This chapter presents the topic of the study. The reader is introduced to the basics of the research, such as Industry 4.0 technologies, reverse logistics and sustainability in terms of economic, environmental and social aspects. The problem discussion addresses the reasons why the fourth revolution technologies in reverse logistics are relevant and which economic, environmental and social effects can be identified and measured. It follows by presenting the research questions.

**Chapter 2: Methodology**

Chapter 2 presents the methodology of the study. All relevant methodology is presented based on the research onion from Saunders et al. (2016). Additionally, the sampling of the study is presented and also the data collection which includes the companies chosen.

**Chapter 3: Theoretical Framework**

In chapter 3, the authors review previous studies and literature on reverse logistics, Industry 4.0 technologies and sustainability where the economic, environmental and social dimensions are derived from. Lastly, these sections are integrated with each other. This is to provide some background information on the concept of the subject area.

**Chapter 4: Empirics**

The gathered empirical data is presented in chapter 4. Every respondent is presented by itself under the corresponding company. Every company is guided by the three main topics of this study, which are Industry 4.0 technologies in reverse logistics, economic, environmental & social effects of Industry 4.0 technologies in reverse logistics and measurements of these effects created by Industry 4.0 technologies in reverse logistics.

**Chapter 5: Analysis**

The analysis combines the results from the empirical data and the content from the theory. This way, the relationship between theory and practice is made visible. The understanding created will form the basis for the conclusion of the study.

**Chapter 6: Conclusion**

The conclusion of this study is done in chapter 6. All central findings of this study are gathered here and based on the analysis, the study's research questions are answered. Additionally, theoretical and practical contributions, limitations and future research opportunities are given.

# 2. Methodology

The purpose of this chapter is to outline the research strategy used for this study. A literature review is being conducted in order to evaluate the different authors' perspectives on the topic. In order to analyse the research issue and guarantee the quality and validity of the data collection, a number of scientific publications were compiled and used as the primary source for an exhaustive review of the study topic.

## 2.1 Research Methodology

Each philosophy, which will be discussed later on, is built on different assumptions. These assumptions are ontology, epistemology and axiology and can be seen as a foundation to distinguish between research philosophies.

### *2.1.1 Ontology*

The ontological premises affect how you see and evaluate your study materials, as ontology refers to presumptions about the nature of reality. Management, organisations, organisational events, people's professional lives and artefacts can all be considered as part of these study materials in business and management. Furthermore, and as a consequence, it can be said that the decision process of what to investigate for a research project is affected by ontology as it affects how the business and management environment is perceived (Saunders et al., 2016).

### *2.1.2 Epistemology*

Due to the multidisciplinary character of business and management, a wide range of knowledge types, from numerical data to textual and visual data, from facts to interpretations, and even from narratives, stories, and made-up accounts—can be used in a respectable manner. Epistemology addresses these assumptions about knowing, what constitutes suitable, valid, and legitimate knowledge, and how we communicate information to others. This leads to a variety of business and management specialists using diverse epistemologies in their research (Saunders et al., 2016).

### *2.1.3 Axiology*

The role that ethics and values play in scientific study is referred to as axiology, which furthermore involves looking at the ways in which researchers manage both their own values and the values of the subjects of their study. As was previously said, if the findings are to be taken seriously, the importance of personal values throughout the whole study process cannot be overemphasised (Saunders et al., 2016).

To be able to build up a comprehensive methodology, the methodology choice is guided by the "research onion" from Saunders et al. (2016) which can be seen in figure two below.

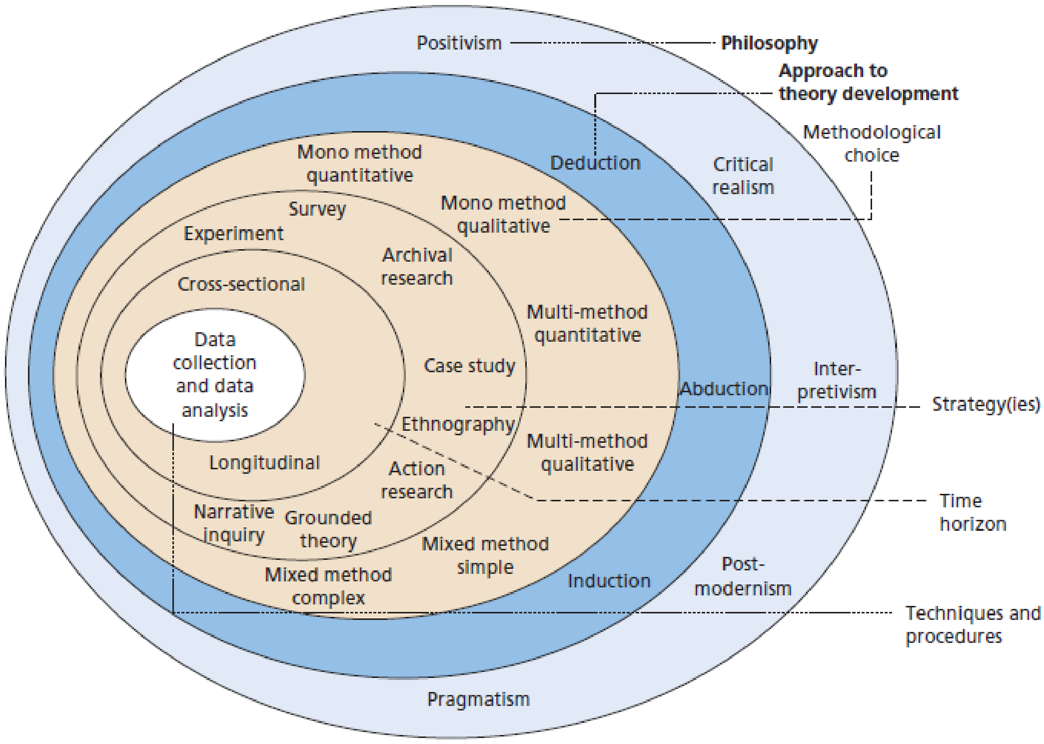


**Figure 2:** *Research Onion (Saunders et al., 2016)*

When making choices on research philosophy, approach to theory development, methodological choice, research strategy, time horizon, techniques and procedures, a cohesive methodology is produced. This structures the following parts of this methodology chapter.

## 2.2 Research Philosophy

Saunders et al. (2016) include positivism, critical realism, interpretivism, postmodernism, and pragmatism as the five main business and management philosophies.

### *2.2.1 Positivism*

Positivism is based on the teachings of Francis Bacon, Auguste Comte, and the Vienna Circle, a group of philosophers and scientists active in the early twentieth century and is known for its offering of clear and precise information. Positivism is a natural scientist's philosophical viewpoint which advocates utilising social reality that has been seen to produce generalisations that resemble rules and furthermore, the core of positivism is the significance of what is 'posited', or 'given'. This highlights the positivist emphasis on strictly scientific empiricist technique designed to deliver pure data and facts free from human interpretation or prejudice (Saunders et al., 2016).

### *2.2.2 Critical Realism*

Critical realism initially evolved as a response to both positivist direct realism and postmodernist nominalism in Roy Bhaskar's writings from the late 20th century, and it presently lies in the middle of these two ideologies. Furthermore, it seeks to explain what we see and experience in terms of the fundamental forces that shape reality. For critical realists, reality is the most important philosophical consideration, necessitating the need for a well-structured, multi-layered ontology. Critical realists see the empirical as what we observe or experience (which also includes feelings) and not as actual objects, which is founded on the fact, that for critical realists reality is the most important philosophical consideration, necessitating the need for a well-structured, multi-layered ontology (Saunders et al., 2016).

### *2.2.3 Interpretivism*

In the early and middle of the twentieth century, in the writings of German, French, and occasionally English philosophers, an idea known as interpretivism, which is composed of a number of strands, most notably hermeneutics, phenomenology, and symbolic interactionism, emerged. Interpretivism underlines how individuals differ from physical events as they create meaning. These connotations are studied by interpretivists and furthermore, interpretivism emerged as a subjectivist critique of positivism, much like critical realism did. According to interpretivism, social science research must be separate from that of the scientific sciences rather than aiming to mimic it since people and their social settings cannot be studied in the same manner as physical phenomena (Saunders et al., 2016).

### *2.2.4 Postmodernism*

Since the birth of postmodernism in the late 20th century, the work of French philosophers Jean-François Lyotard, Jacques Derrida, Michel Foucault, Gilles Deleuze, Félix Guattari, and Jean Baudrillard has been most closely associated with it. In an effort to question accepted knowledge and give voice to unpopular, alternative ideas, postmodernism lays a particular emphasis on how language functions and power relations. Postmodernism and the poststructuralist school of thought have a history together, while postmodernists emphasised the importance of language more than interpretivists do in their critique of positivism and objectivism. They reject the modern objectivist, realist ontology of objects in favour of emphasising the chaotic supremacy of flux, movement, fluidity, and change (Saunders et al., 2016).

### *2.2.5 Pragmatism*

In the United States, pragmatism initially arose in the works of the philosophers Charles Pierce, William James, and John Dewey in the late nineteenth and early twentieth century. It seeks to strike a balance between subjectivism and objectivism, morals and facts, precision and rigour, and numerous contextualised experiences. It does this by considering theories, concepts, ideas, hypotheses, and research findings practically rather than merely abstractly, in terms of their roles as instruments for thought and action as well as the implications they have in specific contexts. Pragmatism holds that concepts are only significant when they help people take action. Pragmatists value knowledge because it enables actions, and they worry about reality because it impacts how ideas may be put into execution, furthermore, they approach research from the perspective of a problem and aim to offer helpful solutions that have an impact on current practises. When there is doubt and a sense that something is strange or out of the ordinary, the reflexive process of inquiry is triggered, and once the problem has been resolved, it re-creates belief (Saunders et al., 2016).

### *2.2.6 Selected Philosophy*

This thesis can be considered as a paper within the philosophy of pragmatism as it achieves to balance objectivism and subjectivism, values and knowledge, thorough and precise research, and many contextualised experiences, by taking into account theories, conceptions, ideas, hypotheses, and research findings in terms of their functions as tools for thought and action, as well as the practical ramifications they have in particular situations. A pragmatist approaches research from the standpoint of a problem and seeks to provide useful answers that influence current practice, which this thesis is also going to do (Saunders et al., 2016).

## 2.3 Research Approach

There are three different types of approaches to theory development, which are deduction, induction and abduction (Saunders et al., 2016).

### *2.3.1 Deduction*

Deduction is the preferred research approach in the natural sciences, where rules act as the basis for explanation, allow for the anticipation of events, permit the forecasting of their occurrence, and then allow for the management of those occurrences, as in deduction, a theory is developed and then put to the test against a set of assertions. Deduction has a lot of important characteristics. In the beginning, efforts are made to pinpoint the reasons for the relationships between concepts and variables. Deduction necessitates that concepts be operationalized in a way that allows for the frequent quantitative quantification of facts. The highest kind of deduction is generalisation. The sample must be carefully chosen, and its size must be sufficient to permit generalisation (Saunders et al., 2016).

### *2.3.2 Induction*

When the plan is to better understand an observed problem, induction may be the appropriate approach. Here, the goal would be to obtain a sense of what was happening in order to better comprehend the nature of the issue. The next step would be for you to interpret the gathered data. This investigation would lead to the creation of a theory, which is frequently presented as a conceptual framework. Inductive reasoning is used to develop theory, where theory comes after data rather than the other way around as with deduction (Saunders et al., 2016).

### *2.3.3 Abduction*

An abductive technique swings back and forth, effectively integrating deduction and induction, as opposed to moving from theory to data (as in deduction) or data to theory (as in induction). Abduction starts with the observation of a "surprising event" and develops a reasonable explanation for how it may have happened (Saunders et al., 2016).

### *2.3.4 Selected Approach*

Given these impressions, this paper uses a deductive approach to develop suitable theory. This paper is built on several other papers and theory, which is later on tested and evaluated with empirical data. These findings may contribute finally to new developed theory.

## 2.4 Methodological Choice

When thinking about methodological choices it is very important to distinguish between quantitative and qualitative methods. Making a distinction between numerical data (numbers) and non-numerical data (words, images, video clips and other similar material) is one method of separating quantitative study from qualitative research. In this sense, the term quantitative is frequently used to refer to any method of data collecting (such as a questionnaire) or method of data analysis (such as graphing or statistics) that produces or uses numerical data. On the other hand, the term qualitative is frequently used as a synonym for any method of data collecting (such as an interview) or method of data analysis (such as categorising data) that produces or employs non-numerical data. But nonetheless, the distinction between these two methods can be problematic, as many research designs in business and management combine qualitative and quantitative methods. This research design can be seen as a mixed method (Saunders et al., 2016).

### *2.4.1 Quantitative Research*

Positive thinking is typically connected with quantitative research, particularly when planned and highly organised data gathering approaches are utilised. However, a difference must be made between statistics based on views, sometimes known as "qualitative" figures, and data regarding the characteristics of individuals, organisations, or other objects. In this approach, certain quantitative survey research may be understood to somewhat adhere to an interpretivist ideology. Realist and pragmatic ideologies both permit the use of quantitative research. The deductive method is typically used in quantitative research, with the goal of using evidence to evaluate theory. It could also include an inductive strategy, in which theory is developed through facts, though (Saunders et al., 2016).

### *2.4.2 Qualitative Research*

An interpretative philosophy is frequently linked to qualitative research. It requires interpretation because researchers must make sense of the varying, socially created interpretations of the event under study. In order to build trust, engagement, access to meanings, and in-depth knowledge, researchers must conduct their work in a natural environment, or research context, which is why this type of study is frequently referred to as naturalistic. Qualitative research may be applied within realist and pragmatist ideologies, much like quantitative research. Several types of qualitative research start with an inductive approach to theory building, using a naturalistic and emergent research design to construct theory or establish a deeper theoretical viewpoint than what is currently there in the literature. To evaluate an established hypothesis using qualitative methods, other qualitative research methodologies, on the other hand, begin with a deductive approach. In reality, a lot of qualitative research employs an abductive method to theory formation, in which inductive inferences are created and deductive ones are iteratively evaluated during the investigation (Saunders et al., 2016).

Another methodological choice is, if one only considers one (mono-method study) or multiple methods (multi-method study), which can be done in a quantitative, as well as in a qualitative research design (Saunders et al., 2016).

### *2.4.3 Methodological Choice*

As a methodological choice, due to the qualitative research questions and the deductive research approach, this thesis works with a multi-method qualitative study. The starting point when choosing our research approach has been the study's research questions. The study will provide a deeper understanding of which Industry 4.0 technologies are used in the reverse logistics process. It will also show what social, economic and environmental effects the Industry 4.0 technologies provide and how these are measured. In this case, surveys are prepared and send to suitable companies. Additionally, semi structured interviews as well as focused group talks are conducted, which cover the themes of the research questions and some prepared key questions that may be used during the interviewing process. This is done to be able to remove or reorder some questions in particular interviews to adapt to given specific organizational context. This enables further to understand the consequences of the research questions in an empirical context (Saunders et al., 2016).

## 2.5 Research Strategy

The objective of research might be exploratory, descriptive, explanatory, evaluative, or a mix of these.

### *2.5.1 Exploratory Study*

An exploratory research is a useful tool for posing open questions in order to learn more and build understanding about a particular subject of interest. Exploratory research questions frequently start with "What" or "How," depending on the topic. If you want to better understand a topic, issue, problem, or phenomena, or if you are unclear of its exact nature, an exploratory research can be quite helpful (Saunders et al., 2016).

### *2.5.2 Descriptive Study*

Gaining a precise profile of events, people, or circumstances is the goal of descriptive research. The words "Who," "What," "Where," "When," or "How" are frequently used at the start of or in the body of descriptive research questions. A descriptive study may be an expansion of an exploratory study or a precursor to an explanatory study. Prior to collecting the data, it is essential to have a thorough understanding of the phenomena you desire to study (Saunders et al., 2016).

### *2.5.3 Explanatory Study*

Explanatory study refers to studies that demonstrate the causal links between various variables. Research inquiries that seek explanations are more likely to start with "Why" or "How" than other words. Studying a condition or a problem in order to understand the connections between variables is the focus of explanatory research. For instance, you could discover that a quick examination of quantitative data on transport punctuality reveals a connection between the number of trucks and transport punctuality. To gain a deeper picture of the relationship, you may go ahead and put the data through statistical tests like correlation (Saunders et al., 2016).

### *2.5.4 Evaluative Study*

Evaluative research seeks to determine the effectiveness of a given concept. The word "How" or the word "What," in the form of "To what extent," are frequently used in research questions that aim to assess the accuracy of the responses. The success of a corporate or organisational strategy, policy, programme, initiative, or process is likely to be the focus of evaluative study in business and management. Every element of the organisation or business might be affected by this, such as the evaluation of a marketing campaign, a personnel policy, a costing strategy, or the provision of support services (Saunders et al., 2016).

#### *2.5.5 Selected Strategies*

Research questions one and two of this thesis are set up in the style of an exploratory study with the target to clarify how one comprehends a situation, issue, or phenomena. Research question three is set up in the style of an explanatory study, as the target is to explain the relationships between the two concepts Industry 4.0 techniques in reverse logistics and measurements of sustainability (Saunders et al., 2016).

### 2.6 Research Design

#### *2.6.1 Survey*

The survey tactic is frequently linked to a deductive research methodology. The what, who, where, how much, and how many questions are the ones that this popular and widely utilised technique is most usually using to address in business and management research. As a result, it frequently appears in exploratory and descriptive research. Questionnaire-based survey tactics are common because they make it possible to collect standardised data from a sizable population in an extremely cost-effective fashion, facilitating simple comparison. Also, the survey approach is viewed as authoritative by the general public and is quite simple to explain and comprehend (Saunders et al., 2016).

#### *2.6.2 Case Study*

A case study is a detailed investigation into a subject or phenomena in its actual environment. In the case of study research, the term "case" can refer to a variety of case subjects, including a person (such as an employee or manager), a group (such as a work team), an organisation (such as a factory or business), an association (such as a joint venture), a change process (such as restructuring a company), and events (such as a weekly group meeting or annual general meeting). One of the most important aspects of developing a case study is selecting the case to be investigated and establishing the parameters of the investigation. Case study research, once defined, aims to comprehend the dynamics of the subject under investigation within its environment or context (Saunders et al., 2016).

### *2.6.3 Selected Design*

A research study's design may have many objectives. This can be accomplished by include exploratory, descriptive, explanatory, and/or evaluative research in the study design using mixed techniques. A single method study design can also be employed in a way that allows for the facilitation of several goals (Saunders et al., 2016).

There are many strategies that could be applied in research, which are: experiment, survey, archival and documentary research, case study, ethnography, action research, grounded theory as well as narrative inquiry. As a strategy, this thesis is applying an interview study to make an in-depth inquiry of the topic in the real life setting of multiple organisations, focus group talks as well as surveys (Saunders et al., 2016).

## 2.7 Time Horizon

The research needs to establish a time horizon over which the study extends. The time horizon of the research can be referred to as cross-sectional or longitudinal. Cross-sectional research means that a phenomenon is examined at a specific point in time; the research thus creates an overview at a given time. The second time horizon, referred to as longitudinal, involves a series of snapshots showing a selection of events over a period of time (Saunders et al., 2016). In cross-sectional research, it is common to use the survey approach, which describes the occurrence of a phenomenon. Qualitative or multiple research strategies also exist where case studies are based on interviews conducted over a short period of time. While longitudinal research observes change and development.

In order to study what Industry 4.0 technologies is used in reverse logistics and which social, economic and environmental effects can be identified and measure, our study will apply cross-sectional time horizon.

## 2.8 Sampling and Population

Based on our choice of Method Strategy made in 2.5 this study will have three approaches for data collection, interview study, focused group talks, as well as surveys.

