“TECHNOLOGY INTEGRATED GREEN LOGISTICS”

Ninad Killedar

(12775008)

Module Leader:

Mr. Owen Richards

Thesis Supervisor:

Mr. Cyrus Fardaghaie

Aug 2023

Coventry University

Declaration of Originality

This project is all my own work and has not been copied in part or in whole from any other source except where duly acknowledged. As such, all use of previously published work (from books, journals, magazines, internet, etc) has been acknowledged within the main report to an item in the References or Bibliography lists.

I also agree that an electronic copy of this project may be stored and used for the purposes of plagiarism prevention and detection.

Copyright Acknowledgement

I acknowledge that the copyright of this project and report belongs to Coventry University.

Signed: *Ninad Killedar* Date: *07/08/2023*

ABSTRACT

The dissertation examines the integration of Industry 4.0 technologies and sustainable logistics practices in the context of environmental degradation, resource shortages, and global warming. Due to the substantial contribution of the logistics industry to greenhouse gas emissions, businesses face increasing pressure to adopt environmentally friendly practices and utilize emerging technologies for a more sustainable and environmentally responsible supply chain. This research thesis emphasizes the importance of green logistics and Industry 4.0 technologies, both individually and in their integration. The study highlights the advantages of incorporating technology, including lower emissions, cost savings, waste reduction, and improved customer satisfaction. The review highlights Industry 4.0 technologies, including AI, big data, blockchain, IoT, and automation, as potential drivers for the transformation of green logistics practices. The research seeks to evaluate the impact of technology integration and its alignment with the United Nations' Sustainable Development Goals. It also aims to analyze the challenges and opportunities in adopting the integrated framework. This study employs an interpretivism research philosophy and qualitative research methods to analyze real-world case studies of two prominent logistics companies, DHL and Ocado Group. The case studies offer specific instances of effectively implementing Industry 4.0 technologies in green logistics. They focus on overcoming last-mile delivery obstacles, enhancing warehousing procedures, and increasing efficiency in reverse logistics. The dissertation addresses the gap among theory and practice by offering valuable insights for businesses aiming to improve their sustainability practices through technology integration. The findings provide a comprehensive understanding of the potential benefits and challenges of adopting the integrated framework, contributing to further advancements in sustainable logistics. The dissertation highlights the importance of businesses adopting technology in green logistics to attain sustainability objectives and reduce environmental effects. Companies can improve transparency, traceability, and circular economy principles, as well as address last-mile challenges and contribute to global sustainability goals by utilizing Industry 4.0 technologies. This research establishes a basis for future studies and provides stakeholders with insights into the transformative possibilities of green logistics in the Industry 4.0 era.

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to all those who have contributed to the successful completion of my dissertation on "Technology Integrated Green Logistics," which was conducted as part of Module Code 7030MAA - Individual Project. I express my gratitude to my module leader, Mr. Owen Richards, and my supervisor, Mr. Cyrus Fardaghaie, for their precious guidance and support during my research. Their professional expertise and constructive feedback significantly influenced the course and focus of this research thesis. I express my gratitude to the teaching and administrative staff of Coventry University for creating an academic environment and providing the necessary resources to undertake this research. I am grateful to lecturers and instructors who have deepened my comprehension and knowledge in the field of green logistics and technology integration. I am grateful to my friends for their consistent support and camaraderie. Their support during difficult periods has served as a motivating factor that helped me maintain my focus on the research goals. Finally, I would like to express my gratitude to my family for their unwavering affection, encouragement, and understanding during this endeavor.

CHAPTER-1 INTRODUCTION

1.1 Introduction to research field

Businesses must implement structural and operational changes to become more environmentally friendly in response to growing public concern over environmental degradation, shortages of resources, and global warming. Businesses are under rising demands to mitigate the unfavorable environmental effects caused by logistics operations in order to make them sustainable in consideration of the growing number of sustainability issues around the world. Currently, projections estimate road freight's proportion of CO_2 emissions from worldwide trade-related transport at 53%; by 2050, that number is projected to climb to 56%. About one-fifth of all man made greenhouse gas emissions come from the logistics industry. Even without significant attempts at mitigation, the International Transport Forum (ITF) predicts a further 60% increase in worldwide emissions from the logistics sector until 2050. As an outcome of the government's and society's increased concern about guaranteeing a sustainable environment, logistics businesses are under pressure to lessen the detrimental effects of their business practices on the environment.

While there has been research looking at how the logistics industry would be affected by Industry 4.0 and how logistics would affect the environment but not much attention has been paid to how the two may function together. While there has been progress in connecting Industry 4.0 and green logistics, more study is needed to determine the best methods for doing so, the extent to which adopting the framework will help achieve the Sustainable Development Goals set by the United Nations, the ESG (Environmental, Social, and Governance) obstacles in the way, and the key performance indicators (KPIs) that will be used to evaluate success.

1.1.1 Potential of technology integrated green logistics framework.

Green logistics aims to minimize the negative environmental and energy impact of freight distribution. It encompasses various activities such as material handling, waste management, packaging, and transport. Its main objective is to efficiently manage the movement of goods and data between the point of origin and the point of consumption while considering ecological factors. (Seroka-Stolka, 2014). The fourth industrial revolution introduces Industry 4.0 technologies that can convert traditional supply chain solutions into cyber-physical supply chain solutions. This shift enables improvements in the effectiveness, accessibility, quality, and cost-effectiveness of the value chain, while also reducing energy consumption and greenhouse gas emissions. (Bányai & Zaher Akkad, 2021). Industry 4.0 emphasizes the integration of Internet-based communication technologies, technological advancement, and intelligent manufacturing technologies to create smart machinery, processes, systems, and products. Industry 4.0 technologies enable a smart production network that enables monitoring in real-time, responsive communications, autonomous processes, and smooth material flows. Technological progress has created opportunities for value creation and proposition through individualized modifications and service innovations in novel business models. (Sun et al., 2021)

1.1.2 Research Aim and Objectives

Supply chains in the age of Industry 4.0 need to do more than just use new technologies and improve their skills if they want to accomplish vertical integration that makes sense. The dynamic between producers, distributors, retailers, and consumers may shift as a result of this. The advantages of technological infrastructure in terms of reliability, responsiveness, and transparency in service provision are self-evident. (Soosay & Kannusamy, 2018). Businesses that have sustainable supply chains are setting themselves up for success in the future. Sustainable businesses would stand out from the competition by gaining social approval from consumers and increasing sales. Therefore, economic benefit and competitiveness are realized through green practices that lead to organizational sustainability success. (Saini et al.). Thus, this research aims to investigate the intersection of green logistics and Industry 4.0

technologies to see what it means for boosting openness, traceability, sustainability, the circular economy, and robustness in green logistics.

The specific research objectives include:

1. To comprehend the potential advantages and difficulties of technology integration as well as its effects on key performance indicators for green logistics, such as emissions reduction, cost reduction, waste reduction, and customer satisfaction.
2. To evaluate the potential of newly developed Industry 4.0 technologies for enhancing both the effectiveness and sustainability of green logistics practices.
3. To assess whether integrating green logistics and modern technology can help achieve more general sustainability objectives, like the Sustainable Development Goals of the UN.
4. To analyze the present state of green logistics practices and technological developments as well as determine specific areas in need of development.
5. Investigate the potential of integrating green logistics with technology to boost innovation and competition in the logistics sector.