Saunders et al. (2016) describes that there are two different types of sampling techniques: probability sampling or representative sampling and non-probability sampling. Probability sampling is usually associated with research strategies for surveys and experiments. For sampling, the probability of each case being selected from the target population is known and is normally the same for all cases. In non-probability sampling, the target population is the opposite, meaning it is not known and it is impossible to answer research questions that require statistical conclusions about the characteristics of the population.

As it is not possible within this thesis to collect data from an entire population, sampling is done in order for the study to be researchable (Saunders et al., 2016). While sampling, companies where chosen that are using the observed technologies in their reverse logistics to represent that chosen population. Finally, four Swedish and one German company are making up the research population. In these companies suitable managers where chosen as interviewees to gather suitable data for the thesis.

As this thesis has the target to build up an advanced understanding of Industry 4.0 technologies used in reverse logistics and observed effects on sustainability and measurements for these in Swedish and German manufacturing companies, this thesis collects information from top management (leading manager rock tools, leading manager strategy and company growth, leading manager logistics and planning and leading manager technology) and middle management (manager remanufacturing electronics, manager logistics and manager reverse logistics) as they have a profound knowledge of the processes needed to answer the research questions of this thesis.

### *2.8.1 Company Descriptions*

To find appropriate companies to study for this thesis was a central point of this study. This study focuses on Swedish and German companies in the manufacturing area, which are developing and manufacturing their own products. Additionally, it was important for the sampling that they have some sort of own reverse logistics and are using Industry 4.0 technologies in that.

**Swedish Engineering Company Rock Tools (A)**

Respondents 1 & 2 are working as leading managers at the rock tool division of company A, which can be considered as a relevant industry to study the sustainability effects of Industry 4.0 technologies in reverse logistics. The company is a multi-national, Sweden based, high-tech engineering organisation that offers products and services to the infrastructure, mining, and industrial sectors that improve productivity, profitability, and sustainability.

**Swedish Manufacturing Company Construction Equipment (B)**

Respondent 3 works as a manager within remanufacturing at company B, which can be considered as a relevant industry to study the sustainability effects of Industry 4.0 technologies in reverse logistics. In addition to being a leading manufacturer of wheel loaders and articulated haulers, company B is also a top producer of road construction tools, compact construction equipment, and excavation machinery. They also provide servicing, financing, used equipment, rental, and other associated services as a whole solution provider.

**Swedish Manufacturing Company of Electronical Products (C)**

Respondents 4 & 5 are working as (leading) managers in logistics and logistics and planning at company C. Company C can be seen as a highly developed and advanced company in regard to modern production technologies and therefore Industry 4.0 technologies which are used in reverse logistics. The company is focusing on the production of European and sustainable electronical products and the recycling of those.

**German Manufacturing Company of Joining Technology (D)**

Respondent 6 is working as a leading manager in technology at company D. Company D is a family-owned German manufacturer of joining technology as well as assembly and logistics solutions that offers its services and products worldwide. The studied company has a focus on sustainability especially within its logistics solutions and due to the enhanced recycling of its products.

**Swedish Manufacturing Company of Network Products (E)**

Respondent 7 is working as a manager in reverse logistics at company E. Company E is a Swedish Manufacturer of different network products as well as access control for the security and surveillance industries worldwide. Enhanced sustainability is reached at this company due to its offering of reverse logistics solutions as repair and recondition.

### *2.8.2 Sampling Technique*

This study uses the non-probability sampling design approach.

## 2.9 Data Collection

In this chapter the data collection is presented. Qualitative data was gathered with the help of a mixed approach of semi-structured interviews, focused group talks and surveys. In addition to the semi structured interview, focused group talks were conducted to gather additional data in a discussion. At last surveys complete the data collection process. The interview guide as well as the survey can be found in the appendix.

In total this paper works with 7 respondents out of 5 companies, from which respondents 1-3 participated in an interview, respondents 4 & 5 in a focused group talk and respondents 6 & 7 in a survey.

| | Position description | Company | Industry | Company description | Date | Type | Duration |
|---|---|---|---|---|---|---|---|
| **Respondent 1** | Leading manager rock tools | Swedish engineering company rock tools (A) | Mining | Swedish engineering company specialized in, among others, mining and rock excavation | 29.03.2023 | Single Teams-Interview | 75min |
| **Respondent 2** | Leading manager strategy and company growth | Swedish engineering company rock tools (A) | Mining | Swedish engineering company specialized in, among others, mining and rock excavation | 12.04.2023 | Single Teams-Interview | 75min |
| **Respondent 3** | Manager remanufacturing electronics | Swedish manufacturing company construction equipment (B) | Construction Equipment | Swedish manufacturing company of construction equipment | 06.04.2023 | Single Teams-Interview | 75min |
| **Respondents 4 & 5** | Leading manager logistics and planning & Manager logistics | Swedish manufacturer of electronical products (C) | Electrics | Swedish manufacturing company of, among others, electronical products | 05.05.2023 | Group Teams-Interview | 60min |
| **Respondent 6** | Leading manager technic | German manufacturer of joining technology (D) | Fasteners | German manufacturer of joining technology | 08.05.2023 | Survey | / |
| **Respondent 7** | Manager reverse logistics | Swedish manufacturer of network products (E) | Communication | Swedish manufacturer of communication and network technology | 09.05.2023 | Survey | / |

**Table 1:** *Overview of Respondents*

## 2.10 Method for Data Analysis

This study is using thematic analysis to analyse the qualitative data which is gathered during the interviews and focused group talks. This method's main goal is to look for common themes or patterns in a data set, such as interviews, like in the case of this study. When doing a thematic analysis, the researcher codes their qualitative data to find themes or patterns that may be further examined in relation to the research topic and questions. The thematic analysis can be considered as a systematic approach as it offers a rational and ordered method for analysing qualitative data. This leads to the possibility, that this method can analyse qualitative data sets of any size and is further able to produce detailed descriptions, justifications, and theorising (Saunders et al., 2016).

In case of this thesis for the empirical part, interviews were conducted with multiple companies to be able to gather suitable data. For the thematic analysis, the data is coded after the three research questions, as the interview guide and survey are also separated in these three parts. It is also coded after insights from the literature and reoccurring themes and patterns in the content of what the interviewees said. In this way at first the data is coded after Industry 4.0 technologies used in reverse logistics at that certain company, after that the data is coded after the sustainability effects of Industry 4.0 technologies that can be seen in reverse logistics and at last after the measurements of that sustainability effects of Industry 4.0 technologies in reverse logistics at the companies. The companies and interviewees were anonymised, to protect the personal and sensible data of the interviewees and companies contacted.

## 2.11 Quality of the Research

Validity and reliability are crucial for evaluating the quality of research according to Saunders et al. (2016). Replication and consistency are referred to as reliability. If a study with a given research design can be replicated by a researcher and it delivers the same findings, then it would be seen as being reliable. Therefore, the suitability of the measurements utilised, correctness of the results analysis, and generalizability of the findings are essentially relating to validity (Saunders et al., 2016).

A given interview protocol is one part to ensure reliability in this study. In that way, all interviews are structured the same and the interviewers practised the interview questions before to further ensure that consistency and accuracy. Furthermore, all interviews are transcribed to ensure the reliability. To be able to ensure a suitable validity for this study and the therein conducted interviews and focused group talks, all questions asked are based on the research questions and given theoretical framework and can be found in the appendix of this study.

The survey is built up according to the findings in theory of this thesis and structured after the research question of this thesis to ensure the validity of the survey. Survey and interview guide can be found in the appendix of this thesis.

With the including of these measures the quality of the research is ensured to further contribute to the theory of Industry 4.0 technologies in reverse logistics and its effects on sustainability.

## 2.12 Ethics

According to Saunders et al. (2016), access and ethics are important aspects to consider for the success of research. Whether researchers collect primary data through, for example, face-to-face interviews, internat-mediated, surveys and questionnaires or using secondary data, these aspects are just as important. The ethical principles that govern your conduct in regard to the rights of persons who become the topic of your study or are otherwise impacted by it are referred to as research ethics (Saunders et al., 2016).

When one request access, for instance, is one of the crucial phases when one need to take ethical concerns into account. It shouldn't be tried to persuade the targeted participants to allow access by putting any pressure on them. When one goes to a manager of an organisation to ask for access, it's doubtful that this will be the case. Additionally, all persons interviewed must agree to participate and to use the data gathered from them in the way it is needed in the thesis. Further as a researcher the privacy of the interviewees needs to respected and all data need to be handled confidential. To give the participants time to prepare and not take them by surprise, the relevant topics were introduced to them before doing the interview (Saunders et al., 2016).

## 2.13 Summary of Methodology

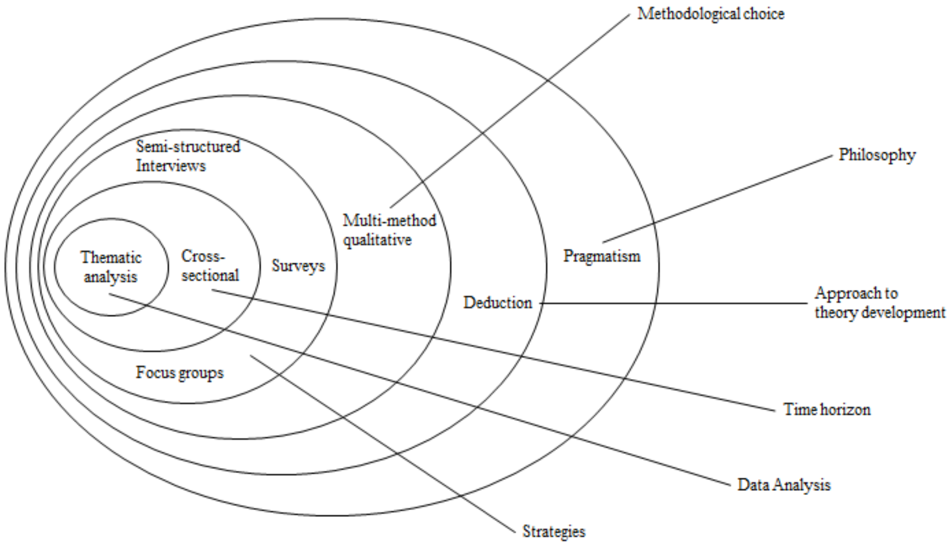


**Figure 2**: *Summary of Methodology (own figure based on Saunders et al., 2016)*

In the figure above the summary of the chosen methodology can be seen, which was described before in this chapter.

## 2.14 Individual Contribution

The individual work done for this study is regarded as equal between all three group members. In order to contribute as effectively as possible, researchers divided the labour between the three members throughout the thesis according to their levels of expertise in the three key disciplines, which are reverse logistics, Industry 4.0 technologies and sustainability.

# 3. Theoretical Framework

This section of the paper presents a theoretical understanding of reverse logistics, Industry 4.0 technology and the economic, environmental and social effects that are created and measured. At the beginning of this chapter, a table is presented, divided according to the research questions of the thesis, with the derivation of sub-headings for the relevant theory. These terms and theories are operationalized in a model at the end of the chapter.

| Research Questions | Referred Chapters |
|---|---|
| What Industry 4.0 technologies are relevant for a company's reverse logistics processes? | 3.1 Reverse Logistics & 3.2 Industry 4.0 Technologies |
| What are the social, economical and environmental effects of using Industry 4.0 technologies in a company's reverse logistics? | 3.2 Industry 4.0 Technologies, 3.3 Economic, Environmental & Social Sustainability & 3.4 Integration of Interfaces |
| How can the social, economical and environmental effects of using Industry 4.0 technologies in the reverse logistics be measured? | 3.2 Industry 4.0 Technologies & 3.4 Integration of Interfaces |

**Table 2:** *Referred Chapters for Research Questions*

The following conceptual model which can be seen in the figure below is set up with the help of the theory.

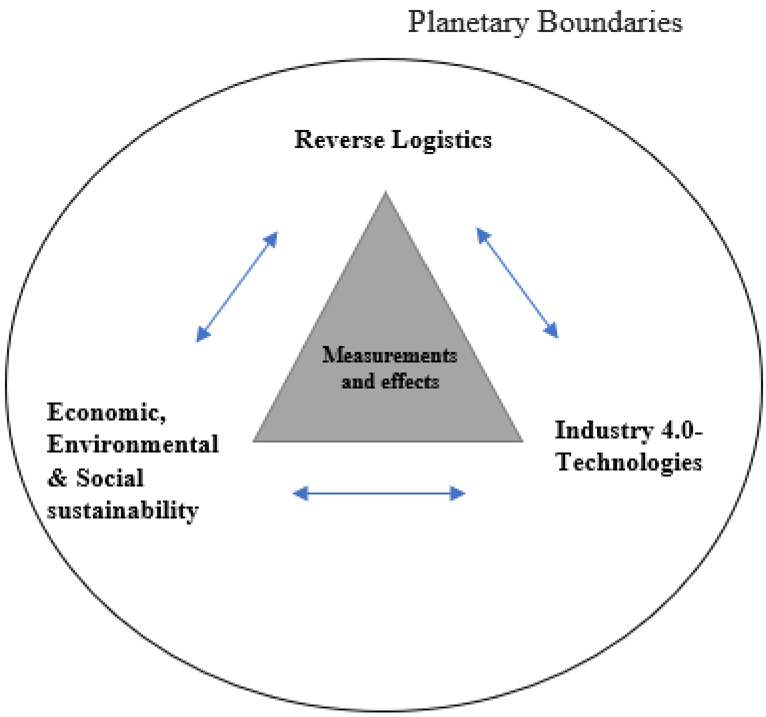


**Figure 3:** *Conceptual Model*

This study investigates the role of Industry 4.0 technologies in reverse logistics and furthermore the effects that reverse logistics, with Industry 4.0 technologies have on sustainability. Additionally, measurements for the effects on sustainability are shown and it is investigated what and how these measurements are used by companies. All this has to take place within the planetary boundaries (Rockström et al., 2009) to not seriously damage the environments in the future.

## 3.1 Reverse Logistics

This theoretical framework begins with the topic of reverse logistics as part of the research gap model that was presented earlier in the introduction and is visible in the figure above.

Reverse Logistics, as defined by Murphy and Poist (1988) is, "the movement of goods from a consumer towards a producer in a channel of distribution". Materials and goods can be recycled back into the production process or sold to businesses in different supply chains. Products and parts that has been returned can be resold, refurbished, or disposed away. Every item that meets these requirements is eligible to participate in the Reverse Logistics procedures. Businesses may lessen their influence on the environment with the use of reverse logistics by recycling and reusing items and reducing trash (Quesada, 2003). The following illustration shows a depiction of the various reverse logistic flows that were previously mentioned.

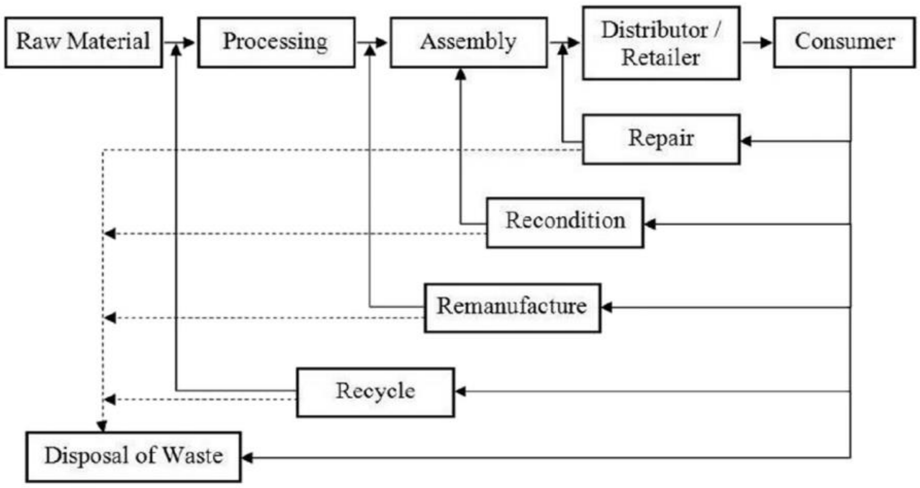


**Figure 4:** *Material Flow and Activities in Reverse Logistics (Govindan and Soleimani, 2017)*

### *3.1.1 Repair*

Repair is the process of bringing broken or flawed products back to their initial state, so that they can be used again. In recent years, there has been a rise in popularity for the process of mending things because of the financial savings and environmental advantages that it offers. When compared to the production of brand-new goods, Fleischmann et al. (1997) found that repair greatly cut down on the amount of waste generated and the amount of resources that were used. This is due to the fact that the process of repairing something makes use of components and materials that already exist, hence lowering the requirement for new resources. In addition to this, the authors emphasize the significance of the repair network in terms of its role in facilitating the repair process. The network is made up of a collection of specialized repair shops, repair professionals, and suppliers who collaborate with one another to speed up the process of repairing faulty items and getting them back on the market as soon as possible.

### *3.1.2 Recondition*

Reconditioning is the process of bringing previously used products back to their original state of functionality after they have been used. During the course of the procedure, it is likely that certain components will require maintenance in the form of either repair, an upgrade, or replacement. The fact that reconditioning may be applied to high-value products like electronics and machinery, for which the cost of repairing or replacing parts may be prohibitively expensive, makes it an extremely important practice (Bai et al., 2015). Reconditioning can greatly reduce the adverse effects that these products have on the environment by prolonging the useful life of the objects, minimizing the production of waste, and conserving resources (Bai et al., 2015). However, the authors also mention that the primary criteria that influence whether or not reconditioning is effective are the demand from customers, the level of technical expertise available, and the availability of replacement parts.

### *3.1.3 Remanufacture*

Remanufacturing refers to the procedure of refurbishing previously utilized products to their initial specifications. In order to attain comparable levels of quality as a newly manufactured item, the process entails disassembling the product, replacing any worn-out or broken components, and reassembling it. Remanufacturing, as opposed to producing new goods, can greatly minimize waste generation and resource consumption, claim Sundin and Bras (2005). Remanufacturing, according to the authors, can also result in significant cost reductions, especially in sectors like aerospace and automotive that have high product values and extended service lives. The authors also draw attention to some of the difficulties involved with remanufacturing, such as the accessibility of old goods and the requirement for specific tools and knowledge.

### *3.1.4 Recycle*

Recycling is the process of converting waste resources into new ones that may be used to create new products. Recycling is the process of recovering valuable components from discarded goods and reusing them in new things, according to Reverse Logistics. According to Atasu et al., (2010), recycling can significantly reduce waste production and resource consumption when compared to traditional disposal methods. The authors claim that recycling can also produce significant cost savings and new business opportunities. The authors also emphasize the importance of product design in streamlining the recycling process as well as the necessity of sufficient infrastructure and logistics to enable the efficient collection and processing of recovered materials.

### *3.1.5 Disposal of Waste*

Disposal is the last step in reverse logistics, where things that cannot be recycled, mended, reconditioned, or remanufactured are thrown away. When waste materials are not correctly managed during disposal, they can have a major negative influence on the ecosystem (Amin et al., 2014).

## 3.2 Industry 4.0 Technologies

Industry 4.0 technologies are another important part of the research gap of this thesis and are presented in this chapter.

Businesses will create worldwide networks in the future that include their manufacturing equipment, warehouse systems, and other infrastructure in the form of Cyber-Physical Systems (CPS) which is also known as the fourth industrial revolution or Industry 4.0. These Cyber-Physical Systems in the industrial environment include intelligent equipment, storage systems, and production facilities capable of independently sharing information, initiating actions, and managing one another. With the help of these technologies, major changes to the industrial techniques used in production, engineering, material utilisation, supply chain, and life cycle management are enabled. The current and known way of production will be changed to an entirely new method with the help of the already-starting to emerge smart factories. A core element of these new production methods are smart items which have a unique identifier and can be located at all times. Additionally, they are aware of their own past, present, and potential detours from their intended condition. The business operations of factories and organisations are vertically networked with embedded manufacturing systems, and dispersed value networks are horizontally connected to them. These networks may be handled in real time, from the time an order is placed all the way through to outbound logistics (Kagermann et al., 2013).