These objectives are guided by following research questions:

RQ 1 - How can emerging technology integration improve the sustainability of green logistics practices? What are the key drivers, benefits, and potential barriers that influence the adoption of technology in green logistics practices?

RQ 2 - What role does technology play in enhancing the transparency and traceability of green logistics operations?

RQ 3 - How can technology integration support circular economy principles in green logistics, such as closed-loop supply chains, waste reduction, and resource recovery?

RQ 4 - How can technology integration with green logistics help address the last-mile delivery challenges of urban logistics in a sustainable and efficient way?

RQ 5 - How can technology integration help address the energy and resource intensity of logistics operations, such as through renewable energy and smart logistics planning?

1.1.3 Thesis Structure

The introduction highlights the increasing worry regarding environmental degradation and resource scarcity, underscoring the pressing need for sustainable logistics operations. The research objectives and questions are introduced, providing a clear direction for the study.The literature review examines the importance of green logistics and Industry 4.0 technologies separately, emphasizing their potential advantages and obstacles. This paper subsequently explores the integration of these domains, with a particular focus on the utilization of blockchain technology to improve transparency and traceability in green logistics. Furthermore, this review examines the impact of Industry 4.0 technologies on enhancing environmentally sustainable warehousing and circular practices, while also addressing the obstacles faced in last-mile logistics. A SWOT analysis evaluates the strengths, weaknesses, opportunities, and threats of this integration, providing a foundation for further research. The research approach section provides a rationale for adopting the interpretivism research philosophy in order to investigate how businesses perceive and implement technology integration in green logistics. Qualitative research methods, specifically case studies, are employed to gain a comprehensive understanding of the topic's context-specific characteristics. This section discusses the limitations of alternative research methods and emphasizes the importance of qualitative data in examining the complexities and variations of integration. This study provides a comprehensive analysis of two case studies: DHL and Ocado Group, focusing on data collection and analysis. These examples demonstrate how companies incorporated Industry 4.0 technologies into their environmentally friendly logistics operations. The analysis examines the best practices and challenges of the subject, offering valuable insights and identifying potential areas for further investigation. The discussions and solutions section incorporates theoretical knowledge from the literature review and integrates it with the findings from the case studies. This synthesis aims to reconcile any inconsistencies between theory and practice and provides suggestions to businesses on how to better incorporate Industry 4.0 technologies into green logistics. The conclusion and future recommendations chapter summarizes the research study's contribution to the research objectives and questions. This study recommends the implementation of the Triple Bottom Line (TBL) Framework and Life Cycle Assessment (LCA) to enhance the evaluation of Industry 4.0 technologies in the context of green logistics. This chapter highlights the importance of the research and suggests potential areas for future investigation in the field. Each chapter enhances comprehension of the research topic and effectively addresses the research objectives and questions.

1.2 Summary

As concerns about the environment have grown, the intersection between Industry 4.0 and green logistics has become an important area of study. The logistics business is a major contributor to greenhouse gas emissions and environmental degradation, making the transition to environmentally friendly practices imperative. The purpose of this research is to examine the possible advantages, challenges, and deployment strategies of combining Industry 4.0 and green logistics. The primary goals are to evaluate how effectively these modern developments achieve sustainable development objectives, to conduct a thorough analysis of the current state of the technology-integrated green logistics framework, and to devise a strategy for enabling their smooth integration. This study also analyses the groundbreaking impact of this alignment in terms of increasing productivity whilst effectively addressing the intricate problems associated with last-mile logistics. In conclusion, this study aims to provide invaluable insights and recommendations based on research to help businesses improve their logistics management strategies in order to become more strategically economical and environmentally viable. Last but not least, a well-planned study plan implies an organized and complete examination of Technology 4.0's potential role in eco-friendly supply chain management. To further improve the caliber and extent of the research findings, the following section of the research overview will focus on the coherence between various research methodologies employed in this research thesis.

CHAPTER 2. RESEARCH APPROACH

2.1 Introduction

The purpose of this research, entitled "Technology 4.0 integrated green logistics," is to investigate the difficulties and consequences of such an integration. Green logistics could undergo a radical transformation with the help of cutting-edge technologies like Industry 4.0, allowing businesses to improve their sustainability, efficiency, and operational efficacy. However, there are a number of obstacles and factors to take into account during this process of integration. And We will take a methodical and all-encompassing approach to researching this issue by breaking it down into manageable steps. Overview, philosophy, process, technique, data collecting, and an executive summary of the complete study strategy are all part of this approach to research. All of these factors are critical in providing direction for the study and guaranteeing the validity and reliability of the research. Each chapter provides an overview of the specific research procedures, research philosophies, research methodology, and data-gathering techniques that are employed throughout the course of the dissertation. Therefore, this kind of systematic inquiry will facilitate thorough and organized responses to the study's objectives and research questions.