### *3.2.1 Cyber-Physical Systems*

The term cyber-physical system (CPS) which refers to a system that combines software with mechanical or electronic components, can be applied in a variety of ways.

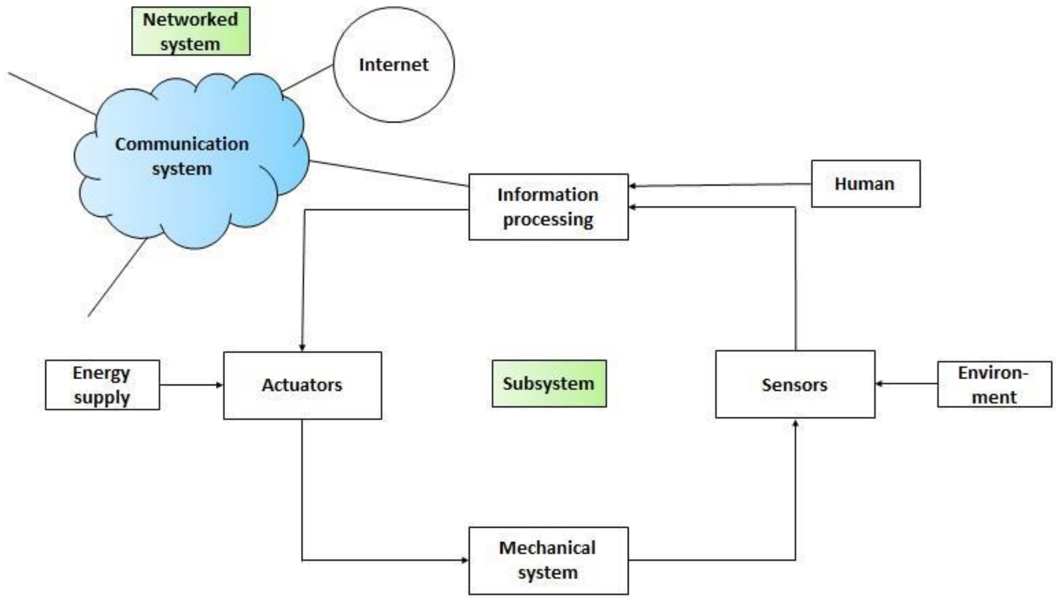


**Figure 5:** *The structure of a Cyber-Physical System (own figure based on van de Venn, 2017)*

As seen in the above diagram, a CPS is composed of a mechanical system as well as a processor used to process information. The functionality can be described in a variety of ways. In addition to a direct link between the physical and digital worlds, indirect networks of sensors and actuators are among the characteristics of CPS, according to Broy (2010). Additionally, networking is important since CPS are linked internally and externally to other systems (Broy, 2010).

According to Bauernhansl (2014), CPS are objects that have embedded systems and have been made communicable. They are able to communicate with other CPS online while using internet services. Also included in the definition of CPS are systems that employ sensor technology to instantly collect their surroundings, evaluate it using data and services that are made available globally, and then store it. CPS may also affect the physical environment thanks to actuators (Bauernhansl, 2014).

The underlying claims of both definitions are surprisingly similar, as can be seen from their respective examples. CPS have interfaces that are suitable for both the physical and digital worlds because they act as a bridge between both. They have their own computers that they utilize to process the data from their sensors and control the physical environment through actuators.

Autonomous Robots or Cobots, which can be seen as a form of CPS, are characterized through information-based and physical interaction between humans and robots. Information-based interactions between people and robots are intended to provide the robot instructions for a task or to give it direct control over the process. For the physical interaction between humans and robots, Cobots are no more in the need of protective devices like fences and instead use flexibly configurable software security systems to interact directly with humans, which leads to an even more flexible usage of these robots (Naumann et al., 2017).

Another application would be additive manufacturing (AM), which is defined by the ASTM (American Society for Testing and Materials) as “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies” (ASTM F2792-12a, 2012). This manufacturing technology is quickly developing and permits on-demand part manufacture with the potential for cost savings (Frazier, 2014). AM is continuously improving in process capabilities, which is due to increased material availability (Pinkerton, 2016), part weight reduction (Seppälä and Hupfer, 2014), higher efficiency, shorter lead times, and lower supply chain costs, as well as more flexibility in component design and customization (Thomas, 2015).

### *3.2.2 Internet of Things*

The Internet of Things (IoT) is the enabler of the connection between different CPS, which further makes it possible to connect them to Cyber-Physical Production Systems (CPPS). Additionally, it enables the information generation and transmission related to these techniques. The transmission is made to a central or decentralized system and involves more advanced identification than typical RFID technology, which also helps to make this identification possible (Winkelhaus & Grosse, 2019). When looking at the definition by Gubbi et al. (2013, p. 1647), the IoT is the “interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications."

The distribution of computer services via the Internet (the cloud), databases, software, networking, comprising servers, storage, analytics, and intelligence, may be referred to as cloud computing in order to provide speedier innovation, flexible resources, and scale economies. Together with artificial intelligence, this forms predictive analytics, so the use of current analytical methods and historical data to forecast future occurrences and get real-time insights (Jović et al., 2020).

Due to the huge amounts of connections within a network which are present with Industry 4.0 technologies, the scope and diversity of cyberattacks have increased dramatically. It is well established that cybersecurity breaches might have a detrimental impact on company performance in such a linked industrial environment. The cost of cybercrime generally varies depending on the nation, organizational size, industry, kind of cyberattack, and effectiveness of the organization's security posture. Such cyber-attacks can of course cause some serious negative business impacts which include in particular: sabotage of the entire critical infrastructure or targeted machines and components, denial of service of networks and computers, theft of industrial trade secrets and intellectual property, violations of laws pertaining to safety and pollution and up to the occurrence of life-threatening situations for employees (Lezzi et al., 2018). Companies suffer large economic losses while coping with such difficult situations because they must return to regular working conditions, which results in a decrease in productivity, and because they lose their ability to compete in the relevant market. An important factor in maintaining a company's competitive edge (in terms of market position strengthening and economic growth) is the ability to deal with cybersecurity challenges in a proactive manner (Barbier et al., 2016). Furthermore, to improve the performance of the whole industrial value chain, cybersecurity policies should be properly integrated with organizational and IT plans (Waslo et al., 2017).

### *3.2.3 Big Data Analytics*

Without using the phrase "Big Data", it is challenging to discuss the concept of Industry 4.0. There are enormous amounts of data collected on top of the data that is typically created in a traditional, non-smart factory with the connection of loads of devices (like CPS). It is difficult to gauge the actual volume of data collected nowadays and to give them the proper interpretation. One can discover everything conceivable when seeking for credible estimates of how much data is demonstrably created, saved, or analysed every day, but there is no evidence that can be verified. Also, the growth of computer hardware, information technology, and the advancing digitalization are all moving too quickly for comprehensive overview at this time (Sendler, 2016).

Big Data, however, refers to more than just the sheer volume of data. Volume, Velocity, and Variety are the three requirements that must be met. This indicates that the volume is merely one of several criteria. The second criterion, velocity, takes into account how quickly data is gathered, e.g. the data in a Smart Factory is gathered in real time. As a result, a significant quantity of data is produced by CPS, which are outfitted with sensors and other digital components, and this data is gathered quickly and in real time. The change of the data itself also serves as a third criterion. Because CPS and their sensors might vary greatly (e.g. in terms of machines or storage systems), a wide range of data must be gathered (Sendler, 2016).

In conclusion, big data is primarily concerned with the collection and analysis of data in order to use it and improve efficiency in a variety of areas, such as manufacturing or logistics. Moreover, sensors are used to collect the majority of the data during automation. These variables are employed in automation technology to control or regulate production, which can be carried out electronically or by computer algorithms. Until recently, this data has been kept and used, for instance, to compare a setpoint with an actual value, but it has seldom been evaluated or associated with other data. One of the most significant changes to "Industry 3.0" is that data is no longer solely utilised for regulation and then erased, perhaps preserved, but never again used. In contrast, data is gathered and made available for various purposes in Industry 4.0, where the systems in a company's production and other departments are integrated (Hänisch, 2017).

#### *3.2.4 Artificial Intelligence*

The study and use of artificial intelligence (AI) focuses on creating machines that can mimic human intelligence. A few essential elements of AI are machine learning and the capacity to handle unstructured data. The former includes computational techniques that let AI develop its own learning capabilities; for instance, machine learning enables AI to enhance its performance without being explicitly trained to do so. The capacity of AI to handle unstructured data, such as photos and natural language, is its second crucial feature. Computers are now able to discern patterns in and derive meaning from pixels by processing pictures, a process also known as computer vision (Wilson et al., 2022). Based on its capacity to carry out various activities, AI can be categorized into four types: mechanical, analytical, intuitive, and empathic (Huang & Rust, 2018).

Mechanical intelligence refers to the capacity to automatically carry out repetitive, regular actions that take the shape of mechanical labour in the context of human service; this type of work is unskilled and frequently does not call for extensive training or education. Mechanical AI is intended to have limited learning and adaptive capabilities to preserve consistency in order to resemble human automation (Huang & Rust, 2018). Disassembly robots that "perceive" and deconstruct things according to predetermined criteria for their pieces are an example of mechanical AI in reverse logistics (Wilson et al., 2022).

The capacity to digest information for problem-solving and learning is known as analytical intelligence. Information processing, logical thinking, and mathematical abilities are all relevant here. The two main analytical AI applications are machine learning and data analytics. There are many different kinds of machine learning, but typically analytical AI relies on algorithms to discover meaningful information from data without being explicitly trained where to seek for it (Huang & Rust, 2018). For instance, analytical AI may be able to optimise the quantity and position of collecting locations in reverse logistics utilising AI algorithms (Wilson et al., 2022).

The capacity to think imaginatively and respond well to unfamiliar situations is known as intuitive intelligence. Based on holistic and experience-based reasoning, it might be regarded as wisdom. The main characteristic that sets intuitive AI apart from analytical AI might be considered to be understanding. AI is designed to mimic a variety of human cognitive functions and learn much like a human child (but much more quickly because to its computing power and networking). In this sense, AI may be compared to human intelligence (Huang & Rust, 2018). As an instance of intuitive AI, consider choosing the best 3PL suppliers as part of creating the reverse logistics network using fuzzy logic AI algorithms (Wilson et al., 2022).

Understanding other people's feelings and being able to affect others' emotions through appropriate emotional responses are all characteristics of empathetic intelligence. It involves social, interpersonal, and people skills that enable individuals to be considerate of others' feelings and collaborate well with others. Empathetic AI is characterised by experience or the capacity to have feelings (Huang & Rust, 2018). Despite the fact that empathic AI may be very useful in many social sciences, such as consumer behaviour or service sciences, it is not well adapted to dealing with the requirements of quantitative issues like those encountered in reverse logistics (Wilson et al., 2022).

*3.2.5 Augmented Reality*

A developing human computer interaction (HCI) technique called augmented reality (AR) projects virtual data onto an actual scene. The five components that make up a standard AR application are registration, tracking, rendering, interaction, and content production. Simply said, computer-generated data like annotations, images, and 3D models should be rendered and registered on the actual scene with precise tracking and alignment. This needs to be followed by user-friendly interaction modalities like gesture-based input, speech input, or with the aid of external input devices like data gloves or ray casting using a mouse to finally create a form of augmented reality, where a human being can interact naturally. Additionally, users should be presented with relevant material that is created in response to a specific request or activity (Baratoff & Regenbrecht, 2004). To summarize it can be seen that AR expands the user's visual experience into the information space from the actual world and AR teaching incorporates interactive virtual content into the actual environment, enhancing how users engage with it and leads furthermore economic benefits due to its easy integration (Wang et al., 2022). A formal definition of an AR system is that it is an application that can merge real and virtual material in a real environment, is real-time and interactive, and can register virtual content in a three-dimensional environment (Azuma, 1997).

In the industry, using HCI methods to improve industrial processes has a long history. Virtual reality (VR), which is more immersive than AR, has been used in a variety of industrial sectors since the 1990s, including prototype design, simulation, and virtual manufacturing. As AR makes it possible to superimpose virtual elements over real-world scenes, it is more suited to facilitating real-world manufacturing operations and is frequently used in virtual assembly design or training (Chang et al., 2017).

### *3.2.6 Blockchain Technology*

In 2008, Satoshi Nakamoto introduced and contextualised blockchain in the context of the cryptocurrency known as Bitcoin (Varriale et al., 2021). This technology no longer depends on bitcoin as a cryptocurrency; it now stands alone and is entirely unrelated to the digital currency. This division of interests between bitcoin and its technological underpinnings demonstrates the dynamic utilisation of technology. A decentralised equitably shared ledger called blockchain can help to store and document data and transactions that are secured by a cryptographic value (Dutta et al., 2020; Choi, 2020). Blockchain technology is a chain of data that is kept in blocks and has equal copies that are accessible to each block's nodes (Dutta et al., 2020). It is a series of blocks that keeps growing as more system important nodes accept them (Queiroz et al., 2020).

Blockchain technology enables all participants within a supply chain to access identical data, which has the potential to mitigate challenges related to data transmission and communication. Data confirmation may be done in less time and with more speed (Karamchandani et al., 2021). Pournader et al., (2019) claim that the implementation of blockchain technology enables all stakeholders involved in a supply chain to attain identical access to pertinent information, thereby mitigating the likelihood of communication and data transfer challenges. As the company incorporates the larger portion of it, public and private blockchains are being developed. Blockchain technology operates on a decentralised peer-to-peer network and possesses the capacity to completely reinvent the supply chain system (Zhang et al., 2019).

While Blockchain technology offers many advantages, there are also possible drawbacks. These can be especially unclear laws and regulations surrounding the Blockchain environment and also high costs of operation and implementation of Blockchain systems (Dutta et al., 2020).

## 3.3 Economic, Environmental & Social Sustainability

In order to treat the effects of economic, environmental and social created by Industry 4.0 technologies and Reverse Logistics, this chapter presents the three terms economic, environmental and social aspects which are explained and derived from the concept of sustainability that introduces this chapter.

*3.3.1 Sustainability*

The term "sustainability" is one that is thrown around a lot, especially nowadays, and is open to a lot of interpretation. This idea of sustainability is frequently used to explain how people or businesses interact with different natural resources and ecosystems. They include things like social fairness, stability, and access to resources like clean water, clean air, and fertile land (Borglund et al., 2017).

The UN report "Our Common Future" is frequently mentioned when a definition of sustainability is required. According to this research, "meeting the needs of the present without compromising the ability of future generations to meet their needs"(Brundtland et al., 1987, p. 8) encapsulates the essence of sustainable development. This notion is based on the reciprocal obligation that successive generations have to one another. However, this definition is also rather vague because "need" is a highly personal concept that requires more clarification. When a person has access to food, water, and a place to live, one might claim that their fundamental requirements are met. But other people would argue that a person's basic needs also include access to the internet, education, and vegetarian or vegan meals. What a person of one civilization may perceive as essential may be the ultimate luxury for a member of another one.

The notion of sustainability provided by Rockström et al., (2009) who study planetary limits, is also quite intriguing “Here, we present a novel concept, planetary boundaries, for estimating a safe operating space for humanity with respect to the functioning of the Earth System. We make a first preliminary effort at identifying key Earth System processes and attempt to quantify for each process the boundary level that should not be transgressed if we are to avoid unacceptable global environmental change. Unacceptable change is here defined in relation to the risks humanity faces in the transition of the planet from the Holocene to the Anthropocene” (Rockström et al., 2009, p.2).

Due to restrictions placed on how the Earth System functions, this definition is far more precise than the one provided by the UN. Climate change, ocean acidification, stratospheric ozone, global P and N cycles, atmospheric aerosol loading, freshwater consumption, land use change, biodiversity loss, and chemical pollution are the nine planetary boundaries that Rockström et al., (2009) identified.

In this thesis sustainability is further considered in the form of the three pillars of sustainability, which includes economic, environmental as well as social sustainability perspectives, that can be seen in the figure below.

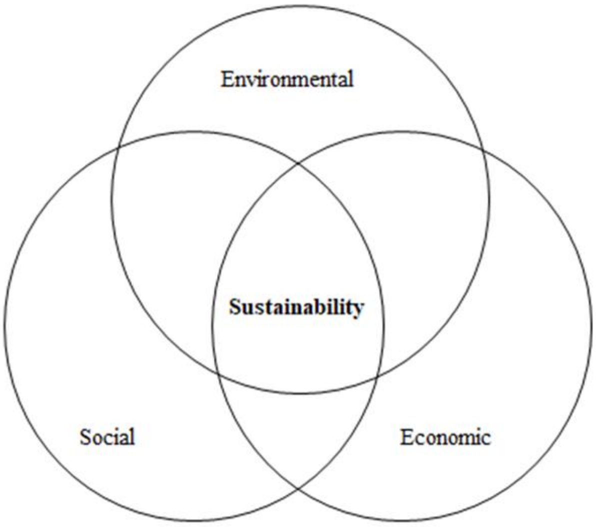


**Figure 6:** *Three Pillars of Sustainability (e.g. Ramos et al., 2014)*

### *3.3.2 Economic Sustainability*

Preserving economic growth is generally an accepted goal and of importance to the general public. Optimal resource use is central to economic sustainability. This means that the current use of resources should not reduce real incomes in the future because natural resources and the environment are the basis for shaping future economic operations, meaning that progress of economic in future will be increasingly dependent on the lasting integrity of resources and the environment (Moldan et al., 2012).

Economic sustainability is usually measured using financial indicators that relate to the profitability of the company in terms of long-term efficiency of operations, effectiveness and productivity, such as return on equity, return on assets and economic value addition (Alsayegh et al., 2020).

### *3.3.3 Environmental Sustainability*

There is no single definition of the meaning of environmental sustainability. A fundamental purpose, however, is to counteract significant environmental changes, which is central to the concept. The ecosystem and nature's services are strongly connected with human well-being because well-being is affected by a healthy ecosystem (Moldan et al., 2012).

The evaluation of environmental performance typically entails a measurement of the diminution of carbon footprint, encompassing pollution and carbon emissions, and the enhancement of the quality of both air and water. This reflects how effectively companies embrace environmental challenges that improve the environment in the future. Reducing pollution and carbon emissions, in turn, means increasing resource efficiency and reducing waste, which affects a company's financial performance (Alsayegh et al., 2020).

### *3.3.4 Social Sustainability*

Social sustainability pertains to the manner in which the fulfilment of individual requirements, such as those related to health and well-being, education, and cultural expression, is achieved (Moldan et al., 2012). Within companies, this can be expressed through the development of good working conditions for safety, satisfactory working conditions or addressing principles of fairness. Social sustainability can also be reflected in how companies take and support actions to strengthen and develop the local community (Żak., 2015)

Social sustainability performance shows the extent to which companies put social objectives into practice, which can be through working conditions, health and safety, well-being, diversity and fair labour practices (Alsayegh et al., 2020).

## 3.4 Integration of Interfaces

### *3.4.1 Industry 4.0 Technologies in Reverse Logistics*

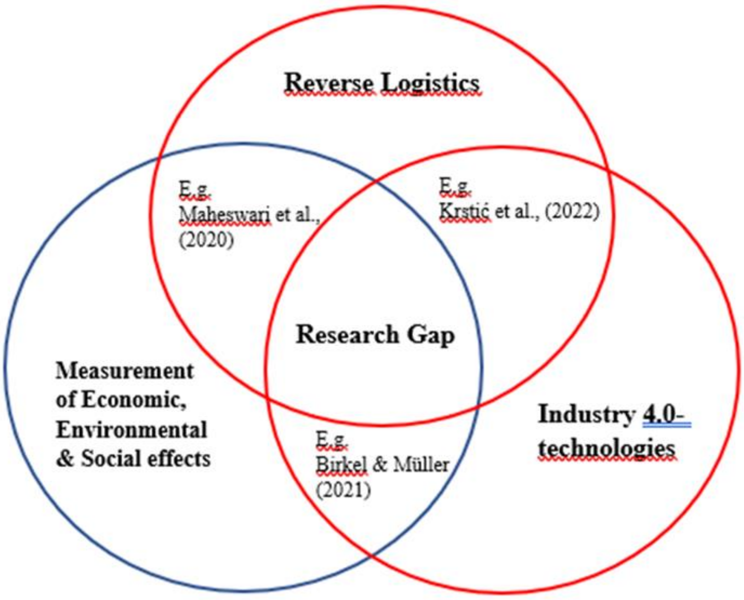


**Figure 7:** *Research Gap Model: Reverse Logistics & Industry 4.0*

In our research gap model concerning reverse logistics and Industry 4.0 technologies, Krstić et al., (2022) presents an overview of possible Industry 4.0 technologies that can be applied in reverse logistics and logistics in general. IoT, Blockchain, Big Data Analytics, Artificial Intelligence, Augmented Reality and Cloud Computing are shown to be the most applicable technologies in reverse logistics processes and activities. These Industry 4.0 technologies will have a significant effect on reverse logistics as data networks and physical real-time are linked together which is a common factor regardless of the type of technology (Krstić et al., 2022).

The Industry 4.0 technologies can be linked to certain types of Reverse Logistics that were presented in chapter 3.1. This can be seen in table 3 below.

| Reverse Logistic Processes | Industry 4.0 Technologies |
|---|---|
| Repair | CPS (3.2.1), IoT (3.2.2), Big Data Analytics (3.2.3), AI (3.2.4), AR (3.2.5) |
| Recondition | CPS (3.2.1), IoT (3.2.2), Big Data Analytics (3.2.3), AI (3.2.4) |
| Remanufacture | CPS (3.2.1), IoT (3.2.2), Big Data Analytics (3.2.3), AI (3.2.4), AR (3.2.5) |
| Recycle | CPS (3.2.1), IoT (3.2.2), Big Data Analytics (3.2.3), Blockchain Technology (3.2.6) |
| Disposal of Waste | IoT (3.2.2), Blockchain Technology (3.2.6) |

**Table 3:** *Linked Industry 4.0 Technologies to Reverse Logistic Processes*

IoT makes it possible for the Industry 4.0 technologies used in reverse logistics to communicate and share data as it is the foundation for all smart and connected technologies (Sun et al., 2022). Furthermore, it could lead to an improvement of service levels (Jović et al., 2020). By using big data analytics to assess the data obtained from the products engaged in reverse logistics, performance metrics and performance management systems are developed (Shah et al., 2019). One or more analytics components may be deployed in the cloud as part of a service model called cloud analytics. Organizations may increase their analytics capabilities as their business expands thanks to the cloud approach. Moreover, it handles massive amounts of Big Data as it is added to a data warehouse (Jović et al., 2020). Therefore, these technologies are important in every part of reverse logistics.

For repair the usage of AR might be very advantageous as it has the potential to increase the effectiveness of the disassembly process carried out by a human operator without the aid of a professional (Chang et al., 2017) and furthermore, can eliminate severe technological barriers within repair and maintenance due to the product design and its variation in response to consumer requirements and needs by guidance (Eswaran et al., 2023). Additionally, the usage of AI might be very advantageous as analytical AI could be able to optimise the number and placement of collection points and times in repair (Wilson et al., 2022) and CPS in the form of AM may be a gain too, due to its shorter lead times and higher production flexibility (Frazier, 2014) and in this way AM could add some substantial benefits to the reverse logistics processes ,as repair and maintenance, of companies (Strong et al., 2020).

For reconditioning and remanufacturing, additionally to AI, the usage of CPS and Big Data Analytics might be very advantageous. CPS are discussed in a wider setting with Logistics 4.0 nevertheless, reverse logistics has not received as much study attention. Industry 4.0 technologies like CPS may aid operations in reverse logistics just like they do in forward logistics. Through real-time information exchange or the spread of green products, CPS can enhance sustainability of reverse logistics operations (Sun et al., 2022).

As Blockchain technology enhances the trust between the participants in a supply chain through access to the same data, which can minimise problems with data transit and communication (Pournader et al., 2019), it plays a vital role in recycling and disposal of waste, where trackability is a main point.

When it comes to CPS in general in reverse logistics, Cobots, which have a substantially lower ratio of programming time to production time, are meant to make small quantities of production particularly cost-effective, which makes this part also very interesting for reverse logistics, as quantities can be very small (Naumann et al., 2017).

### *3.4.2 Measurements of Economic, Environmental and Social Effects created by Industry 4.0 Technologies*

The measurements of economic, environmental and social effects of Industry 4.0 technologies in reverse logistics are explained in the following chapter.

Technologies related to Industry 4.0 provide vital prospects for future innovation and corporate expansion (Javaid et al., 2022). The effects of Industry 4.0 technologies on fostering a sustainable environment in terms of economic, environmental and social aspects in manufacturing and other industries are integrated in this chapter.

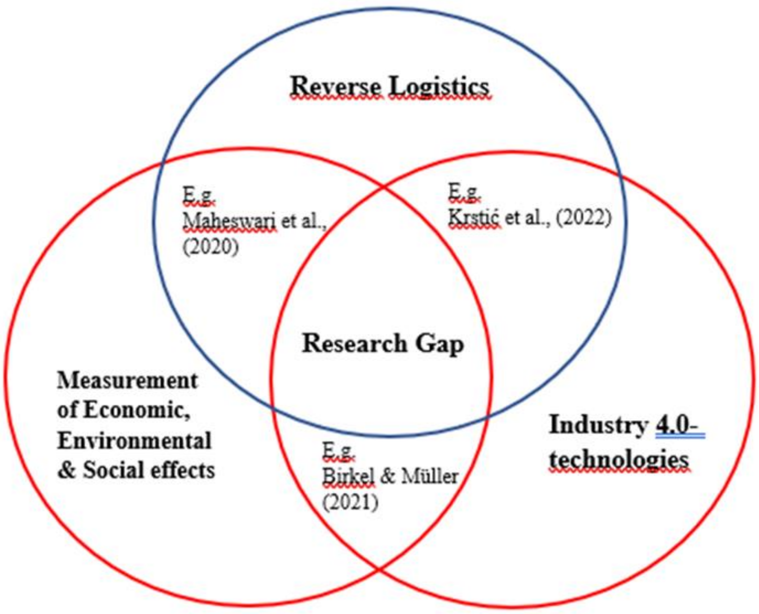


**Figure 8:** *Research Gap Model: Industry 4.0 & Measurements and Effects*

In the figure that illustrates the study's research gap, Industry 4.0 technologies and sustainability effects are linked by Birkel & Müller (2021) who highlight the possible potentials that Industry 4.0 technologies have in social, economic and environmental terms. Changes and opportunities that Industry 4 technologies create are increased competitiveness, productivity and revenues that are defined as economic values. A new technology like Industry 4.0 creates fear in employees of losing their job but the integration between human and technology can also reduce stress and monotonous and dangerous tasks when the virtual and physical world is combined, which is related to the social aspect. The environmental dimension that Industry 4.0 technologies create can be, for example, reduced resource consumption due to a better planned process and improved integration of capacity and demand that can avoid inventory problems (Birkel & Müller, 2021).

**Economic Effects**

According to (Rajput & Singh, 2021), the technologies of Industry 4.0 have important consequences for reverse logistics. These implications include the optimization of costs as well as the maximizing of end-of-life items. The employment of Industry 4.0 technologies like a cyber-physical system in smart manufacturing can aid in efficient work planning and execution, which can save money and resources and increase the flexibility of the availability of natural resources and environmental costs. Reducing batch sizes can lead to a more accurate response to fluctuations in demand, thereby minimizing production waste. (Bag & Pretorius, 2022). Automation, advanced analytics, and networking help speed up and improve returned product processing, lowering lead times and customer responsiveness. These systems also provide real-time reverse logistics monitoring, improving visibility and enabling flexible decision-making to meet changing market demands. (Barreto et al., 2017). It is possible to determine the financial impact of implementing Industry 4.0 methods in reverse logistics by conducting a data-driven analysis (Rajput and Singh, 2021). This analysis entails quantifying and assessing several criteria, such as cost reduction and long-term growth. Organizations may analyse the success of Industry 4.0 technology in reverse logistics and find areas for improvement by employing data analytics and performance metrics. (Barreto et al., 2017; Rajput & Singh, 2021). When products are remanufactured, repaired or recycled, companies can benefit from profitable business opportunities in terms of optimal use of products or customer issues (Agrawal et al., 2016).

Industry 4.0 technologies contribute to a longer life cycle of materials, better utilization of resources and existing assets, better adaptation to the demand curve and longer machine lifetimes (Bag & Pretorius, 2022).

**Measurements of Economic Effects**

The economic metrics that Industry 4.0 brings are product customization, value creation and flexibility in (re)manufacturing, which increases customer satisfaction (Akanmu et al., 2022). Industry 4.0 technologies have the ability to better adapt through communication, information and intelligence which will create shorter lead times, reduced material and labor costs, higher production flexibility and productivity, and better customization (Bai et al., 2020). This in turn will influence other economic values for companies such as competitiveness, productivity and revenue growth (Birkel & Müller, 2021).

**Environmental Effects**

With the increased use of Industry 4.0 technologies in reverse logistics and also in other places within a company the environmental effects are becoming more visible. Industry 4.0 has mainly focused on production and further the achievement of highest profits, which leads to negative environmental impacts as well as natural resource depletion and further an unsustainable consumption pattern. Nonetheless the focus of Industry 4.0 technologies often lies on increasing production to further increase revenues and competitiveness, the modern technologies will also increase sustainability and the quality of the products which enhances the lifetime and leads to less material use (Oláh et al., 2020). Additionally, Industry 4.0 technologies are able to especially reduce negative environmental effects due to the procedures of manufacture and transportation (Krstić et al., 2022).

Sun et al., (2022) argue, that the paradigms of reverse logistics have changed primarily in three areas as a result of technology advancements: data, services, and operations. By using IoT, smart devices, AI, and big data analytics, which allow for improved and real-time planning of various activities and resources, the value of data has been discovered in a way that was not possible before. The dynamic and intelligent cloud-based digital platform links various service providers and clients in order to maximise resource sharing and offer modern services (Sun et al., 2022). Further, Tseng et al. (2023) show that their findings indicate that the most important factor of Industry 4.0 technologies in reverse logistics is the digitalizing accessibility. The term digitalization refers to the adoption of modern technologies, like Industry 4.0 technologies, to improve resource and material competence, clean and green production practises, as well as sustainable consumption performance. Examples of these technologies include sensors, virtual simulation, digital products/services like the IoT, and CPS (Tseng et al., 2023).

Using technology like AI and machine learning can help find appropriate solutions for environmental problems including waste management, resource optimisation, carbon neutrality, and water. Using wireless networking technology and IoT capabilities, Industry 4.0 connects machines, sensors, and other appliances to the individuals in charge of overseeing the process of monitoring production processes and efficiency. The level of transparency offered by these technologies furnishes operators with significant information necessary for making informed decisions. It facilitates connection, enabling users to gather substantial quantities of data and knowledge from various stages in the production chain to support development and identify key opportunities for innovation and change (Javaid et al., 2022).

**Measurements of Environmental Effects**

Due to the higher efficiency and connectivity of Industry 4.0 technologies, compared to non-smart technologies, this could lead to a reduced energy consumption in (re-)manufacturing processes, increased yield as well as reduced transportation costs and therefore less emitting of greenhouse gases (Javaid et al., 2022). Additionally, the usage of Industry 4.0 technologies can lead to improved environmental circumstances, including less waste, toxic materials, emissions, and water and energy use (Toktaş-Palut, 2022).

**Social Effects**

For the advancement of sustainable development, it is essential that the social effects of adopting Industry 4.0-related technology in reverse logistics be measured (Bai et al., 2020). According to Grybauskas et al., (2022) beyond their economic advantages, it is crucial to think about the societal ramifications of these technologies and learn more about the wider implications of Industry 4.0 technologies on society by assessing the social repercussions of these technologies. This involves being aware of how these technologies affect inclusion, social responsibility, and sustainable practices (Grybauskas et al., 2022).

The data gained by assessing the social impacts of Industry 4.0 technologies can be used to develop policies and regulations that support social responsibility, diversity, and sustainable practices. Businesses might use this information, for instance, to develop instructional programs that promote social inclusion and help staff members become accustomed to new technologies. Policies can be developed to promote sustainable practices like recycling and waste minimization (Varriale et al., 2023).

Industry 4.0 has decreased human labour in various vocations and industries, but technology has also increased employment opportunities and boosted job security in certain industrial sectors in the face of the Covid-19 epidemic. Notwithstanding some industry publications' appreciation for Industry 4.0's improvement of working conditions, there are serious worries about the technology-centric nature of the movement and the danger of undermining human dignity and free will. Industry 4.0 does, however, fall short of integrating human-centric methods to the digital industrial revolution by not allowing modern business models to be optimised in line with the market dynamics and economic conditions already in place. The technical assistance component of Industry 4.0 includes a paradigm change in the use of human resources from manual labour to decision-making and problem-solving through digital empowerment. This characteristic might provide the wealthy and high-middle social classes exclusive access to future employment that pay well, causing inequality, income polarisation, and social cleavage if it is not properly governed (Grybauskas et al., 2022; Sindhwani et al., 2022).

On a micro-individual level, Industry 4.0 presents opportunities and risks that are relatively comparable for societal sustainability. This conclusion is intriguing in that it suggests that each of Industry 4.0's micro-social possibilities has a distinct cost, highlighting the critical role that digital transformation governance can play in reducing Industry 4.0's micro-social risks. Particularly, the literature frequently makes the claim that the introduction of Industry 4.0 will result in the creation of numerous new employment possibilities. The new employment would improve worker safety and well-being because of Industry 4.0's technological assistance premise. These advantages, however, can come at a huge price if society's digital revolution is not effectively managed. The new employment produced by Industry 4.0 would require a high level of competence, and it is anticipated that future occupations would require an even higher level of skill. This would result in a severe skill mismatch, particularly among the elderly working class, which would severely disrupt employment and result in job loss. Future occupations under Industry 4.0 could become limited to middle- and upper-class people who can pay and have access to excellent education services since they would demand a high skill profile and a university education in cutting-edge programmes like software engineering. This negative situation may worsen interregional or cross-regional mobility globally and result in significant job displacement and employment inequality (Grybauskas et al., 2022).

**Measurements of Social Effects**

For social metrics, Industry 4.0 provides great opportunities for employees to adapt to new technologies, increasing their motivation and morale. Therefore, Industry 4.0 technologies bring safe working conditions and improved working environments for employees (Akanmu et al., 2022).

### *3.4.3 Measurement of Economic, Environmental & Social Effects in Reverse Logistics*

In the process of reverse logistics where, for example, end-of-life products are recycled or remanufactured will create economic, environmental, and social benefits for businesses. This means that if companies work on reverse logistics processes, their sustainability performance can be improved (Agrawal et al., 2016). This chapter will present the effects and measurements in the three sustainability areas in the process of reverse logistics.

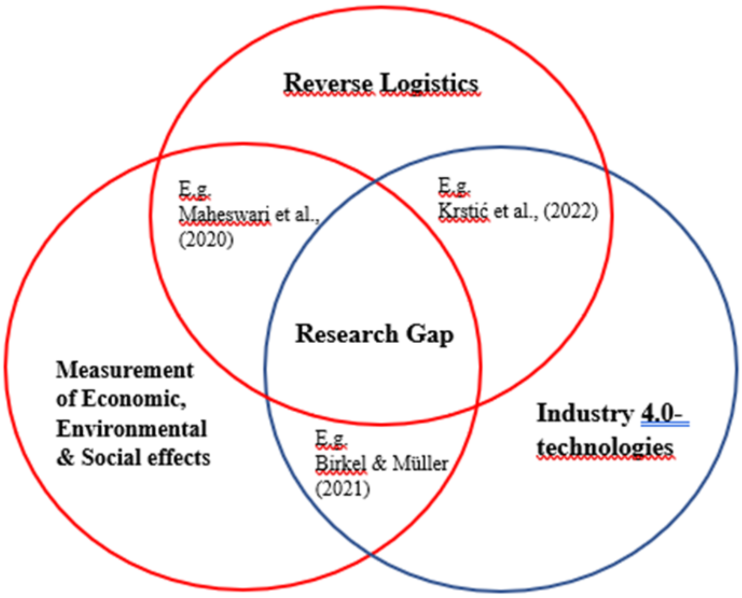


**Figure 9:** *Research Gap Model: Reverse Logistics & Measurements and Effects*

Reminiscent of our research gap model integrating reverse logistics with performance measures, Maheswari et al. (2020) develop appropriate conditions for reverse logistics performance using the Sustainable Reverse Logistics Scorecard (SRLS). For SRLS performance measures to be applicable, internal factors such as company policy and top management support as well as external factors such as laws and customer awareness and demand must be addressed. In addition, the authors also consider environmental and social dimensions, aspects that are missing in SRLS. The metrics that the article identifies related to reverse logistics could for example be profit of returned product, decreasing total reverse logistics cost and reasonable reimbursement cost, which are defined as economic measures. From the environmental perspective it could for example be decreasing waste and environmental protection. Performance measures in a social dimension refer, for example, to job opportunities (Maheswari et al., 2020).

**Economic Effects**

The economic effect in reverse logistics broadly focuses on financial success, which includes the continuous and profitable growth of an organization (Ali et al., 2018; (Maheswari et al., 2020). From a reverse logistics perspective, the quantity of goods returned by customers calls for the focus on customer satisfaction related to corporate practices such as quality management and incorporating favorable return policies. The costs connected to reverse logistics are developing and implementing the suitable technology to perform activities. The direct advantages of using reverse logistics activities are increased profitability and improved reputation (Presley et al., 2007). Dabees et al. (2023) argued that the economic component related to reverse logistics focuses on the reduction of expenses that is crucial in promoting sustainability. The economic measures related to reverse logistics are vehicle cost, fuel usage, production levels, and elimination of risks. Besides, an advanced business model in an economic dimension for reverse logistics (Sun et al., 2022).

**Measurements for Economic Effects**

The economic performance of reverse logistics can be assessed using factors such as cost restrictions, decrease in stock investments, improvement on profitability rates, labor efficiency, and recovering value from items accessibility (Banihashemi et al., 2019). By paying more attention and taking action on defective products, companies will achieve higher customer loyalty. Companies will also increase their revenue from sales if products are recycled or remanufactured (Banihashemi et al., 2019). Recycling costs are connected to expenses that influence the organization’s financial account through the establishment of product return activities such as recovering, disassembling, and disposing of products (Ali et al., 2018). Labor, transaction, and transportation expenses influence the reputation of the company. The operational expenses associated with inspecting, handling, and repackaging affect the ecological as well as economical activities of an organization (Ali et al., 2018). To specify KPIs in reverse logistics, measurement of customer satisfaction is common but again the focus is on costs such as collection cost, labor cost, total repair/refurbishment/exchange costs, time is taken for defect detection to correction or volumes specifying return volume and collection volume (Ahlström et al., 2020).