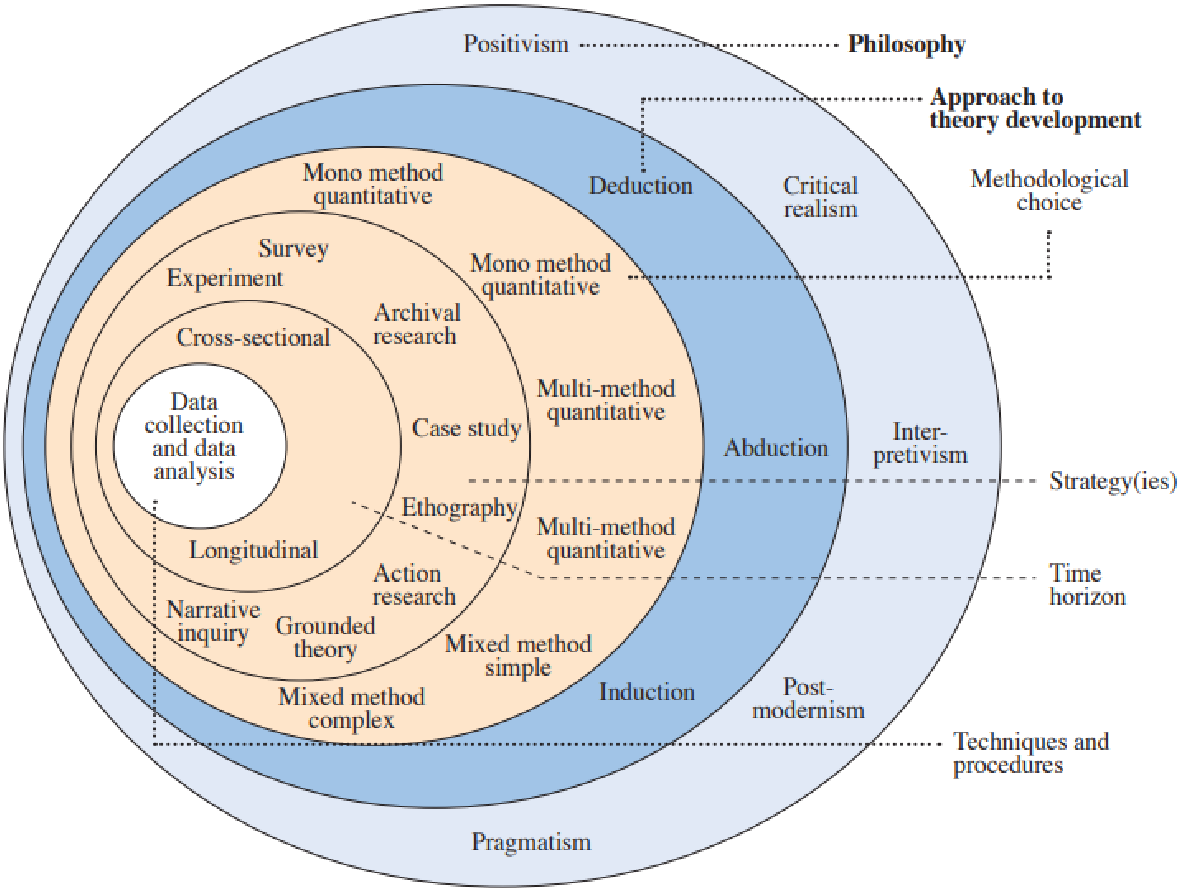


Figure 2.1 : Research Onion theoretical framework for research developed by Saunders, Lewis and Thornhill. (Melnikovas, 2018)

2.2 Research Overview

The dissertation seeks to investigate the implementation of Industry 4.0 technology to environmentally conscious logistics procedures. To better understand how the people under study make sense of the social reality, an interpretivism research philosophy has been adopted. The necessity to learn how businesses comprehend technological integration in the realm of green logistics justifies the selection of interpretivism as the research philosophy. The thesis acknowledges that positivism and pragmatism fall short when it comes to understanding the significance of context and the possible effects of applying technology in green logistics. This research philosophy also places an emphasis on the inductive study technique and qualitative research methodologies like case studies to better understand the topic's situation-specific nature. It has been determined that the subject of the thesis is not a good fit for the deductive or abductive research methods. Therefore, their shortcomings in relation to the study have also been discussed. It is agreed that case studies and other forms of qualitative research are ideally suited to the study of the issues at hand in this dissertation. It paves the way for further investigation and contextualization, both of which add weight to the argument. Qualitative research data can help advance hypotheses, guide practical applications, and account for the topic's inherent intricacies and variability. Given the exploratory character of the study, no quantitative nor mixed research methods were employed.

2.2.1 Research Philosophy

Knowledge, reality, and the place of ethics and values in scientific inquiry are all topics that can be categorized under the umbrella term "research philosophy," which describes an overarching set of beliefs and assumptions about these topics. Positivism, interpretivism, pragmatism, critical realism, and postmodernism are just five of the research philosophies commonly employed in studies of business and management. (Saunders et al., 2016). According to adherents of interpretivism, the best way to make sense of the social environment is to put oneself in the shoes of the individuals who are being studied and to try to comprehend the motivations driving their actions. Since it draws its findings from empirical evidence instead of logical justifications that could not hold up under investigation, it must employ the inductive method. Understanding how businesses process and comprehend technology integration in the setting of green logistics is crucial in the era of technology 4.0. (Kuada, 2012). Since interpretivism favors the inductive strategy of constructing hypotheses on the basis of findings and correlations observed in qualitative evidence, it made it possible for novel findings, concepts, frameworks, and creative solutions to develop from case study evidence.(Thanh & Thanh, 2015). In contrast to positivism, which uses induction to determine universal truths or ideologies. (Alharahsheh, Pius, 2020). When it comes to establishing attainable findings, positivism frequently employs quantitative methodologies. (Sachdeva, 2009). Likewise, pragmatism may place an emphasis on numerical data in its pursuit of practical answers to particular situations. While all of these points of view are valid, the successful implementation of technological advances in green logistics is heavily reliant on the specifics of each business and its surrounding environment. Research methods that can examine and analyze the peculiarities of the context are more compatible with interpretivism, which is necessary in comprehending the particular contextual significance and practical significance of technology integration in green logistics. It has been shown that

By taking an interpretive research philosophy stance, we were able to delve into the needs, motivations, and decision-making procedures of those engaged in technology integration, gaining a richer appreciation for the broader context that shapes how technology 4.0 is used in green logistics. (Greeff, 2015). The ability to delve more deeply into fresh concepts and develop patterns makes it especially useful in investigating the dynamic and intricate structure of technology integration in green logistics. (Cowling, 2016). Mono-method qualitative research studies, such as case studies, were appropriate for obtaining extensive and profound data, and this implies that interpretivism supported their usage. (Saunders et al., 2016). In particular, this approach made it possible to investigate the obstacles to incorporating technology into green logistics and to record the various viewpoints, difficulties, and gains connected with doing so. Interpretivism allowed for a more thorough knowledge of the topic's intricacies and diversity through its emphasis on distinct case studies. (Rahi, 2017)

Interpretivism enabled greater comprehension and understanding concerning research questions and objectives within its intricate context, instead of generalizing the findings to various individuals and different contexts, and consequently tends to leave out a gap in confirming the reliability and effectiveness of research findings by employing scientific methods, which proved to be a significant challenge for this research thesis. The failure to consider the effect of ideology on learning and social life was a further shortcoming. (Pham, 2018)

2.2.2 Research Process

Technology, logistics procedures, and environmental sustainability are just a few of the many interrelated aspects that make the integration of Technology 4.0 in green logistics a complicated and ever-evolving topic. As a result, the inductive research approach is advantageous since it allows researchers to investigate research challenges by first identifying relevant facts and trends in the data. Novel links, emerging trends, and insightful understandings about the role of technology in green logistics were all uncovered through induction's ability to capture nuances in situations that could otherwise be missed. (Hauer et al., 2018; Sachdeva, 2009). The inductive research method additionally encouraged theory construction based on practical evidence and data evaluation, strengthening the study's theoretical underpinnings.(Saunders et al., 2016). In contrast, deductive reasoning begins with a broad hypothesis or principle and then applies that principle or hypothesis to particular instances to determine whether or not it holds weight. To apply a deductive approach in the framework of technology 4.0 integrated green logistics, it would have been necessary to develop some concepts or assumptions about how the integration of technology affects sustainability, operational effectiveness, and other facets of green logistics. The investigation of new concepts and the development of technical changes that might not fit into established paradigms may have been hampered as a result. Considering the complex and ever-changing structure of the subject, deductive reasoning may have overlooked what was needed. (Mooney, 2000). Qualitative study approaches are frequently linked with the induction research process because they allow for a thorough examination and the comprehensive investigation of organizational perspectives, thus gathering the intricate details connected to technology integration and resulting in valuable findings. (Reichertz, 2014). In contrast, abduction also requires hypothesizing believable reasons for something that utilizes observational evidence. While abduction might pave the way for the testing of new theoretical frameworks, it is more often linked to the generation of working concepts than to their refinement. Since the subject of this thesis demanded a more structured approach to the development of theories in order to comprehend the relationships among various factors, an inductive approach was taken as it seemed most appropriate. The abduction approach could possibly have proven helpful within the context of technology 4.0 integrated green logistics for producing initial concepts or perspectives, however, it wouldn't have been capable to deliver the thoroughness needed for a research thesis. (Åsvoll, 2013).