**Environmental Effects**

The increased environmental awareness and emphasis on environmental preservation has arisen from various factors such as customer pressure, ethical motives and regulatory issues, which have created effects on reverse logistics. Public regulations and laws force producers to take responsibility for the proper disposal and collection of their products. Reverse logistics extends the life of products and helps the company to support environmentally friendly practices through recycling and remanufacturing. (Presley et al., 2007).

Management of biodiversity processes, air emissions and chemical use are related to ecological practices that companies should consider integrating environmental aspects into their operations (Ali et al., 2018). The environmental aspects are greenhouse gas emissions, harmful substances, recycling rates, green products, resource use and green operations (Dabees et al., 2023). The environmental aspects focus on the preservation of the environment where the preservation activities are disposal and recycling processes which are elements of reverse logistics (Sun et al., 2022).

Minimizing air, water and waste pollution is a way for businesses to contribute to environmental performance (Banihashemi et al., 2019). Environmental KPIs relevant for reverse logistics are material use, energy use and share of recycled production from customer returns as some examples (Ahlström et al., 2020).

**Measurements for Environmental Effects**

The environmental performance in an organization encompasses its contribution in minimizing air, water, and waste pollution. Also, it encompasses the ability of an organization in decreasing the usage of harmful and hazardous materials to address the recurrence of environmental incidences accessibility (Banihashemi et al., 2019). Environmental sustainability can be measured using different factors including decrease in energy levels, material usage, and reduction in pollution levels. Besides, the elimination of waste and toxic materials can be utilized in measuring environmental sustainability accessibility (Banihashemi et al., 2019). The decrease in emission levels and the generation of waste are indicators of recycling performance (Ali et al., 2018). KPIs are traditionally defined by financial figures to monitor performance both within the company but also as a benchmark for external stakeholders. In many cases, other indicators are used to measure, for example, environmental performance. When companies set environmental targets such as waste reduction, pollution reduction and prevention, this can be reported through ISO 14001, which is a separate report from traditional KPIs. (Ahlström et al., 2020).

**Social Effects**

The social dimension in relation to reverse logistics can be different depending on the industry and organization due to the varying materials and products in different contexts (Sun et al., 2022). Some companies or sectors may experience more or less distinct impacts from maintaining reverse logistics practices. For example, the safety issues for workers associated with reverse logistics depend on the type of items or materials being reversed or remanufactured. In the chemical industry, safety is less so due to the significant risks associated with the products that will be returned from the system (Ali et al. 2018). In this case, safety issues, working hours and work climate become social effects created by reverse logistics within the organization (Sun et al., 2022). In addition, the material quality of the material returned may be less reliable than that of the material leaving the system, increasing the risk of significant waste. This creates external effects as the population suffers when the community faces the challenge of managing the waste that could have been disposed of in another area (Presley et al., 2007).

**Measurements for Social Effects**

The indicators of social sustainability are internal employees, shareholder participation, external persons, and significant social concerns. Besides, the other social indicators are safety, health issues, equity, and accessibility (Banihashemi et al., 2019; Sarkis et al., 2010). The categorization of societal issues can be delineated into categories such as equity, safety, employment opportunities, labour opportunities, and professional development (Ramos et al., 2014).

With the help of the literature review an enhanced conceptual model can be created which can be seen in the figure below.

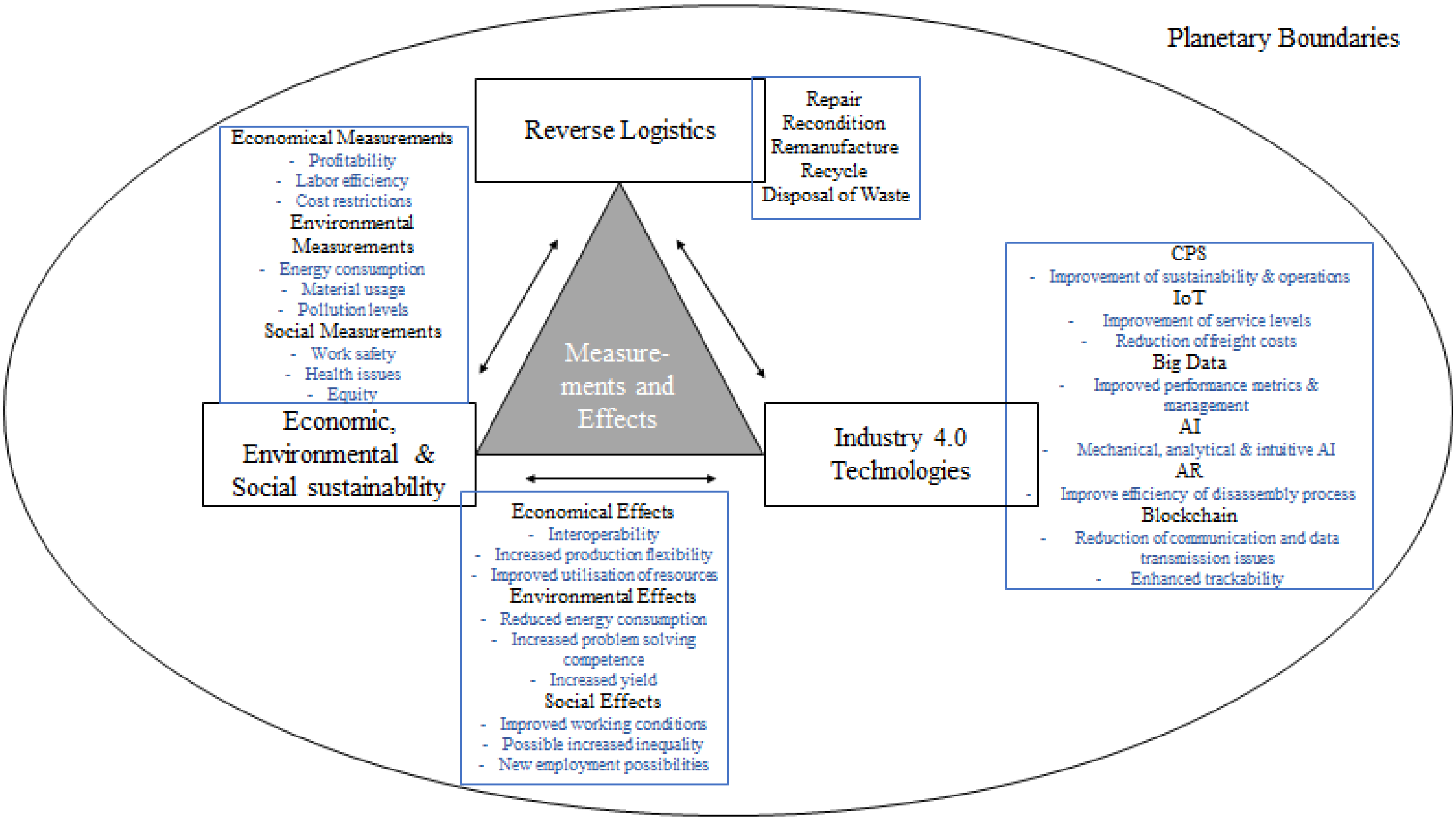


**Figure 10:** *Enhanced Conceptual Model with Integration of Reverse Logistics, Industry 4.0 Technologies & Sustainability*

# 4. Empirics

Here the material is presented which has been gathered during the interviews and surveys. For each interview first the material about the used Industry 4.0 technologies in reverse logistics are presented, followed by the sustainability effects of that technologies in reverse logistics and finally the measurements for the effects on sustainability of these technologies are presented.

## 4.1 Engineering Company Rock Tools (A)

### *4.1.1 President*

The first interview was conducted with a leading manager in rock tools of a large Swedish engineering company for among others rock tools. The interviewee sees sustainability aspects as central within his department and sees additionally an increased demand after sustainability by customers. Within reverse logistics the company uses mainly repair, recondition and recycling, but remanufacturing is also considered. One big thing here is the recycling of cemented carbide which is used in drilling bits. Industry 4.0 technologies in reverse logistics are right now mainly used to analyse data at this company, so to forecast reparations before something breaks down, which is done with a combination of AI and Big Data analytics. Additionally, automation and connection through the Internet of Things is playing a role while remanufacturing and recondition certain objects. In the future the company aims to use AM as well as more RFID technology within their reverse logistics.

#### *4.1.1.1 Industry 4.0 Technologies in Reverse Logistics*

Manufacturing processes for drilling tools can be significantly improved, both in terms of their efficiency and their level of precision, through the application of technologies that are part of the Industry 4.0 movement. Automation, for instance, can assist reduce the amount of manual work that is necessary and minimize the number of errors that occur during manufacturing, leading to production times that are both more dependable and faster. By providing real-time information on the location and status of products, the use of QR codes for tracking and identification can also assist streamline the reverse logistics process. This results in improved inventory management and more effective transportation planning. The reconditioning process of cemented carbide drill bits uses also highly automated processes as CPS.

The technology known as AM, which has the potential to change the procedures involved in reverse logistics, is another essential component of Industry 4.0. This technology enables the production of things that are both more accurate and more easily customised, minimizing waste production and increasing efficiency by only producing what is necessary at the precise moment it is necessary. Along with being good for the environment, this has the potential to lead to significant cost savings. Here, the president further explains, that the company is using AM also in an early test phase to recondition cemented carbide drill bits.

#### *4.1.1.2 Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

The ability of Industry 4.0 technology to considerably reduce waste and energy use should assist reverse logistics systems greatly. While additive manufacturing technology allows for more exact production, which reduces material waste, automation can help reduce errors, which result in wasted materials or energy.

In addition to these advantages, Industry 4.0 technologies also hold the promise of lowering carbon footprints through increased productivity and decreased transportation requirements. Companies can lessen their dependency on transportation networks and cut down on their carbon emissions by manufacturing only what is required when it is required. The definition of sustainability is understanding that sustainability and productivity go hand in hand. The President expresses *"doing more with less"* as a principle that both benefits the environment in terms of producing less CO2 and greenhouse gas equivalents, and it's good for company profitability because it saves money.

In general, the adoption of Industry 4.0 technology in reverse logistics has the potential to change conventional industrial processes into activities that are more environmentally friendly and sustainable.

#### *4.1.1.3 Measurements of Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

When it comes to the measurements of sustainability effects, the company mainly uses AI, big data analytics as well as cloud computing to digitalize the data collection on mine sites. Tools are in place that are analysing the gathered data and better understand the performance of the tools that are in place to finally offer a better service and enhanced lifetime for the customers.

Another big thing to be measured is the level of circularity and the proportion when it comes to steel and especially cemented carbide. The focus lies here especially on the total CO2 emissions and also the CO2 emissions that can be reduced with the help of that processes.

Measurements for social related topics are principally linked to work safety and education of the employees and their families. Work safety can be increased due to the increased automation and gathering of data which leads to fewer machine failures and further to a reduction in accidents.

#### *4.1.2 Strategy Manager*

The second interview within the Engineering Company Rock Tools was conducted with a leading manager in strategy and company growth of a large Swedish engineering company for among others rock tools. This interview was conducted in addition to the first interview with a leading manager in rock tools, to get a broader perspective of the company's perspective on the research topic. The interviewee supports the statement that sustainability is a central theme in the company and that this theme is getting more and more important for the customers and the company needs to make increasing statements about it. The demand for new technologies (Industry 4.0) from the company's perspective is also there and is getting expanded more and more. The perspective for this interview is laying more on machines as a whole instead of single equipment.

##### *4.1.2.1 Industry 4.0 Technologies in Reverse Logistics*

When it comes to reverse logistics, the interviewee is talking mainly about repair and maintenance, recycling and recondition that is present from its perspective. The target is to expand the lifespan of the machines and equipment and to give the customer a better service experience.

When it comes to repair and maintenance the company is very much into remote monitoring services which are using quite a lot of Industry 4.0 technologies and are a type of predictive maintenance. The remote monitoring service means an automated monitoring service by the company, where the machines and equipment are constantly controlled over a computer system. This aims to minimize wear of the equipment and find the right time for certain maintenance. All this is done with the help of sensors in the machines which are connected to a central system where the gathered data is evaluated with the help of algorithms which are constantly improved by data scientists. The company has further at certain mines 3D printers in place to be able to produce spare parts locally at service workshops or mines to reduce shipping and warehousing costs due to the ability to just produce the parts that are really needed. Currently this technology is in a trial phase in this company, but the plan is to increase its usage in more service workshops and mines.

The company is sensing a higher inquest in electrical machinery and with that the problem of battery recycling. The company is selling these machines but is planning to offer the service for customers to recondition or recycle the batteries after the lifespan to either expand their lifespan with giving them a second life or recycling their raw materials and use these again for the production. Further the company plans to increase the usage of sensors and tags within these parts to be better able to track the recycling process and provide more information about it also to customers. Right now the numbers of sold batteries are too low, so this process is done manually.

#### *4.1.2.2 Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

As described earlier by the interviewee, the company mainly uses AI, IoT, Cloud and CPS technologies within their reverse logistics which is mainly their remote maintenance system. Another thing is production technology in the form of AM locally at the workshops of the mines. According to the interviewee sustainability is a wide definition that encompasses the environment, social aspects and economic benefits.

When looking at sustainability effects of these technologies in reverse logistics, the company is mainly looking at CO2 from a central perspective. Locally it is also a lot about the employment of new and current employees. When it comes to the remote maintenance system the company sees a lot of effects on the CO2 reduction of that system. Through the very early detection of damage to the equipment the customers are using a total breakdown can be prevented. This leads to an increased lifetime of the equipment and therefore a reduced emission of CO2 gases. This procedure is also able to generate economic benefits especially for the customer as predictive maintenance is done and the downtime of the equipment is reduced which saves a lot of money and serves also a more efficient process.

The local production of spare parts directly at the workshops of the mines or the customer in general, is able to achieve effects on environmental, economic and social sustainability. Due to the local production an effect in the way of reduction of CO2 gases can be seen, as the spare parts don't need to be sent to the workshops. Also, at mines placed in for example India where a lot of sun is shining, the company is using mainly solar energy. This leads to the case that the AM machines are running on green energy which reduces the impact on CO2 again. Another thing is the possibility to create more local workplaces for the employees due to the local production. In this way AM can have a positive effect on social sustainability.

#### *4.1.2.3 Measurements of Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

When it comes to measurements of the sustainability effects of the used Industry 4.0 technologies in reverse logistics the interviewee sees some problems at the moment. The company is not measuring the sustainability effects, but the interviewee highlights the importance of that topic for the company. Right now the company gathers a lot of data with their remote maintenance system and the algorithms they use within this which includes also the sustainability effects. Nonetheless, there are no automatic measurements in place to keep track and measure these effects. Sometimes measurements of the effects are done manually based on the gathered data, but according to the interviewee this is not a regular procedure. Within the recycling of their own batteries these measurements would be interesting for the company as well, but due to the small numbers of the battery production at the moment, these processes are all done manually.

Furthermore, the interviewee highlights the high importance of these measurements for the company in the future and that the company needs to work more with it, due to stricter and tougher regulations which are going to come and an increased interest of the company. The ability to get audited is getting very important in the future and therefore an increased need for measurements is present.

## 4.2 Manufacturing Company Construction Equipment (B)

The third interview was conducted with a manager within remanufacturing for electronics at a large Swedish manufacturing company for construction equipment. When looking at reverse logistics at this company it mainly meant remanufacturing. The target is here to restore the equipment to new conditions and in many cases the condition after the remanufacturing is better than the new engine was, due to for example software upgrades and the latest technology used. Equipment that is remanufactured can be everything from engines, transmissions, turbos, injectors up to machine computers. The remanufacturing follows a circularity principle, as old equipment needs to be returned to the company before the customer gets remanufactured equipment. This has the target to secure that the company has enough equipment that is shipped to the remanufacturing factories and further back to the retailer to make them available for customers. The remanufacturing is structured similarly to the normal production so AI, IoT and robotics are especially used. The company is further mainly focusing on environmental and economic aspects, as it measures the impact on greenhouse gases. Additionally, the lead times in remanufacturing are quick, due to connected Industry 4.0 technologies used, which leads to economic benefits for the company and faster lead times also for the customer, which is an essential benefit of remanufactured parts for the customer as they can be ordered from the shelf.

### *4.2.1 Industry 4.0 Technologies in Reverse Logistics*

The organization is incorporating Industry 4.0 technology into its reverse logistics processes to increase operational efficiency and make better use of the resources that are already available. Among the advanced technologies in this category are automation, robots, artificial intelligence, the Internet of Things (IoT), and data analytics. The company uses robotics in their remanufacturing process to assure accuracy and consistency in the final product, among other elements that are similar to their conventional production approach. The Core Management System (CMS), which is in charge of tracking cores all around the world, has also been updated by the firm to include a machine that can carry out tasks autonomously. This state-of-the-art tracking technology has a significant positive impact on the efficiency of their reverse logistics operations as a whole. The use of Internet of Things (IoT) sensors and data analytics throughout the remanufacturing process provides real-time monitoring of the statuses of components, which improves decision-making and resource allocation.

### *4.2.2 Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

The social, economic, and environmental effects of using Industry 4.0 technologies have been identified as important factors to consider when implementing them in a company's reverse logistics operations. - the interviewee discusses the sustainability effects of using Industry 4.0 technologies in reverse logistics, including examples such as Reman being a cheaper alternative for customers compared to a new component, quick delivery times, good margins for the company, and being a good alternative for the environment.

Remanufacturing at the company has shown to save a significant amount of energy and materials while reducing $CO_2$ emissions. For instance, remanufacturing an engine reduces energy use by 80% and $CO_2$ emissions by 56%. Organization's efforts at remanufacturing resulted in a reduction of 14,100 tons of $CO_2$ in 2021. By increasing productivity and lowering waste, the utilisation of Industry 4.0 technologies like automation and robots further strengthens these environmental advantages.

Remanufacturing provides customers with a cost-effective alternative and boosts company profit margins, aligning with the ethos of *"good business for our customer, for the company, and for the environment"*, like explained by the interviewee. The company enjoys larger profits on remanufactured components, especially when a higher percentage of remanufactured parts can be used, while customers benefit from cheaper prices compared to new components. Industry 4.0 technologies aid in resource optimization and manufacturing cost reduction, resulting in a more financially sustainable model.

Companies' dedication to upholding uniform working conditions for their employees at all of its locations around the world contributes to the social sustainability element of their reverse logistics procedures. Automation and AI-based Industry 4.0 technologies can also assist in increasing worker safety and open up new career options in fields like robot maintenance and data analysis, which will further support social sustainability.

### *4.2.3 Measurements of Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

The interviewee offers insight into the measurement aspects and mentions that calculations and measurements related to environmental impacts, logistics, and production aspects are conducted by a dedicated department within the company.

The company employs a variety of measures to assess how the remanufacturing process affects sustainability, as mentioned. These calculations likely involve factors such as transportation and production comparisons between new and remanufactured components. The interviewee also suggests that the company has established mechanisms to evaluate the sustainability effects of its reverse logistics practices.

A large amount of material can be used again in the process of remanufacturing. Industry 4.0 technologies can make it even easier to recover materials by making it easier to take things apart and figure out what they are.

A huge amount of energy is saved by remanufacturing a part instead of producing a new one. For example, 80% less energy is used to produce a new engine and 80% less energy is used to make a new generator. Automation and AI, which are both part of Industry 4.0, can help find flaws in the remanufacturing process that waste energy.

The total quantity of CO2 saved through remanufacturing was about 14,100 tons in 2021. Industry 4.0 technologies can provide businesses with real-time data and analytics to help them monitor and enhance their sustainability performance. By making shipping and logistics processes more efficient, new technologies can help reduce emissions even more.

These indicators give a solid platform for analyzing the efficiency with which a company’s reverse logistics operations contribute to environmental sustainability.

## 4.3 Manufacturing Company of Electronical Products (C)

In high-volume industrial processes like electronic product recycling, the interviewee emphasizes the significance of automation and digitization. The interviewee also emphasizes the value of big data and analytics in determining CO2 emissions equivalent.

### *4.3.1 Industry 4.0 Technologies in Reverse Logistics*

The respondents to this interview bring up the topic of advanced robotics as an example of an Industry 4.0 technology that can be implemented in reverse logistics procedures. They remark that automation and digitization are needed for economically feasible high-volume production processes like electric components recycling. One example of this is the recycling of batteries. It would not be possible to achieve the requisite levels of efficiency that are required for profitability if these technologies were not available. Furthermore, the respondents name Cloud Computing, RFID, Big Data Analytics as well as AI as future application examples.

### *4.3.2 Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

The persons being interviewed highlights that utilizing Industry 4.0 technologies such as automation and digitalization can have major economic benefits for reverse logistics operations such as battery recycling by boosting efficiency and reducing costs. Specifically, the interviewee cites these two advantages. The application of Industry 4.0 technologies is viewed as a necessity rather than an option. The firm's scale of operations calls for automation and digitalization to maintain economic viability. In addition to this, they stress the environmental benefits of utilizing these technologies, such as a reduction in the amount of carbon dioxide emissions. The organization is committed to reducing carbon emissions and operates on 100% fossil-free energy. The use of big data analytics plays a crucial role in managing their complex supply chain and measuring CO2 emissions.

In addition, they point out that safety is an essential component of sustainability, and that sophisticated robots may make the working environment safer for people who are forced to engage in strenuous manual labor when dismantling operations are being carried out.

They also mention that societal advantages can be gained through the introduction of Industry 4.0 technologies by establishing new job opportunities related to the technology's upkeep and installation.

#### *4.3.3 Measurements of Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

Big data and analytics, according to the interviewees, are essential tools for assessing the social, economic, and environmental impacts of Industry 4.0 technologies used in reverse logistics procedures like recycling. Furthermore, the interviewees explain that certain KPIs are in place to measure the sustainability effects of these technologies in recycling.

The interviewees point out that estimating CO2 emissions equivalent is a challenging process that necessitates extensive data analysis but is necessary to comprehend how reverse logistics operations affect the environment. Furthermore, while quantifying the economic and social impacts of Industry 4.0 technology can be difficult, it is possible by looking at data on cost savings, employment growth, and worker safety.

The firm measures its sustainability impact across several parameters, with defined, measurable targets outlined in its sustainability report. For instance, a chief environmental goal is to reduce CO2 emissions by 75% of the CO2 equivalent emissions. Other targets include the percentage of female employees and the count of suppliers that have adhered to the code of conduct. Economically, there are internal figures and targets, but these are kept confidential. The company use a common expression "*walk the talk*" to pinpoint that the measurement of these impacts, especially CO2 emissions, is considered pivotal as it authenticates the company's central mission of manufacturing the greenest product in the world. The company believes that measuring these effects is necessary to fulfil their promises to stakeholders.

## 4.4 Manufacturing Company of Joining Technology (D) & Manufacturing Company of Network Products (E)

In this chapter the findings at company D and E are presented together as the data was gathered in a survey and not through interviews or group talks.

### *4.4.1 Industry 4.0 Technologies in Reverse Logistics*

According to the respondents both companies are using Industry 4.0 technologies in their reverse logistics. At company D recycling is present and the Industry 4.0 technologies IoT as well as Big Data Analytics are present. In accord with the respondent at company E, the reverse logistics types of repair and recondition are present at the company and the Industry 4.0 technology Big data Analytics is used there.

### *4.4.2 Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

When it comes to the economic, environmental and social effects of Industry 4.0 technologies in reverse logistics, the participated companies are using different definitions. While company D defines its sustainability according to all three pillars named before, company E defines its sustainability without the pillar of social, therefore company E sees no social effects of the usage of Industry 4.0 technologies in their reverse logistics.

For the economic effects, company D sees reduced costs, increased competitiveness, secured additional customers and/or markets and increased productivity. Company D sees reduced resource consumption, improved integration of capacity and demand, reduced energy consumption, reduced emissions and reduced waste as important environmental effects of Industry 4.0 technologies in reverse logistics. Higher workplace safety, Improved working conditions are important social effects that can be seen by company D.

Company E sees reduced costs and increased competitiveness as important economic effects of Industry 4.0 technologies in reverse logistics. Furthermore, reduced emissions and reduced waste are environmental effects that are considered by company E.

### *4.4.3 Measurements of Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

For the measurements of economic, environmental and social effects of Industry 4.0 technologies in reverse logistics company E is not measuring social effects, as this is not part of their sustainability definition.

Company D measures the economic effects of Industry 4.0 technologies in reverse logistics especially with the help of their recycling costs. The environmental effects are measured especially with the help of numbers of material usage, reduction in pollution levels, emission reduction, waste reduction and standards according to ISO 14001. Health issues are considered as a measurement for social effects.

According to company E, economic effects are especially measured with numbers of customer satisfaction as well as the return volume of their products. Environmental effects are measured by numbers of material usage and waste reduction in their reverse logistics.

An overview of the empirical findings can be seen in table 4 below. The findings are structured after the research questions and the companies studied.

## 4.5 Summary

| | | Company A (Mining Industry) | Company B (Construction Equpment) | Company C (Electronics Industry) | Company D (Fasteners Industry) | Company E (Communication Industry) |
|---|---|---|---|---|---|---|
| **Industry 4.0 Technologies** | CPS | ■ | ■ | ■ | | |
| | IoT | ■ | ■ | ■ | ■ | |
| | Big Data | ■ | ■ | ■ | ■ | ■ |
| | AI | ■ | ■ | ■ | | |
| **Economic effect** | Reduced costs | ■ | ■ | ■ | ■ | ■ |
| | Increased competitivness | | | | ■ | ■ |
| | Secure additional customers and/or markets | | | | ■ | |
| | Higher customization | | | | | |
| | Increased productivity | ■ | ■ | | ■ | |
| | Higher profits | | ■ | | | |
| | Shorter lead times | | | | | |
| | Higher efficiency | | | ■ | | |
| | Resource optimimaztion | | ■ | | | |
| **Environmental effects** | Reduced resource consumption | | | | ■ | |
| | Improved integration of capacity & demand | | | | ■ | |
| | Reduced energy consumption | ■ | ■ | | ■ | |
| | Reduced CO2 emissions | ■ | ■ | ■ | ■ | ■ |
| | Reduced waste | ■ | ■ | | ■ | ■ |
| | Reduced material use | | | | | |
| **Social effects** | Increased employment oppurtunities/Increased jobs | ■ | ■ | ■ | | |
| | Higher workplace safety | | ■ | ■ | ■ | |
| | Improved working conditions | | ■ | | ■ | |
| **Economic measurements** | Impovement on profitability rates | | | | | |
| | Revenue | | | | | |
| | Reduced costs | | ■ | ■ | | |
| | Customer satisfaction | | | | | ■ |
| | Recycling costs | | | | ■ | |
| | Return volume | | | | | ■ |
| | Transportation costs | | | | | |
| **Environmental measurements** | Energy levels | | | | | |
| | Material usage | | | | ■ | ■ |
| | Pollution levels | | | | ■ | |
| | CO2 emission | ■ | ■ | ■ | ■ | |
| | Waste | | | | ■ | ■ |
| | ISO 14001 | | | | ■ | |
| **Social measurements** | Safety | ■ | | ■ | | |
| | Health issues | | | | ■ | |
| | Professional development | | | | | |
| | Employment growth | | | ■ | | |

**Table 4:** *Summary of the Empirical Findings*

# 5. Analysis

In the following analysis the gathered empirical data is compared and connected to the theory to be able to answer the research questions of this thesis. At first a within case analysis is conducted with regards to the research questions which is then followed by a cross case analysis.

## 5.1 Engineering Company Rock Tools (A)

### *5.1.1 Industry 4.0 Technologies used in Reverse Logistics*

According to table 3 that can be found earlier in chapter 3.5.1 of this thesis, for the reverse logistics processes repair, recondition and recycling, especially the Industry 4.0 technologies IoT (Sun et al., 2022), Big Data Analytics (Shah et al., 2019; Sun et al., 2022) and AI (Wilson et al., 2022) are used. According to theory the Industry 4.0 technology AR is advantageous due to its potential to increase the effectiveness of the disassembly process (Chang et al., 2017). Additionally, for the process of reconditioning and recycling, the usage of CPS can enhance the sustainability of reverse logistics due to their real-time information exchange or the spread of green products (Sun et al., 2022). Furthermore, for recycling, where tracking is one of the most vital roles, Blockchain technology can help a lot to minimise problems with data transit and communication (Pournader et al., 2019).

When comparing this to the gathered empirical data at Company A, it can be seen, that many described technologies for the reverse logistics can be found. As this company is mainly focusing on repair and maintenance, they use most of their technologies in that part of reverse logistics. According to the strategy manager, the company is using an automated remote monitoring service for their equipment. With this system the equipment is constantly controlled by the company.

To be able to do this, the strategy manager describe the usage of a lot of sensors in the equipment which are connected to a central control system and share their data in real time. This description goes in line with the definition of a CPS done by Bauernhansl (2014) who describes CPS as systems that employ sensor technology to instantly collect their surroundings, evaluate it using data and services that are made available globally to finally store it. The connection to a central control system of these CPS used by the company can be described as an IoT application, as this goes in line with the definition of the IoT done by Gubbi et al. (2013, p. 1647) according to which the IoT is the "interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications."

As with this automated remote monitoring service a lot of different equipment or like analysed before, CPS, are connected to a central control system over the IoT, the data also fulfils the criteria of volume (due to the amount of equipment and sensors), velocity (real time connection to the monitoring system) and variety (a lot of different sensors in the equipment). This leads to the conclusion, that this automated remote monitoring system can also be seen as an application of Big Data Analytics, as it fulfils the criteria of volume, velocity and variety which are described by Sendler (2016) and also the usage of that data by an automated system is going in line with the definition of Hänisch (2017). Furthermore, the strategy manager describes the usage of algorithms which the data scientists of the company are writing and constantly improving. These algorithms can be seen as some sort of analytical AI as they handle unstructured data and are used in data analytics. Also, the algorithms do information processing, logical thinking and have mathematical abilities which are used in that automated remote system and furthermore fulfil the requirements of analytical AI described by Wilson et al. (2022). At last, the president describes the usage of AM in repair and maintenance especially local in the workshops at the mines where their equipment is used and can also be described as an application of CPS (Frazier, 2014; Pinkerton, 2016).

The only Industry 4.0 technology that was described earlier in this thesis and is not being used by the company in their repair and maintenance is AR. This technology would have the potential, according to Chang et al. (2019), to increase the effectiveness of the disassembly process. Due to the decentral position of the workshops from the company at the mines could be the reason for the lack of this technology.

When it comes to reconditioning, the company is mainly reconditioning drill bits which are using cemented carbide according to the president. This process is highly automated, and CPS are used within this process as part of the production environment.

Furthermore, the company is in an early test phase for the usage of AM in the reconditioning of the drill bits.

When it comes to recycling, the company normally mainly recycles the cemented carbide of the drill bits in the way of buying it back from the customers and using the material in the production for new drill bits. For other products the company normally sells the equipment to customers and therefore the recycling is part of the customers responsibility, but with the emergence of battery driven electric vehicles and the own production of batteries, the company starts to recycle the batteries as well. As this process is quite new many things when it comes to e.g., tracking, are done manually at the moment due to the low amounts of batteries. As the demand for batteries is raising, the company is planning to include sensors in the batteries to enhance the tracking possibilities and which would made them to CPS (Bauernhansl, 2014). Another Industry 4.0 technology that could be useful here is Blockchain technology due to its possibility to reduce communication and data transmission issues and furthermore, increase the speed of data confirmation (Karamchandani et al., 2021). Additionally, all participants of a supply chain would have access to the same data which would enhance trust and the possibility to audit the data of the company when it comes to recycling (Pournader et al., 2019).

### *5.1.2 Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

Of the Industry 4.0 technologies that Company A uses in its reverse logistics, they can identify economic, environmental and social effects. The technologies used can identify environmental effects such as reduced energy consumption, reduced carbon footprint through increased productivity, reduced transportation needs and reduced material waste. The President specifically mentions that additive manufacturing technologies reduce errors and provide more specific production, ensuring that unnecessary materials and energy are wasted. When Birkel & Müller (2021) anchor the environmental dimension with Industry 4.0 technologies, a better planned process is created resulting in reduced resource consumption. Javaid et al., (2022) also states that due to the higher efficiency Industry 4.0 technologies create compared to non-smart technologies, this leads to reduced energy consumption and reduced transportation costs and thereby reduced greenhouse gas emissions. Toktaş-Palut.,

(2022) confirms that Industry 4.0 technology reduces CO2 emissions, energy use with the addition of reduced waste leading to better environmental conditions.

The Strategy manager further explains how they extend the life of the customers' equipment when they can detect damage to the equipment at an early stage using the technologies (AI, IoT, Cloud & CPS) linked to remote maintenance. Preventive maintenance reduces equipment downtime and creates economic benefits, mainly for the customer, but the procedure also saves costs and contributes to a more efficient process. These are economic effects for the use of Industry 4.0 technologies as Bag & Pretorius (2022) suggest that the technologies create a more efficient work planning which saves costs and resources. Bai et al., (2020) argue that Industry 4.0 technologies provide increased customization as in the case of the Company A that through remote maintenance can help its customers achieve economic benefits to extend the life of its equipment. These customer cases also increase their own business opportunities by offering their reverse logistics solution (Agrawal, 2016). According to Presley et al., (2007), Company A's ability to offer reverse logistics services creates direct benefits such as increased profitability and improved reputation. The President also argues that Industry 4.0 technologies increase productivity, which is supported by Birkel & Müller (2021).

In mine workshops where additive manufacturing is present, the Strategy Manager mentioned that this locally creates the possibility of more jobs and employment for new and current employees in these areas which is a positive effect on social sustainability. This fits well with how Industry 4.0 technologies create new employment opportunities in social aspects and thanks to the technology, employee well-being and safety can be improved (Grybauskas et al., 2022; Sindhwani et al., 2022).

Overall, the company is working in many ways to reduce carbon emissions, but this cannot be directly identified as effects that Industry 4.0 technologies create in the reverse logistics process. The Strategy Manager explains that next to the customers' and mines' workshops, the company produces spare parts, which has reduced the company's carbon footprint as spare parts do not need to be transported to the workshops. At mines in India, solar energy is used, among other things, as a fuel for additive manufacturing, which reduces carbon emissions. The Strategy Manager says that the company is mainly looking at carbon emissions from a centralized perspective related to the Industry 4.0 technologies in reverse logistics. This is similar to what Moldan et al., (2012) defines as environmental sustainability, commitments companies make to counteract environmental change. In addition, as the President made the statement "*doing more with less*" when describing sustainability that sustainability and productivity go hand in hand which is in line with what Moldan et al., (2012) mean by economic sustainability where the environment provides the basis for shaping economic activity.

These statements are reflected by how the company interprets or generally works with sustainability, which tends to be described in environmental terms but also includes some economic aspects, e.g. when it's good for the environment, it will save money for the company. This, according to Javaid et al., (2022), suggests that the company takes responsibility for global health in the big picture by consciously acting on environmental behavior that benefits the organization's operations.

### *5.1.3 Measurements of Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

The Strategy Manager can currently see problems with how the Company A measures the economic, environmental and social effects of the Industry 4.0 technologies in reverse logistics and states that they do not measure these types of sustainability effects. The Strategy Manager continues that no automatic measurements are made of the data from remote maintenance systems and the algorithms they use within this system, which include economic, environmental and social effects. However, measurements of the impacts are made manually but are not a regular procedure due to the recycling of their own batteries being on such a small scale. According to Bag & Pretorius, (2022) utilizing the characteristics of Industry 4.0 technologies in smaller batches can result in a more accurate response to the demand curve, which prevents unnecessary waste. If Company A would apply this method, as Industry 4.0 technologies make a more precise demand visible, they can minimize the waste when recycling batteries. Elimination of waste is an environmental measurement for recycling performance (Ali et al., 2018). The Strategy Manager believes that there is an increased need for measurements of these effects in the future due to the introduction of stricter and tougher regulations in the future, which will increase the company's interest and importance.

The President at Company A describes how AI, Big Data analytics and Cloud services are technologies that collect data in the mines. These tools can analyse and create a better understanding of the performance of customer´s equipment that can increase the lifespan of their equipment and thereby offer a better service to their customers. This is in line with what Bai et al., (2020) argue is the ability of Industry 4.0 technologies to better adapt through better information and intelligence which will generate lower labour costs as an example. This is an economic metric that Company A could introduce to measure the economic effect created by Industry 4.0 technologies in their reverse logistics process. Furthermore, Banihashemi et al., (2019) states that when more attention and action is taken to defective products, companies will achieve higher customer loyalty. In addition, using this technology to help customers extend the life of their equipment will also affect a company´s reputation (Ali et al., 2018). According to Ahlström et al., (2020) is customer satisfaction a suitable KPI as an economic measure of these effects. This is another economic measurement that would fit into Company A´s context. Increased customer loyalty associated to a company´s reverse logistics services, such as remanufacturing, will also increase sales revenue (Banihashemi et al., 2019). When Company A focuses on achieving better service towards its customers, this can result in customers returning in more cases, which increases their sales revenue.

Other economic measurements that Company A doesn’t mention but could be relevant are measurements of lead time, material cost and productivity which are directly linked to the effects created by Industry 4.0 technologies (Bai et al., 2020). Economic performance could also be developed into measurements that refers to the reverse logistics process for Company A. Ahlström et al., (2020) mention KPIS such as total cost of repair or replacement, time taken from detection to defects to correction, collection cost or return and collection volume. This will give an understanding how the company optimally uses its resources, which is central to for economic sustainability (Moldan et al., 2012). This will help Company A achieve their interest in creating metrics for the effects of Industry 4.0 technologies in reverse logistics mentioned by the Strategy Manager earlier.

Regarding the environmental measurements, the President describes that steel and special carbide should be measured in the degree of circularity and proportions. What is measured is the total carbon dioxide emissions and how the emissions can be reduced with the help of these processes. Environmental performance measuring carbon emission is a common metric agreed upon by several studies (Banihashemi et al., 2019; Ali et al., 2018; Ahlström et al., 2020). There are several environmental measurements that could be used in Company A to measure the environmental effects of the Industry 4.0 technologies that were presented in 5.1.2 such as reduced energy consumption and material waste. In that case, Environmental Performance and Environmental KPIs measuring air and waste pollution, material use and energy use would be relevant for Company A to incorporate into their reverse logistics process (Banihashemi et al., 2019; Ahlström et al., 2020)

From the collected data, the Company A can also get information about machine failures, this helps the company to increase the work safety of its employees and can monitor the number of accidents as a parameter. These are examples of measurements of social aspects where safety and health issues are important dimensions (Banihashemi et al., 2019); Sarkis et al., 2010).

The fact that the different respondents in company A respond differently to how impacts are measured could be explained by their different areas of work and understanding of these issues. The President, who has overall responsibility, probably has a more detailed insight into the relevant process than the Strategy Manager. Why the President could provide different measures of the effects.

## 5.2 Manufacturing Company Construction Equipment (B)

### *5.2.1 Industry 4.0 Technologies used in Reverse Logistics*

Table 3 from chapter 3.5.1 of this thesis states that for the reverse logistics process of remanufacturing, particularly the Industry 4.0 technologies CPS, IoT (Sun et al., 2022), Big Data Analytics (Shah et al., 2019; Sun et al., 2022), AI (Wilson et al., 2022) as well as AR (Chang et al., 2019) are used. All these technologies offer a certain type of progress for the process of remanufacturing. IoT is laying the foundation for communication and exchange of data and as a result of their real-time information sharing or the dissemination of green products, CPS can improve the sustainability of reverse logistics (Sun et al., 2022). By employing Big Data Analytics to examine the data collected from the goods involved in reverse logistics, performance metrics and performance management systems are built (Shah et al., 2019). AI may be highly useful as analytical AI could be able to optimise and solve numerous difficulties (Wilson et al., 2022), while finally AR could be very helpful because it has the potential to improve the efficiency of human disassembly performed without the assistance of a professional (Chang et al., 2017).