2.2.3 Research Methodology

According to the period, purpose, surroundings, location, and technique used, research can be categorized. While methodology is important in that it influences the choice of research methods, it also embodies philosophical ideas. There are three types of research methodologies: mixed methods, quantitative methods, and qualitative methods. The incorporation of Industry 4.0 technologies in green logistics is a complex issue that combines organizational, social, and environmental aspects. By capturing the varying perspectives, experiences, and activities of the organizations engaged in green logistics, qualitative research enabled a thorough knowledge of these variables. It gave a more thorough understanding of the underlying significance, motives, and elements that influenced the integrating process. (Guercini, 2014). However, utilizing a quantitative study methodology might not have allowed for this because these subjective experiences are frequently ignored in favor of objective evaluation as well as quantitative generalization. (Saunders et al., 2016). The capacity to delve extensively within the broader elements that impacted technology 4.0 integration in green logistics could have been constrained by the actuality that quantitative research frequently requires a standardized methodology and a bigger sample size. Qualitative research allows for additionally sustained investigation of such contextual variables because green logistics practices differ between organizations, industries, and countries so their effectiveness relies upon certain contextual elements.(McBeath & Bager-Charleson, 2020).In order to gather novel elements and viewpoints as they arose throughout the analysis process, qualitative research additionally provided versatility in altering research methodologies and procedures in response to emerging findings and changing research topics. When investigating new integrations like the one involving Industry 4.0 technology and green logistics, this adaptability proved especially useful. The qualitative study contributed to the creation of innovative insights that could prove useful to direct prospective research and recommendations. (Bluhm et al., 2011).

2.2.4 Data Collection

The case method of analysis is widely used in business research, and it is especially applicable to the examination of businesses. Since case studies focus on specifics instead of broad generalizations, their scope may be limited. However, this approach isn't perfect because it's not always easy to guarantee accessibility and consistency to organizations. The results of qualitative case studies may help advance theoretical understanding. There may be wider theoretical ideas that can be informed by the specific investigation of particular examples. This method of collecting and analyzing data in the subsequent research dissertation enabled the triangulation of findings and strengthened the validity of the conclusions, which is common practice in case studies. When looking at the viability of technology 4.0 integrated green logistics, an in-depth and holistic insight was offered by merging data from multiple sources. (Adams et al., 2014). Because secondary data can be used to verify and expand upon primary research. When using secondary data, researchers can tap into a vast amount of facts that already has been gathered by other academics, enterprises, or researchers. Since green logistics that makes use of Industry 4.0 technologies is still in its infancy, looking back at its history can shed light on its development and the difficulties encountered during its early stages of integration. This, in turn, can help researchers organize their findings and formulate more effective proposals for the future. (Mazhar et al., 2021). Ethical issues may arise while collecting primary data from organizations due to the requirement to safeguard private company data or participant anonymity. The anonymity and accessibility of secondary data, on the other hand, lessens the likelihood of any ethical violations. As a result, the case studies' secondary data has been used as the primary data in this thesis' analysis, interpretation, identification of knowledge and research gaps, and formulation of future suggestions. (Rabianski, 2003). The case study is more aligned with the Cross-sectional time frame because data was gathered for a shorter span of time and during a single moment in time. Finally, case studies have real-world relevance for logistics professionals. Best practices, and success variables, alongside possible risks in the implementation of Technology 4.0 in green logistics can be determined through the study of real-world instances. Organizations might employ this research to better understand the prospective advantages and obstacles of integrating such technologies, as well as the most successful strategies and methods for implementing them. (Hox & Boeije, 2005; Saunders et al., 2016).

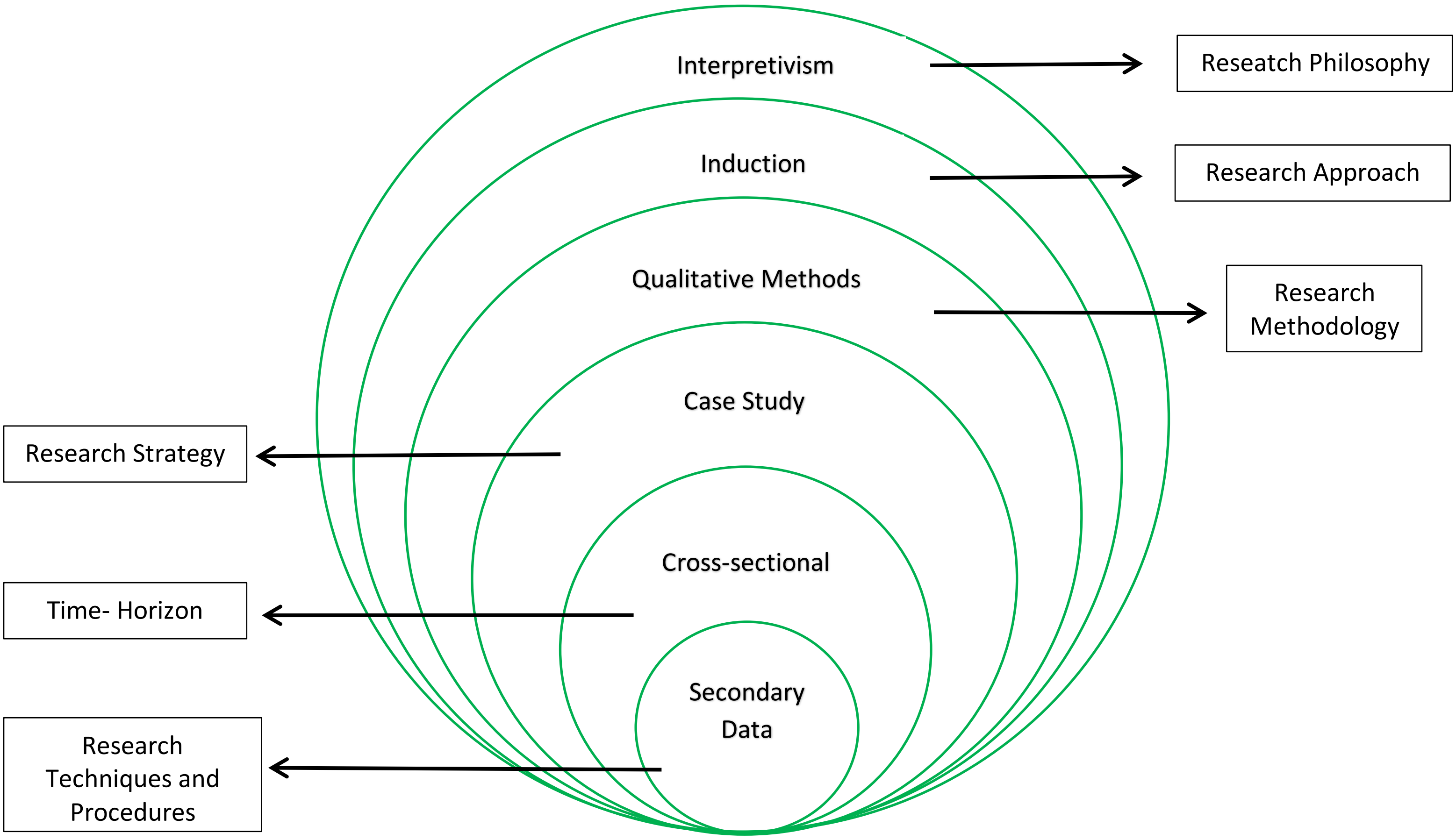


Figure 2.2.4 : Research onion based on this specific research. (Melnikovas, 2018)