As this paragraph above introduces the theoretical view of useful Industry 4.0 processes it is now compared and discussed with the gathered data of the interview with company B. The Remanufacturing Manager explains that the company is using mainly the same structure within their remanufacturing facilities as within their normal production facilities. Coming to that point, it means that the company is using a lot of automation and advanced robotics which goes in line with the definition of CPS given in the theoretical framework, as such advanced robotics and automation systems have networks of sensors and actuators, are connected to each other and therefore have a direct link between the physical and digital world (Broy, 2010).

Furthermore, company B is using the IoT according to the Remanufacturing Manager in their remanufacturing, as well as AI and Big Data Analytics. These three technologies go in line with the findings of the theoretical framework, that these Industry 4.0 technologies have a significant potential in remanufacturing as described before (Sun et al., 2022; Shah et al., 2019; Wilson et al., 2019).

The Industry 4.0 technology that is named in the theory as important for remanufacturing due to its potential to improve the efficiency of human disassembly performed without the assistance of a professional (Chang et al., 2017), but missing in the description of the Remanufacturing Manager, is AR. The reason for this could be the highly automated remanufacturing of the company or even a lack between theoretical findings and practical measures.

### *5.2.2 Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

The Remanufacturing Manager for company B can identify distinct environmental effects that CPS, IoT, AI & Big Data Analytics create in their reverse logistics. The Industry 4.0 technologies used in the remanufacturing of an engine saves material and energy consumption which in turn reduces overall carbon emissions. Remanufacturing as a reverse logistics activity is an environmentally friendly practice according to Presley et al., (2007). When companies integrate environmental aspects such as carbon reduction and resource use into their processes, the environment is preserved (Dabees et al., 2023; Ali et al., 2018). Furthermore, the Remanufacturing Manager states that thanks to the Industry 4.0 technologies used in remanufacturing, these environmental benefits are strengthened as these technologies increase productivity and thereby reduce waste. Oláh et al., (2020) argues that the use of Industry 4.0 technologies in reverse logistics reduces the use of materials, which highlights the environmental effects for companies. Sun et al., (2022) explains that IoT, AI and Big data analytics provide real-time information from service providers and customers, allowing companies to maximize their resource allocation. This means that Company B reduces its waste as Industry 4.0 technologies enable actual planning of resource needs.

In terms of the economic effects, the quotation "*good business for our customer, for the company, and for the environment*" made by the Remanufacturing Manager means that when a higher percentage of remanufactured parts can be used, the company gains more profits and increases the companies' profit margins. Increased profitability is a direct benefit that reverse logistics creates and is confirmed by Presley et al., (2007). In addition, their customers get a cost-effective alternative and can benefit from lower prices compared to new components. Presley et al., (2007) states that customer satisfaction is central from a reverse logistics perspective which will improve the company's reputation. Company C embraces sustainability in line with Moldan et al., (2012) that economic progress will be increasingly dependent on the sustainability of resources and the environment. The Remanufacturing Manager can also define higher productivity from the Industry 4.0 technologies, which is supported by Birkel & Müller (2021)

Company B can also see an enhanced economically sustainable model through the Industry 4.0 technologies present in their remanufacturing. The technologies optimize resources and reduce manufacturing costs. These economic effects in reverse logistics are similar to what Rajput & Singh (2021) consider that Industry 4.0 technologies maximize end-of-life products. Furthermore, Tseng et al. (2023) conclude that reverse logistics has the potential to lead to sustainable economic expansion.

The social effects mentioned by the Remanufacturing Manager from a reverse logistics perspective are that employees are provided with standardized working conditions at Company B around the world. Sun et al., (2022) points out how safety issues, working hours and working climate are social effects created by reverse logistics within the organization which can be equated to factors that regulate working conditions. The Remanufacturing Manager continues with how automation and AI-based Industry 4.0 technologies contribute to increasing worker safety and enable new career opportunities in robot maintenance and data analysis, which the respondent classifies as social effects. This is in line with how Grybauskas et al., (2022) argue that Industry 4.0 technologies will create new employment opportunities and an improvement in worker safety and well-being due to Industry 4.0 technological support. However, the new employment in the future will require a higher skill profile which may lead to class issues due to different opportunities for university education.

#### *5.2.3 Measurements of Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

When it comes to measurements of economic, environmental and social effects of the usage of Industry 4.0 technologies in reverse logistics, the Remanufacturing Manager explains, that the company has an own department which is specialized in the measurements of these sustainability effects overall at the company. The company is conducting these measurements especially focusing on environmental effects and is for example comparing transportation and production effects between new and remanufactured components, which is mostly done with the help of Big Data Analytics.

Another important measurement for the company relates to environmental and economic effects, namely the energy consumption. With the help of Big Data Analytics and AI the remanufacturing process is constantly evaluated which makes it possible for the company to find the flaws within remanufacturing that waste energy and optimise them. Additionally, the company measures how much of their material they can remanufacture with the help of these technologies and furthermore calculate the greenhouse gas emission savings of that.

The factors that the company uses to measure the environmental effects of its Industry 4.0 technologies go in line with the findings of the theory, which name especially the decrease in energy levels, material usage, and the reduction in pollution levels. Furthermore, especially the decrease in energy levels and material usage can be interpreted as an improvement on profitability rates and in that way as an economic measurement (Banihashemi et al., 2019). These figures can furthermore be seen as environmental KPIs which can be further evaluated and used as, for example benchmarks for external stakeholders (Ahlström et al., 2020).

## 5.3 Manufacturing Company of Electronical Products (C)

### *5.3.1 Industry 4.0 Technologies used in Reverse Logistics*

Company C is focusing only on recycling within their reverse logistics. According to table 3, which can be found in chapter 3.5.1 of the theoretical framework, especially the Industry 4.0 technologies CPS, IoT, Big Data Analytics as well as Blockchain Technology are important for recycling. CPS have the possibility to enhance the sustainability of reverse logistics, while the IoT ensures the communication and exchange of data between the CPS (Sun et al., 2022). Big Data Analytics help to develop performance metrics and management systems (Shah et al., 2019), while Blockchain Technology increases confidence amongst supply chain actors, which can reduce issues with data transportation and communication due to access to the same data, which is a central point in recycling (Pournader et al., 2019).

According to the interviewees at company C, the company right now mainly uses advanced robotics in their recycling process, which can be seen as a form of CPS, as they are characterized through embedded systems and the employment of sensor technology, to immediately assess their environment utilising data and services that are made readily available worldwide (Bauernhansl, 2014). Furthermore, the interviewees talk about Cloud Computing, RFID, Big Data Analytics as well as AI as future application examples. RFID can be seen as a form of sensor that can be used in devices to track them and exchange information without an external battery source. Cloud computing can be seen as a form of IoT, as it enables the connection between different CPS and further enables the information generation and transmission related to these technologies (Winkelhaus & Grosse, 2019).

The theory differs with the gathered empirical data of the interviewees with the technologies of AI, which is used by company D and Blockchain Technology, what the theory recommends using in recycling, according to Pournader et al., (2019). The reason that Blockchain technology is not used in practice could be, that it is very expensive to integrate due to its decentralized nature, where the blockchain needs to be stored, but also enables a very fast data confirmation with few data transmission issues (Dutta et al., 2020; Choi, 2020; Karamchandani et al., 2021).

#### *5.3.2 Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

The interviewees of company C mention economic effects such as increased efficiency and reduced costs in their recycling of batteries through the Industry 4.0 related technologies. Bag & Pretorius (2022) point out that the use of Industry 4.0 technologies contributes to efficient planning and execution of work which also saves money and costs. Similarly, Barreto et al. (2017) argue that thanks to the real-time information provided by Industry 4.0 technologies, companies can plan their operations more efficiently based on changing market demands.

The environmental impacts of the use of Industry 4.0 technologies are the reduction of carbon emissions. That Industry 4.0 technologies such as AI can contribute to finding solutions to environmental problems by, for example, neutralizing carbon emissions, is confirmed by Javaid et al. (2022).

The interviewees can identify several social effects that Industry 4.0 technologies create. Sophisticated robots can make the working environment safer for employees who are involved in manual and strenuous work when dismantling works in their recycling process. This goes in line with what several studies claim as social effects, the Industry 4.0 technologies reduce the human workforce in different professions and industries. The human resource can be used in decision making and problem solving instead of manual work (Grybauskas et al., 2022; Sindhwani et al., 2022). Other social impacts mentioned by the interviewees include societal benefits from the creation of new jobs related to the maintenance and installation of the technology. Although concerns can be identified in relation to the Industry 4.0 technologies as it constitutes being of technology-centric nature and the risk of harming human dignity and will, the technology increases employment opportunities which are social impacts at the societal level (Grybauskas et al., 2022; Sindhwani et al., 2022).

### *5.3.3 Measurements of Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

The interviewees at company C are explaining that when it comes to the measurements of economic, environmental & social effects of Industry 4.0 technologies in reverse logistics, they especially rely on Big Data Analytics to be able to calculate their greenhouse gas emissions. As mentioned by Ali et al., (2018) this decrease in emission levels and the generation of waste can also be used as indicators of recycling performance. Further, Banihashemi et al., (2019) are explaining that the measuring of different factors including decrease in energy levels, material usage, and reduction in pollution levels are very important, which can be seen as measured by Big Data Analytics as well at company C.

When it comes to economic aspects, theory names factors such as cost restrictions, decrease in stock investments, improvement on profitability rates, labour efficiency, and recovering value from items accessibility (Banihashemi et al., 2019). These targets are reached by company C through a highly automated recycling process as described before and therefore a high-volume recycling, which aims also to the reduction of recycling costs in total which is described by Ali et al. (2018). Overall data according to the steps is measured and constantly analysed. Additionally, the interviewees are explaining that the company has KPIs in place that measure different processes related to the recycling process which goes in line with the findings by Ahlström et al. (2020).

Banihashemi et al., (2019) as well as Sarkis et al., (2010) define social indicators that measure social aspects as safety, health issues, equity and accessibility. The interviewees also highlight the importance of health and work environments as well as work related safety that needs to be ensured and therefore measured without discriminating employees.

Overall, it can be seen that company C is measuring the economic, environmental and social effects of Industry 4.0 technologies in reverse logistics in line with the theory that was shown in this thesis. The measurements are done with the help of the analysis of big data that is tracking the needed factors and also certain KPIs that are enriched by this information. The only missing part that is named by theory would be customer loyalty (Banihashemi et al., 2019) but as company C only handles recycling to produce new products, this factor may not be suitable for the studied company.

Measuring $CO_2$ emissions is, after all, one of the most important metrics because through their expression "*walk the talk*" must demonstrate how central the environmental dimension is to the organization's business.

## 5.4 Manufacturing Company of Joining Technology (D) & Manufacturing Company of Network Products (E)

### *5.4.1 Industry 4.0 Technologies used in Reverse Logistics*

The results of the survey that the companies completed indicate that Industry 4.0 technologies are being implemented in reverse logistics of both companies, namely the technologies of Big Data Analytics and IoT. According to table 3, these technologies are important parts of Industry 4.0 technologies for the processes of repair, reconditioning and recycling, which are done by company D & E.

Company D, which is working within recycling is using Big Data Analytics as well as IoT, which can be seen as a foundation to share data and generate possibilities of communication between systems (Sun et al., 2022). The possibility to share data can further be used by Big Data Analytics which assesses the data obtained and gives the possibility to develop performance metrics as well as performance management systems (Shah et al., 2019).  In other words, these technological advancements make it possible for businesses to optimize their operations by collecting and analyzing vast volumes of data from a variety of sources, including sensors, machines, and input from customers. Within recycling the Industry 4.0 technology of CPS might be an advancement for the company due to the enhancement of sustainability and the real-time information exchange (Sun et al., 2022). Blockchain technology could be an advancement to, as it minimises problems with data transit and communication and enhances the trust between the participants in a supply chain through access to the same data (Pournader et al., 2019).

Company E which is working with the reverse logistics processes of repair and recondition. The company is namely working with the Industry 4.0 technology of Big Data Analytics which differs with the theory that is presented in table 3. Big Data Analytics gives the possibility to develop performance metrics as well as performance management systems (Shah et al., 2019) and is therefore very useful in reverse logistics. As shown in the text above also for repair and reconditioning, the Industry

4.0 technologies of CPS and IoT have the possibilities for advancement in that processes (Sun et al., 2022). But within repair and recondition also AI gives the possibility to optimize the collected data in a more efficient way (Wilson et al., 2022), while AR might be very advantageous in repair due to its potential to increase the effectiveness of the disassembly process carried out by a human operator without the aid of a professional (Chang et al., 2017).

#### *5.4.2 Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

Company D can identify economic, environmental and social effects created by IoT, Big Data Analytics and AI technologies in the company's recycling process. The environmental effects are how Industry 4.0 technologies reduce resource, consumption, energy consumption, emissions, waste and improved integration between capacity and demand. Sun et al., (2022) state that technologies such as IoT, AI and Big Data have the ability to provide information in real time which helps the company to improve its planning of activities and use of resources. With a better planned process that Industry 4.0 creates, the integration of capacity and demand can be improved which reduces the resource consumption in companies. Due to the higher efficiency of Industry 4.0 technologists, this leads to lower energy consumption, reduced waste and emissions (Toktaş-Palut, 2022; Javaid et al., 2022).

The economic effects that Company D mention are reduced costs, increased competitiveness, increased productivity and secured additional customers and markets. Based on the increased efficiency Industry 4.0 technologies create, costs can be reduced (Bag & Pretorius, 2022). Bait et al., (2020) develop and argue that the improved communication, information and intelligence that Industry 4.0 technologies provide will reduce both labor and material costs and increase productivity. Since Company D offers recycling, a dedication to defective products is reflected which means that the customer loyalty will increase (Banihashemi et al., 2019). With the help of Industry 4.0 technologies in reverse logistics, data analysis can find areas of improvement (Barreto et al., 2017; Rajput & Singh, 2021). This enables Company D to secure additional customers and markets.

Higher workplace safety and improved working conditions are the two social effects Company D can identify of using IoT, Big Data Analytics and AI in their recycling process. Industry 4.0 technologies have both increased employment opportunities and job security (Grybauskas et al., 2022; Sindhwani et al., 2022). The new jobs improve the safety and well-being of the employees due to the new conditions created by the Industry 4.0 technology (Grybauskas et al., 2022).

Company E can only see environmental and economic effects created by Big Data Analytics in their repair and recondition activities. Company E's identified environmental effects are reduced emissions and waste. Hänisch (2017) means that Big Data primarily collects and analyzes data that can be used to improve efficiency. Javaid et al., (2022) emphasize that thanks to the increased efficiency, emissions can be reduced. Toktaş-Palut, (2022) confirms how Industry 4.0 technologies lead to improved environmental conditions through reduced emissions and less waste.

The economic effects Company E can identify are reduced costs and increased competitiveness. Rajput & Singh, (2021) and Barreto et al., (2017) argues that the data-driven analysis can quantify and assess cost reduction. The advanced analytics can speed up and improve the processing of returned products which will reduce customer responsiveness (Barreto et al., 2017). This means that the repair and recondition activities that Company E offers its customers will create advantages such as improved reputation against competitors that don't offer a reverse logistics solution (Presley et al., 2007). Why Company E increases its competitiveness.

Company E can't define any social effects of their use of Big Data Analytics in their repair and recondition activities. Varriale et al., (2023) describes how the data provide from Industry 4.0 technologies can be used to develop policies and regulations that support, for example, social responsibility or diversity. This would be a way for Company E to use the information given by Big Data for them to also embrace the social effects in the process of reverse logistics. Varriale et al., (2023) continues and highlights that the data can be used to develop instructional programs that help staff get used to new technology, which would be a suitable adoption for Company E.

#### *5.4.3 Measurements of Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

Company D finds economic, environmental and social measurements for the effects created by Industry 4.0 technologies in their process of recycling. The economic effects are measured through the recycling costs. This is in line with how Ali et al.,

(2018) means that products being recycling, disassembling and disposing are linked to expenses that affect the organization's financial accounts. The environmental measurements being used by Company D are material usage, reduction in pollution levels, emission reduction, waste reduction and by ISO 14001. Toktaş-Palut, (2022) states that Industry 4.0 will improve certain environmental circumstances including less waste, reduction of emissions and reduction in pollution levels which is also supported by Ali et al. (2018) and Banihashemi et al., (2019). In addition, Ahlström et al., (2020) highlights how ISO 14001 is a separate tool for the company to report waste reduction and pollution reduction.

For the social effects Company D measures health issues. Work climate is a social effect created by the reverse logistics (Sun, et al., 2022). Motivation can increase among employees as Industry 4.0 technologies provide opportunities for adaptation to new technologies, which in turn improves the working environment (Akanmu et al., 2022).

Company E measures the economic effects in terms of customer satisfaction and return volume created by Big Data in their reverse logistic process. Ahlström et al., (2020) specifies both return volume and customer satisfaction as KPIs related measures within reverse logistics. By handling defective products, as Company E repair and recondition, will increase customer loyalty (Banihashemi et al., 2019). Measurements related to the environmental effects that Company E use are material usage and waste reduction. Decreasing waste is a recycling performance (Ali et al., 2018). The environmental performance can also include material usage recording too (Banihashemi et al., 2019).

As Company D didn't identify any social effects by Big Data in their reverse logistics process, they are not able to measure the social aspects either.

## 5.5 Comparison Companies A, B, C, D & E & Summary

This following part closes the analysis chapter of this thesis. The findings at the companies are analysed and compared together. The understanding we create will form the basis of our conclusion.

*5.5.1 Industry 4.0 Technologies used in Reverse Logistics*

As can be seen in table 4 in chapter 4.5 the most commonly used Industry 4.0 technologies by many of the studied companies are CPS, IoT, AI & Big Data Analytics. This goes in line with the findings in theory where it can be seen, that especially IoT and Big Data Analytics can be employed in all stages of reverse logistics (Sun et al., 2022; Shah et al., 2019) and the technologies of CPS and AI are also quite universal usable (Sun et al., 2022; Wilson et al., 2022).

While AR offers potentials for repair, recondition and remanufacturing (Wang et al., 2022), it is not used from neither company A or B which are working with these processes, which leads to the conclusion, that this technology is not as widespread as it is seen by theory. Another technology that is not just as much as seen by the theory is AM. Company A is using AM in their repair and maintenance for its on-demand part manufacture and therefore potential of cost savings (Frazier, 2014) as the transportation costs are much lower, when the parts can be produced directly at their mines. Company B which is working with remanufacturing could use CPS in the form of AM as well according to Hashemi et al. (2016), but is not doing it right now. Also, company A is implementing AM technology right now in a test phase, which could be a sign for the still improving process capabilities of AM (Pinkerton, 2016) that they are right now not fulfilling all company requirements. But nonetheless, company A sees higher efficiency, shorter lead times, and lower supply chain costs, as well as more flexibility in component design and customization with AM compared to conventional manufacturing of spare parts as it is seen by Thomas (2015).

Which technology is missing in all companies is Blockchain technology. It could be usable for especially company C & D, which are working with recycling, as this technology has the possibility to reduce communication as well as data transmission issues (Karamchandani et al., 2021) and therefore could enhance trust along the supply chain of the companies. But still Blockchain technology is not well known along the companies but there are also unclear laws and regulations surrounding that technology and potential high costs of operating and implementation of such a system (Dutta et al., 2020).

To finally answer the first research question of this thesis "*What Industry 4.0 technologies are relevant for a manufacturing company's reverse logistics* *processes?"* it can be seen that our empirical data and theory shows that this differs from which part of reverse logistics is done by a company. Most common are the technologies of CPS, IoT, Big Data Analytics as well as the usage of AI in theory as well as in practise (Sun et al., 2022; Shah et al., 2019 & Wilson et al., 2022). No practical evidence was found in this thesis concerning the usage of Blockchain technology and AR in reverse logistics.

### *5.5.2 Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

All companies except Company E have been able to identify all three economic, environmental and social effects that Industry 4.0 technologies have created in their reverse logistics processes. Company E could not indicate any social effects through the use of Big Data Analytics in their repair and reconditioning activities.

When it comes to the economic effects, there is an even distribution as some of the company can see that Industry 4.0 technologies increase efficiency and reduce costs. The Industry 4.0 technologies provide efficient planning and execution of work which saves costs (Bag & Pretorius, 2022). Company D & E mentions that increased competitiveness occurs as an economic effect, where Company D is the only one that can identify additional customers and markets. Reverse logistics solutions improve reputation which increases the competitiveness of companies (Presley et al., 2007). To secure additional markets and customers can be made through the data Industry 4.0 technologies provide that will help companies to find areas of improvement (Barreto et al., 2017; Rajput & Singh, 2021). In addition to these effects, increased productivity, higher profits and higher customer satisfaction are also mentioned. The improved communications, information and intelligence Industry 4.0 provides will increase the productivity (Bait et al., 2020). The reverse logistics activities create the benefit of increased profitability for a company, where customer satisfaction is a contributing factor due to the improved reputation it creates (Presley et al., 2007).

The environmental effects that all the companies were able to distinguish through Industry 4.0 technology are the reduction of CO2 emissions. All companies except Company C could see that Industry 4.0 technologies minimize waste in their reverse logistics activities. That the Industry 4.0 technologies reduce emissions, and less waste is confirmed by several studies (Toktaş-Palut, 2022; Ali et al., 2018; Banihashemi et al., 2019; Javaid et al., 2022). Company C differs in the way that they were the only ones who could identify minimizing carbon emissions as the only environmental effect. Otherwise, reduced energy consumption and reduction of resource emerged as other mentioned effects. Due to the higher efficiency of Industry 4.0 technologies, this leads to lower energy consumption and the real-time data the technologies presents will allow companies to maximize their resource allocation (Toktaş-Palut, 2022; Javaid et al., 2022; Sun et al., 2022).

As mentioned before, company E cannot identify any social effects related to Industry 4.0 technologies. However, companies B, C, & D state that employees' safety is increased thanks to this technology. The creation of new jobs is also a social effect as stated by companies A, B & C. Industry 4.0 technologies have both increased employment opportunities and job security (Grybauskas et al., 2022; Sindhwani et al., 2022). Other social effects mentioned by the companies are improved working conditions. Sun et al., (2022) argues that safety issues, working hours and working climate are social effects which can be equated with factors regulating working conditions.

The empirical material together with the theory shows that Industry 4.0 technologies create economic, environmental and social impacts in different activities of reverse logistics which is related to the second research question of the study, *"What are the economic, environmental, and social effects of Industry 4.0 technologies in reverse logistics?"*.

#### *5.5.3 Measurements of Economic, Environmental & Social Effects of Industry 4.0 Technologies in Reverse Logistics*

When it comes to measurements of economic, environmental and social effects of Industry 4.0 technologies in reverse logistics, the situation is different at the studied companies. All companies are measuring at least some of their effects, but it is not comprehensive at all. Environmental effects are measured by all companies, but when it comes to measurements for economic and social effects, this differs a lot between the companies.

When it comes to the measurements of the economic effects, it can be seen, that company A is not measuring these effects at all in reverse logistics, while company B & C are explaining that they are measuring the economic effects of Industry 4.0 technologies in reverse logistics with the help of cost reduction they can generate. Company D measures these effects especially with recycling costs while company E focuses on the measurements of customer satisfaction and return volume. Measurements of cost reduction are a common way to measure the economic effects, especially the improvement on profitability rates or labor efficiency are good economic performance measurements (Banihashemi et al., 2019). As company D is applying recycling as their reverse logistics, the measurements of their recycling costs are connected to expenses that influence the organization's financial account through the establishment of product return activities such as recovering, disassembling, and disposing of products (Ali et al., 2018). According to Ali et al., (2018) return volume is also a suitable economical measurement, as used by company E, additionally to customer satisfaction as a common KPI within reverse logistics (Ahlström et al., 2020). All in all, it can be seen that the studied companies see the importance of measurements of the economic effects of Industry 4.0 technologies in reverse logistics and also the companies that don't study them now see the importance to focus more on these measurements in the future according to the empirical data.

Regarding the measurements of the environmental effects of using Industry 4.0 technologies in reverse logistics it can be seen that all studied companies apply measurements for those effects. Most common here are measurements regarding emission reduction which are used by company A-D but also measurements for waste reduction and material usage, that are connected to these and used by companies D & E. Environmental performance measuring air pollution, emission reduction, material usage as well as waste reduction are common metrics agreed upon by several studies (Banihashemi et al., 2019; Ali et al., 2018; Ahlström et al., 2020). The measurements regarding the environmental performance are the most common measurements at the studied companies, as there is also the highest request from customers as well as state laws and certifications according to the empirical data.

Measurements regarding social effects of Industry 4.0 technologies in reverse logistics are the least commonly used measurement at the studied companies. Companies A-D can see social effects of the usage of Industry 4.0 technologies in reverse logistics and company E cannot identify such and therefore has no measurements for them in place. But also from the companies which can identify these effects, just company C and D have measurements for them at place. Both companies have measurements regarding work safety and health issues in place and company C is additionally measuring the employment opportunities provided by the usage of Industry 4.0 technologies in reverse logistics. These measurements are also found by literature, as shown by Banihashemi et al., (2019) & Sarkis et al., (2010), which highlight safety and health issues as suitable measurements. Additionally, they name equity and accessibility as suitable measurements, but these are not further considered by the companies (Banihashemi et al., 2019; Sarkis et al., 2010). Furthermore, employment opportunities are also seen as a suitable dimension for measuring these effects (Banihashemi et al., 2019; Ramos et al., 2014). To sum up, the measurements of social effects are the part that needs to be more focused on in the future, especially also through the fact that the effects of Industry 4.0 technologies may not just be positive on social points as of the technology-centric nature of Industry 4.0 as shown by the literature (Grybauskas et al., 2022; Sindhwani et al., 2022).

As a result, in order to respond to the third research question of this thesis, which is "*How are the economic, environmental, and social effects of Industry 4.0 technologies in reverse logistics measured?*" the empirical data and existing literature demonstrate that the companies are especially measuring with the help of cost reduction, when it comes to economic effects, emission reduction when it comes to environmental effects and work safety when it comes to social sustainability. These differences in measurement aspects are a reflection of the unique priorities and goals of every firm and the measurements for social sustainability are not common under all studied companies so there is a need to focus especially on these measurements to.

| | Summary |
|---|---|
| **Industry 4.0 technologies used in Reverse Logistics** | - CPS<br>- IoT<br>- Big Data Analytics<br>- AI |
| **Economic effects** | - Reduced costs<br>- Increased efficiency<br>- Increased productivity<br>- Increased competitiveness |
| **Environmental effects** | - Reduced CO2 emissions<br>- Reduced waste<br>- Reduced resource consumption<br>- Reduced energy use |
| **Social effects** | - New employment opportunities<br>- Enhanced workplace safety<br>- Enhanced workplace conditions |
| **Economic measurements** | - Cost reduction |
| **Environmental measurements** | - Emission reduction |
| **Social measurements** | - Work safety |

**Table 5:** *Summary of Analysis Findings*

In table 5 above the summarized findings of the analysis can be seen.

Finally, based on the three different methodologies used to collect the empirical data from companies, we can see some differences in the results. For example, Companies D & E were able to provide several and precise measurements of the effects compared to the remaining companies, which may be due to the fact that the empirical data is collected through surveys where the respondents are given several answer options to choose from and which therefore helps the respondents to more easily identify and state their answer.

Company C also stands out among the companies where the empirics result in the three research questions were content-rich and uniform, which can be explained by the focus group as the methodology-approach, as the respondents can reason and discuss the assigned questions together.

Based on the different method choices, we also experienced that the empirical results between the respondents from Company A differed in relation to one of the research questions. The two respondents within the company have different areas of work, so they reasoned differently. This situation did not occur with Company B, as only one person was interviewed at the company.

# 6. Conclusions

Based on the analysis, in this concluding chapter we will answer the study's research questions, which were stated in Chapter 1. Thereby we fulfil the purpose of the study. We also provide theoretical and practical contributions, limitations and suggestions for further future research.

**What Industry 4.0 technologies are relevant for a manufacturing company's reverse logistics processes?**

According to the study's findings and previous research (Sun et al., 2022; Shah et al., 2019; Wilson et al., 2022) the most often used Industry 4.0 technologies in reverse logistics processes among the questioned firms are CPS, IoT, AI, and Big Data Analytics. It is discovered that these technologies can enhance workflows and increase productivity in reverse logistics operations. We could not identify an adoption of AR and Blockchain technologies among the businesses under investigation, however, that shows these technologies are either still in their early stages or are facing some difficulties like regulatory uncertainty and implementation costs.

**What are the economic, environmental and social effects of using Industry 4.0 technologies in a manufacturing company's reverse logistics?**

The study finds outcomes regarding the economic, environmental, and social effects of using Industry 4.0 technologies in reverse logistics. From an economic standpoint, the use of these technologies has facilitated cost reduction, heightened competitiveness, and enhanced productivity for the companies that go in line with previous research (Sun et al., 2022; Bag & Pretorius, 2022; Bait et al., 2020). The integration of Industry 4.0 technologies yields favourable outcomes for the environment through the reduction of emissions, waste minimization, and optimization of resource efficiency. (Toktaş-Palut, 2022; Javaid et al., 2022). They contribute to the improvement of workplace safety, new employment opportunities and working conditions from a social perspective (Banihashemi et al., 2019). However, it is essential for corporations to take into account and tackle the possible adverse societal ramifications of these technological advancements.

**How can the economic, environmental and social effects of using Industry 4.0 technologies in the reverse logistics be measured?**

Currently, companies have not yet fully developed their measurements of the economic, environmental, and social effects. Primarily, it can be observed that firms are quantifying the decrease in expenses resulting from the usage of Industry 4.0 technologies in reverse logistics, the mitigation of emissions to address environmental effects, and the enhancement of workplace safety to promote the social effects. Additionally, it can be observed that corporations are primarily prioritizing the measurement of environmental effects. Although the measurement of social effects is an area that requires further development, it is noteworthy that not all studied companies have implemented a system to measure these effects.

### Theoretical contribution

Based on the three studies conducted by Birkel & Müller (2021), Krstić et al., (2022) & Maheswari et al., (2020), this research has combined these findings to fill a research gap. Krstić et al. (2022) present the most applicable Industry 4.0 technologies IoT and Cloud Services in the process of reverse logistics. These technologies have a significant effect on reverse logistics because physical real-time and data networks are connected, which is the common characteristic of all Industry 4.0 technologies. Effects in economic, environmental and social terms are linked to Industry 4.0 technologies by Birkel & Müller, (2021). Increased competitiveness, productivity and revenue are economic effects. Reduced resource consumption is identified as environmental effects. Reduced monotonous and unsafe work tasks are social impacts of bringing the virtual and physical world together. Maheswari et al., (2020) develop performance measures in reverse logistics. Economic measures include profit on returned products.

Reduced waste is an environmental metric and job opportunities are a social measurement.

Meaning that this research contributes economic, environmental and social effects and measurements derived from both reverse logistics and Industry 4.0 technologies, as can be seen in figure 11 below.

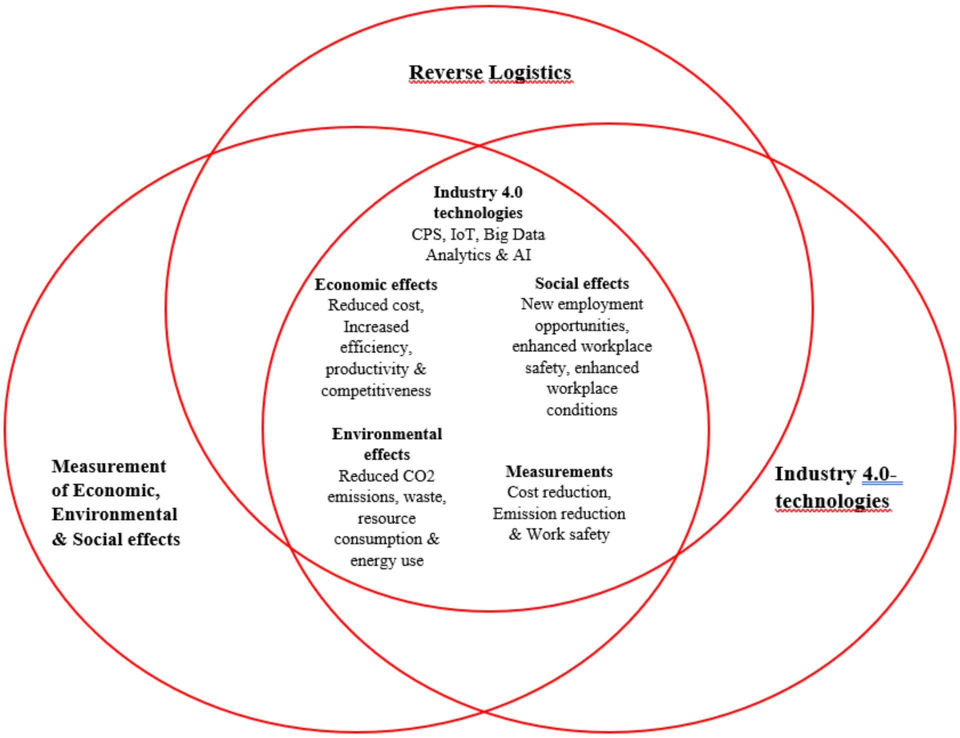


**Figure 11:** *Conclusion Theoretical Contribution*

### Practical contribution

The main results of the study show the effects of Industry 4.0 technologies in the reverse logistic process, broken down by economic, environmental and social dimensions and how these effects are measured. This can help companies to interpret and identify the implications that Industry 4.0 technologies provide in these three sustainable terms in their reverse logistics. In order to later apply measurement to discern its impact on the business as a whole.

### Limitations and Suggestions for Future Research

As this thesis focused especially on Swedish and German manufacturing companies, it needs to be checked, if the findings are generalizable also in other industry sectors that use reverse logistics. With the focus on European companies, it would be interesting to expand the findings with viewpoints from companies outside of Europe, for example American or Asian companies. Also, this thesis shows mainly a state-of-the-art overview, as Industry 4.0 is a topic that still spreads out. Here, further studies with longitudinal time horizons would help to see how the future development and spreading of these technologies unfolds as well as if and how the effects and measurements will change over time. Furthermore, this thesis was designed as a multiple method qualitative study, so it would be interesting to study the topic with a quantitative methodological approach to see if other conclusions can be drawn or the current ones can be expanded.

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# Appendix

## A: Interview Guide

**RQ1:**

1. What type of reverse logistics are present in your company (recycle, refurbishing, remanufacturing etc)?
2. Does your company use Industry 4.0-technologies in these reverse logistics?
3. What type of Industry 4.0 Technologies are in use in your company?
4. Are you planning to implement additional Industry 4.0 technologies in the future?

**RQ2:**

5. How do you define sustainability at your company?
6. Can you identify social, economic, and environmental effects of using Industry 4.0 technologies in reverse logistics?
7. Can you identify different effects of the different Industry 4.0 technologies in your reverse logistics?

**RQ3:**

8. Do you measure the economic, social, and environmental effects that Industry 4.0 technologies are creating?
9. How do you measure the effects?

10. What metrics or indicators do you think are most useful for measuring the social, economic, and environmental effects of using Industry 4.0 technologies in reverse logistics, and why?
11. Do you have some standardized procedure on how to analyse the output of measuring for example, comparing to a target? Do you provide feedback to those involved and discuss corrective actions?

## B: Survey

**RQ1:**

**Reverse Logistics**

1.) What type of reverse logistics are present in your company?
   a. Repair
   b. Recondition
   c. Remanufacture
   d. Recycle
   e. Disposal of waste
   f. Other (please specify)
   g. None

**Industry 4.0 Technologies**

2.) Do you use any of these industry 4.0 technologies in your reverse logistics?
   a. Cobots
   b. Additive manufacturing
   c. Internet of Things
   d. Big data Analytics
   e. Artificial Intelligence
   f. Augmented Reality
   g. Blockchain Technology
   h. Digital Twins
   i. Other (please specify)
   j. None

3.) What type of industry 4.0 technology are you using in your company in general?
   a. Cobots
   b. Additive manufacturing
   c. Internet of Things
   d. Bid Data Analytics
   e. Artificial Intelligence
   f. Augmented Reality
   g. Blockchain Technology
   h. Digital Twins
   i. Other (please specify)

j. None

**RQ2:**
**Sustainability**

The term sustainability has many different interpretations. In the options below, environmental aspects aim to preserve the environment and can be emissions of greenhouse gases, harmful substances, resource use and other activities that have a positive impact on the environment. Economic aspects refer to continuous and profitable growth through environmentally friendly methods. Social sustainability is management of resources within the organization such as increasing equality, diversity or safety. There is an open proposal for those of you who have your own interpretations. It is possible to choose several options.

4.) How do you define sustainability in your company? (Selecting multiple choices possible)
   a. Environmental aspects
   b. Economical aspects
   c. Social aspects
   d. Other (please specify)

**The environmental, economic and social effects of using Industry 4.0**
The consequences that industry 4.0 technologies create are many. The next three questions deal with three different types of effects, environmental, economic and social.

5.) What environmental effects of using Industry 4.0 technologies can be identified in your company?
   a. Reduced resource consumption
   b. Improved integration of capacity and demand
   c. Reduced energy consumption
   d. Reduced emissions
   e. Reduced waste
   f. None
   g. Other (specify)
6.) What economic effects of using Industry 4.0 technologies can be identified in your company?
   a. Reduced costs
   b. Increased competitiveness
   c. Secure additional customers and/or markets
   d. Higher customization
   e. Increased productivity
   f. Increased revenues
   g. Shorter lead times
   h. None
   i. Other (specify)
7.) What social effects of using Industry 4.0 technology can be identify in your company?
   a. Increased employment opportunities
   b. Higher workplace safety
   c. Improved working conditions
   d. Better infrastructure

e. Higher level of competence or skill requirements (skill mismatch)
f. Smaller available workforce due to specialized knowledge/skills/education?
g. None
h. Others (specify)

RQ3:
**Measurements of environmental, economic and social effects**

The next three questions deal with the measurements of the different sustainability effects that were asked about before.

8.) How do you measure the economic effects that Industry 4.0 technologies are creating?
   a. Improvement on profitability rates
   b. Revenue
   c. Labor cost
   d. Customer satisfaction
   e. Recyling costs
   f. Return volume
   g. Collection volume
   h. None
   i. Others (specify)
9.) How do you measure the environmental effects that Industry 4.0 technologies are creating?
   a. Energy levels
   b. Material usage
   c. Reduction in pollution levels
   d. Emission reduction
   e. Waste reduction
   f. Elimination of toxic materials
   g. Recycling performance
   h. Environmental performance
   i. ISO 14001
   j. None
   k. Others (specify)
10.) How do you measure the social effect that Industry 4.0 technologies are creating?
   a. Safety
   b. Health issues
   c. Professional development
   d. Employment opportunities
   e. None
   f. Others (specify)