2.3 Summary

The dissertation utilizes interpretivism, inductive research, qualitative methodology, and case studies to examine the incorporation of Technology 4.0 in green logistics. This approach seeks to gain an in-depth awareness of the particular variables, subjective viewpoints, and practical applications related to the subject. However, it is important to acknowledge their limitations. The thesis acknowledges the limitations of alternative research philosophies, processes, and methodologies. It also provides a rationale for selecting the chosen approach in order to meet the research objectives and address the research questions. The upcoming section of this research dissertation will consist of a literature review. It will offer a comprehensive analysis of Industry 4.0 technologies and green logistics, exploring their combined structure along with their ability to generate economic, sustainable, and social advantages. Additionally, it will assess the constraints and obstacles associated with the implementation of these combined practices.

CHAPTER 3. LITERATURE REVIEW

3.1 Introduction

This chapter on the literature review demonstrates a thorough examination of Industry 4.0 technologies and green logistics, emphasizing the integrated framework. This conjunction encourages the growth of technological structures across the logistics field, establishing the path for long-lasting, revolutionary improvements. This chapter delves further into the topic of integrating cutting-edge technologies including artificial intelligence (AI), big data (BD), blockchain technology, Automation, the Internet of Things (IoT), and cyber-physical system (CPS) into green logistics practices to improve sustainability, advance circular economy fundamentals, and overcome last-mile logistics obstacles. It also examines the broad implication of this integration on meeting the United Nations' Sustainable Development Goals, illuminating its value in aiding worldwide sustainability efforts. At the same time, it takes an in-depth look at the restrictions and bottlenecks that have been placed in the way of this integration, illuminating the difficulties that must be overcome. In order to better grasp the significance and impacts of this combination, a quick SWOT analysis is performed. This literature analysis establishes the foundation for a thorough examination and recognition of any findings and knowledge deficiencies, hence facilitating the development of extensive and enlightening research outcomes. In the subsequent sections, the analysis will also focus on case studies, which will serve as concrete illustrations of these tangible outcomes of the integrated approach.

3.1.1 Drivers of Industry 4.0 technologies

Industry 4.0 refers to the continuing industrial revolution that involves the digital evolution of value-creation procedures across different industries. Industry 4.0 emerged as a means to enhance the competitive edge of Germany's manufacturing sector (Xu & Duan, 2018). These emerging technologies are facilitating increased standards of production efficiency. They possess the capacity to significantly impact both social and environmental sustainability in advancement. Therefore, it is imperative for organizations to take into account the impact of Industry 4.0 technologies on sustainable development (Bai et al., 2020). The Maturity model, consisting of a readiness evaluation model alongside a maturity index, indicates that Industry 4.0 technologies can be adopted by logistics businesses. Smart logistics, also known as Logistics 4.0, is a component of a smart factory that encompasses smart mobility and smart products. These elements collectively contribute to the concept of Industry 4.0 (Angreani et al., 2020). The logistics and supply chain management area is undergoing substantial transformations as a result of the integration and utilization of advanced Industry 4.0 technologies. These technologies include smart manufacturing, simulation, cyber-physical systems, autonomous robots, blockchain, Artificial Intelligence (AI), Internet of Things (IoT), big data, cloud computing, 3D printing, and augmented reality (Cannavacciuolo et al., 2023). These advances are essential for establishing advanced supply chain and logistics ecosystems, enhancing effectiveness, responsiveness, and visibility of goods movements, enhancing transparency, reducing environmental impacts, and optimizing performance (Ching et al., 2022).

3.1.2 Potential of Industry 4.0 technologies

The Internet of Things (IoT) is an emerging industrial ecosystem that integrates intelligent and autonomous machinery, advanced predictive analytics, and machine-human cooperation to enhance output, effectiveness, and validity. The Internet of Things (IoT) enables real-time sensing and fast data transmission, promoting effective cooperation between stakeholders. Current robots are characterized by their autonomy, versatility, and collaboration as seen in the use of automated guiding vehicles within distribution centers. Big data analytics facilitate real-time gathering of data from diverse sources, broad data analysis, and prompt decision-making. This enables enhanced versatility, energy conservation, and service quality through predictive maintenance. The utilization of big data analytics in monitoring processes has become prevalent, with the inclusion of fault identification enabling the adoption of predictive analytics. Yet, achieving these abilities necessitates both high-quality data and specialization in analytics.

(Kamble et al., 2018). Cyber-Physical Systems (CPS) refers to the combination of computing and physical operations, which are crucial elements in the execution of Industry 4.0. CPS incorporates verification technologies, such as RFID tags, enabling distinct identification. RFID technology was employed for managing tasks related to process inventory and achieving lower expenses. Cloud technology is a storage solution on the internet that offers operational simplicity through web-based applications, eliminating the need for installation. Cloud systems offer cost reduction, infrastructure simplification, data protection, and unrestricted access to data. Cloud systems are a viable solution for managing Big Data (Oztemel & Gursev, 2018). Big data technology is utilized to extract pertinent details from diverse and unstructured online data sources, enabling the acquisition of valuable insights. The utilization of big data, in conjunction with data mining processes and data analytics, can enhance the visualization of data, improve credibility and productivity, and facilitate real-time interventions by forecasting critical circumstances. Big data offers advantages such as process optimization, decreased expenses, and improved operational efficiency, leading to increased profits. The blockchain is a decentralized database system designed for the retention and handling of data transactions. Blockchain ensures transaction authenticity, while big data is responsible for evaluation.(Sharma & Pandey, 2019)

3.1.3 Industry 4.0 technologies for sustainable innovation

Industry 4.0 enables the effective allocation of resources, such as water, energy, raw materials, and other products. This is achieved through the use of cutting-edge Industry 4.0 technologies, which acquire real-time data via production processes alongside other stakeholders. The implementation of these technologies promotes sustainable green practices. Industry 4.0 utilizes intelligent equipment and smart production systems to minimize the movement of goods, minimize energy consumption, and promote a circular economy by minimizing waste.(Kamble et al., 2018)

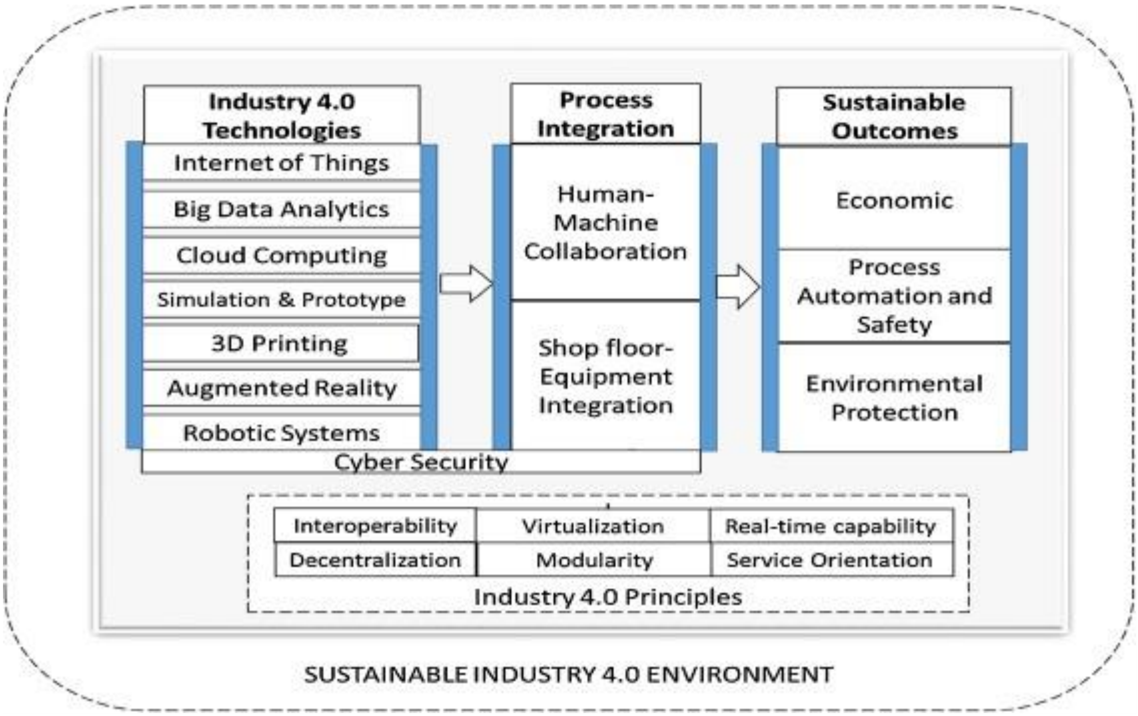


Figure 3.1.3 - Sustainable Industry 4.0 framework. (Kamble et al., 2018)

The Circular Economy is an industrial system that substitutes the notion of 'end-of-life' with restoration, prioritizes green energy, and seeks to eliminate waste through improved material and system design. It also offers enterprises opportunities to generate value that produces revenue, reduces costs, builds resilience, and establishes authenticity. Industry 4.0 technologies facilitate the digitization of the circular economy. The integration of big data analytics and additive manufacturing has the potential to enhance both process and product lifecycle management and improve existing recycling methods (Rosa et al., 2019). Industry 4.0 technologies have a significant impact on the Sustainable Development Goals (SDGs) established by the United Nations. The Internet of Things (IoT) enhances the productivity and efficacy of waste management systems, addressing regulation, economic, social, and environmental aspects. It also contributes to the achievement of Sustainable Development Goals (SDGs) 3, 6, 12, and 13. This technological advancement supports the principles of a circular economy and is closely linked to Sustainable Development Goals (SDGs) 8, 9, 11, and 12. It also has an indirect connection to SDGs 13 and 14. (Patyal et al., 2022)

3.2 Green Logistics

3.2.1 Green Logistics Background

Green Logistics is an academic discipline that examines the environmental impacts of transportation, storage, and management of tangible goods within supply chains, both in the forward and reverse directions. This study evaluates the impact and magnitude of these effects and explores potential strategies for mitigation. (Mckinnon et al., 2015). . The Green Logistics structure comprises six elements: sustainable transportation, green warehousing, green packaging, accumulation and handling of green information, sustainable procurement, and waste management. (Zhang & Zhao, 2012) conducted a study. These six facets incorporate ecological principles and theories of reverse logistics, green design, and sustainable operations into logistical operations to promote societal development via economic, environmental, and social perspectives. Economies are rapidly industrializing, leading to an enormous rise in carbon emissions. In the present era, it is possible to achieve substantial reductions in greenhouse gas emissions and transportation expenses by optimizing logistic network planning, utilizing appropriate transportation options, and effectively controlling load capacities and routes. This can be accomplished with the implementation of green logistics practices. (El-Berishy et al., 2013)

Practices	Sources which impact the sustainability	Practices for removing the negative impact
Green Transport	The construction of transport network The operations of transport vehicles The disposal of transportation vehicles	Modal Choice Freight Consolidation Clean Vehicles/Fuel Efficiency Reuse of Pallets and Containers Standardization of Trucks Sizes
Green warehousing	Layout, design and capacity of the warehouse may impact the sustainability.	Clean material handling equipment Process optimization Automatic warehousing systems Inventory minimization programs and Just-in-time system, Product disposition On-site recycling
green packaging	The elements of the packaging which have an impact on warehouse and transport costs are size, shape and materials.	To sort out the packaging issues, innovative packaging technologies and environmental certifications can be introduced.
green Procurement	Lack in quality raw material	Quality check monitoring tools
waste management	Different kind of waste generate during the logistics like waste from expired product or due to packaging etc	Waste contractor, Trade waste recycling

Figure 3.2.1 - Collective green logistics practices and its impact on sustainability and mitigation through technological innovations. (Kumar, 2015)

The key green logistics practices include the utilization of alternative fuels and recyclable packaging, route optimization to minimize travel distances, intermodal logistics, eco-driving, improving warehouse technologies and machinery for energy conservation, optimizing storage space, reducing paper-based documents through digitization, and using sustainable standards for choosing vendors and business partners. Besides practices include fleet advancement and effective vehicle loading. While the initial adoption of green logistics incurs costs in investment, functioning, training, and procurement of sustainable resources but it ultimately reduces transportation, storage, and energy expenses. Additionally, it enhances the organizational reputation, economic success, and competitiveness of businesses, resulting in customer satisfaction and contributing to waste reduction and lower environmental expenses. (Vienažindienė et al., 2021)

3.3 Sustainable Logistics 4.0 framework

Sustainable logistics 4.0 refers to the implementation of digitalization efforts to expedite the establishment of an interconnected, traceable, and robust logistics system capable of satisfying personalized customer needs through the adoption of eco-friendly practices. The utilization of digitalization innovations in logistics facilitates the timely and accurate delivery of goods while minimizing waste. (Raji et al., 2021). Managing sustainability across multiple dimensions poses challenges as it necessitates organizational transformation toward establishing sustainable practices in production systems. (Gupta et al., 2021). Industry 4.0 technologies have the potential to encourage environmentally friendly practices through several means. These include extending the lifespan of machines, optimizing resource usage, minimizing industrial waste, improving the utilization of final products, and facilitating recycling advantages that promote a circular economy. These aspects contribute to the progressive evolution necessary for achieving sustainable growth in the field of logistics.

(Umar et al., 2021) conducted the study. In addition to Industry 4.0 technologies, incorporating environmental awareness and consciousness, automation, green human resource practices, and reverse logistics can greatly enhance the economic and environmental efficiency of firms. (Bag et al., 2021)

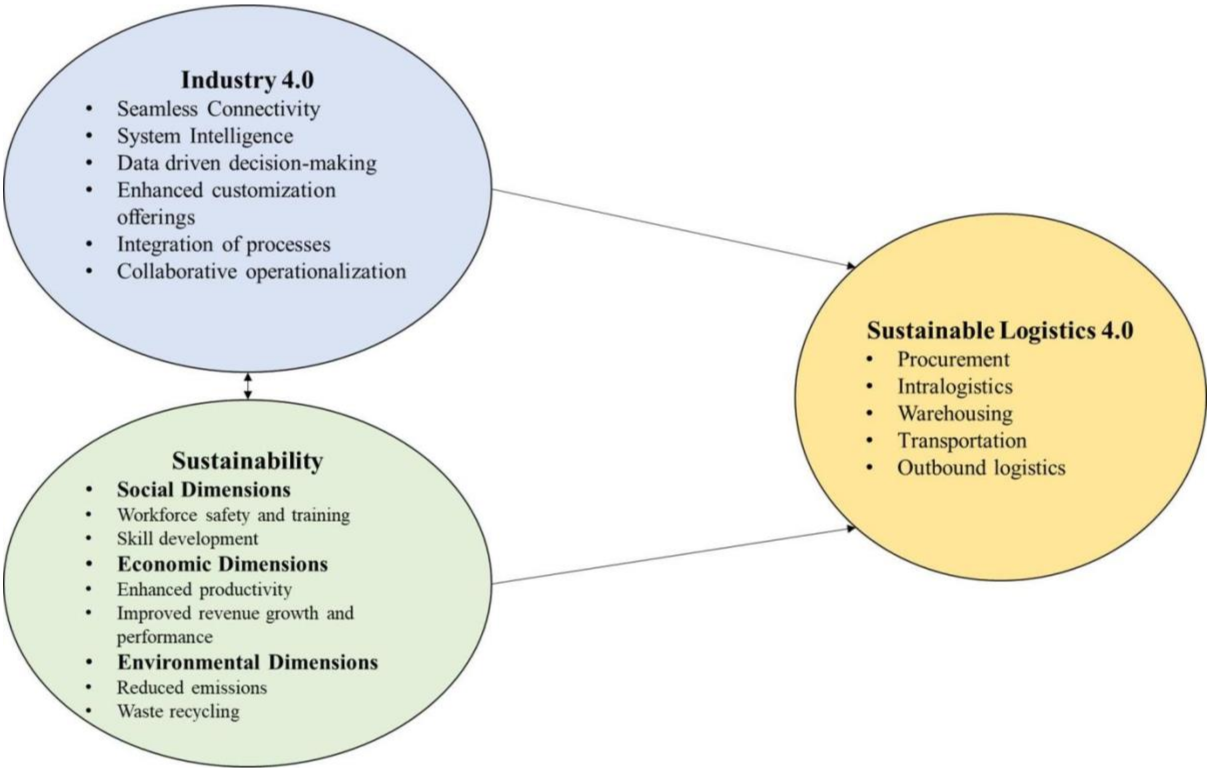


Figure 3.3 - Dimensions of sustainability and Industry 4.0 as an interactive factor in Sustainable Logistics 4.0 (Parhi et al., 2022)

Sustainable Logistics 4.0 aims to create an agile and flexible environment that meets consumer needs and environmental objectives. This is achieved via real-time monitoring, smart warehousing functions, and transportation planning. By implementing these strategies, supply chains can become more productive, resulting in reduced delays, fuel consumption, and expenditures. (Sun et al., 2021).

The smart factory logistics utilizes sustainable strategies, including recycling, reuse, and remanufacturing, to minimize waste and enhance cost optimization. (Allen et al., 2021) conducted the study. Cloud-based enterprise management systems serve as centralized storage for value chain processes. Data obtained from enterprise systems is combined with applications to perform operations that include sustainable logistics planning, intelligent inventory control, and predictive maintenance. These technologies play a crucial role in various aspects of logistics, including real-time product tracking, package traceability, warehouse management, inbound logistics activities, and optimized routing applications. (Parhi et al., 2020). The utilization of information technology (IT) has a positive impact on sustainable digital logistics operations, spanning from procurement to distribution. This helps organizations preserve high levels of client satisfaction and maintain their competitiveness in the global market. (Abdirad & Krishnan, 2020). Electric vehicle (EV) technology, is also revolutionizing Sustainable Logistics 4.0. Electric vehicles (EVs) primarily emphasize energy efficiency, fleet optimization, and environmental advantages. Simulation findings from multiple cities demonstrate that EVs yield significant reductions in carbon emissions. (Ren et al., 2019). Smart packaging, a collection of advanced packaging technologies, can be used by companies to improve product traceability. Smart packaging solutions have the potential to significantly enhance the efficiency and effectiveness of supply chains. Currently, there are only a limited number of economically viable smart packaging systems that utilize RFID tags for monitoring and recording. This is despite the reality that RFID systems have become reliable and gained significant acceptance in the last decade. Sensor-based RFID systems can be integrated into product packaging to track and trace the product's origin, detect situations of contamination or tampering and monitor the whole logistical process. Many components of smart packaging do not align with consumers' expectations for an environmentally friendly and sustainable world. Certain elements such as sensors, circuits, and batteries can pose challenges in terms of disposal or recycling in certain situations. Therefore, it is essential to comprehend and evaluate the impact of smart packaging components on the environment and their durability (Aliakbarian, 2020).

Big data is crucial in the context of sustainable logistics 4.0 as it enables real-time decision-making and predictive solutions. Big data finds possibilities for smart inventory management infrastructure, vehicle routing, and maintenance planning for logistics systems. (Lai et al., 2018). Energy conservation management is a valuable tool for monitoring, controlling, and managing energy usage. The lack of credible energy consumption data hinders effective management and control of energy. Logistics companies lack the ability to comprehensively assess environmental performance. Real-time energy consumption data can be gathered and stored in the blockchain using smart sensors integrated into physical objects. Logistics companies can utilize data for energy evaluation, eliminating the need for manual data manipulation. The outcomes of this evaluation can then be utilized to identify energy-saving solutions. Big data analytics can offer a comprehensive energy-saving solution. (Wang et al., 2018). This application enables logistics companies to effectively choose appropriate transportation, including green vehicles, for various scenarios. Energy management practices can effectively mitigate environmental pollution and address challenges faced by enterprise managers. Establishing a sustainable supply chain is significantly important, and this approach plays a crucial role in achieving that objective.(Tan et al., 2020).. The utilization of big data and machine learning enables the incorporation of historical data to forecast logistical delays and enhance the reliability of fuel consumption predictions, thereby improving the certainty of schedules. (Chung, 2021).

3.3.1 Block chain Technology for green logistics

Supply chain transparency is a crucial and challenging aspect to enhance in the field of logistics. Blockchain technology has the potential to be highly beneficial in tracking goods from their origin to the final consumer, due to its primary characteristics. The decentralized framework allows for inclusive participation and ensures integrity. Full transparency refers to the ability to track the movement of goods in terms of their location and time during different stages of logistics. This includes monitoring the physical state of the goods, such as temperature changes, to assist logistics professionals in making informed decisions. This approach to conducting business or implementing a business process aligns with the primary objective of logistics, which is to ensure the timely and accurate delivery of goods in the appropriate quantity and condition (Tijan et al., 2019). Blockchain technology has the potential to enhance supply chain transparency and support sustainable development in logistics. (Bai & Sarkis, 2019).

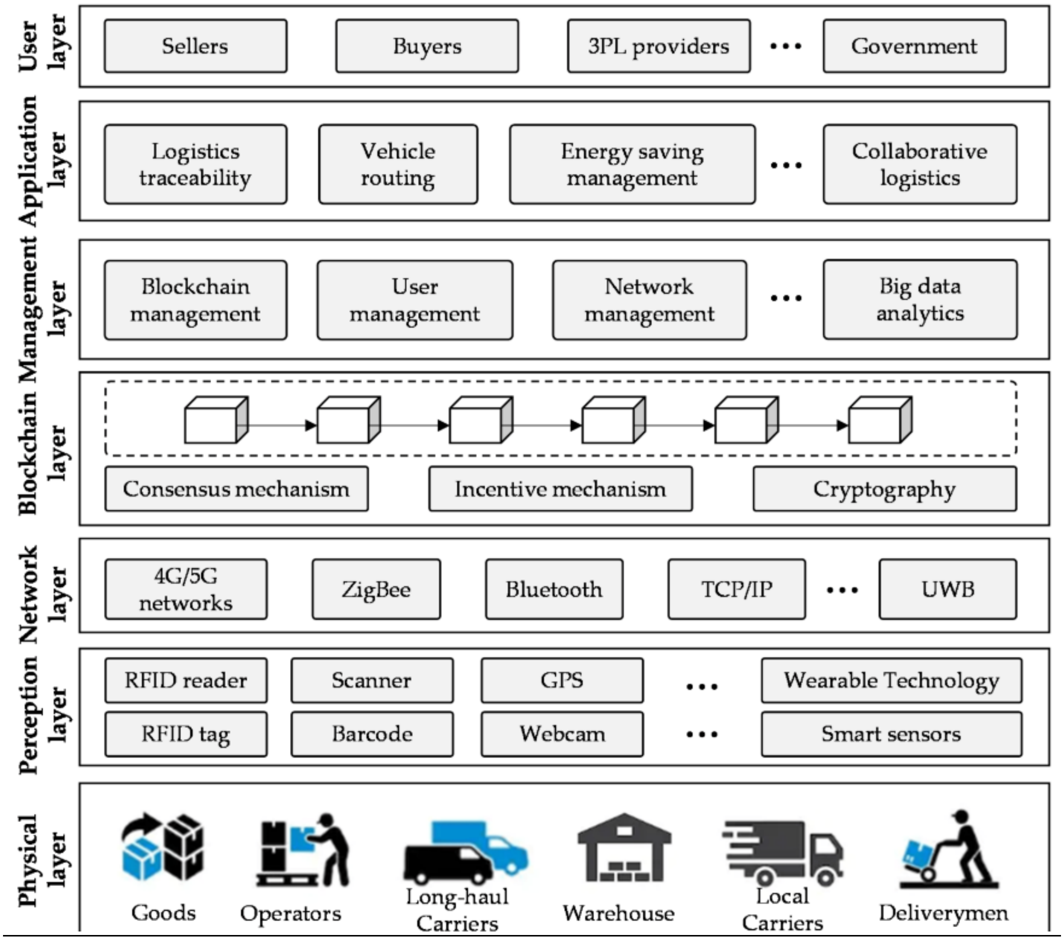


Figure 3.3.1 - Blockchain-based framework for green logistics (Tan et al., 2020)

The bottom physical layer encompasses various logistical assets essential for supporting the logistics procedure and its operations. The perception layer, as th following layer, enables the monitoring and understanding of logistics resources using various sensor technologies. These technologies include radio frequency identification (RFID) technology for distinctive identification of merchandise, web cameras for workplace monitoring and product security, and global positioning systems (GPS) for real-time tracking of truck locations. Wearable technology is utilized in logistics businesses to enhance efficiency and alleviate the responsibilities of logistics managers. This can also be considered as sustainable development from a social standpoint. Smart sensors, including smart electricity, water, and gas meters, can be utilized to identify resource scarcity. The network layer facilitates pathways for communication. Data collected from the perception layer can be transferred to the blockchain layer via the network layer, which facilitates communication channels such as 4G/5G networks and Transmission Control Protocol/Internet Protocol (TCP/IP). The information is preserved in sequential sections that are linked together in sequence to create a blockchain. The management layer of the blockchain structure includes various tools. These tools promote the functioning of the structure by performing specific functions. For example, user management is liable for analyzing and addressing logistics issues in supply chains. Network management serves to manage communication channels. Big data analytics is employed for processing data retained in the blockchain for various purposes. The application layer offers various applications, including logistics traceability, emission assessment, smart transactions, and collaborative logistics, to users in the user layer. The term "user layer" pertains to stakeholders involved in logistics within supply chains. (Tan et al., 2020)

Transportation plays a crucial role in both outbound and inbound logistics, facilitating movement between and among facilities. The utilization of blockchain technology can enhance the tracking and monitoring of transportation when engaging with a third-party transportation company. (Kouhizadeh & Sarkis, 2018). Ocean freight operations include multiple organizations, including exporters, terminal managers, trucking firms, customs officials, freight forwarders, ocean transporters, insurance firms, banks, and importers. Additionally, various documentation such as bill of lading, invoice, certificate of origin, freight shipping paperwork, inspection certificate, export packing list, and insurance certificate are involved. Due to the manual nature of many processes, substantial delays are frequently experienced In 2017, IBM and Maersk established a partnership with the objective of enhancing the effectiveness of the ocean freight sector, which is valued at $200 billion. Their collaboration aimed to create a blockchain platform capable of automating the entire procedure. This would involve the digitalization of shipping container paperwork and the implementation of vessel tracking mechanisms. By utilizing the decentralized and encrypted nature of blockchain technology, updated data and documentation can be examined and compared by all relevant parties, eliminating duplication inaccuracies and ensuring prompt processing. (Tang & Veelenturf, 2019). Blockchain technology plays a crucial part in facilitating green practices. Blockchain technology plays a vital role in green logistics due to its ability to enhance safety, confidentiality, transparency, and traceability (Böckel et al., 2021). The traceability characteristic enhances product flow and supports logistics processes. Blockchain technology improves data accessibility and promotes cooperation among supply chain members. (Orji &

Ojadi, 2022). Blockchain technology has the potential to enhance safeguarding in logistics operations by preventing illegal practices like misleading ownership and data tampering. This can lead to improved effectiveness and expense reduction. (Rehman Khan et al., 2021). From a purchasing standpoint, the blockchain can be utilized to store and track products along with material data and movement, rather than relying solely on supplier information. The blockchain records the transactional features of products, as well as their past activity. These transactions can disclose information about the product's origin, quality, quantity, ownership, and timeframes, enabling the tracing of green quality, recycling capacity, and environmental footprints. Environmental data is provided to clients to inform them about secure and sustainable manufacturing and distribution of products. Clients who can access this information can choose sustainable products.(Dobrovnik et al., 2018).

Blockchain traceability can enhance the lifespan of packaging materials by enabling more effective management, thereby facilitating their reuse and accountability. Recyclable and socially ethical packaging can be successfully examined and controlled. The U.S. Patent and Trademark Office (USPTO) has released an application about Walmart that outlines a "smart package" concept. This package would incorporate an algorithm capable of recording various details, such as the package's contents, environmental conditions, and location, using blockchain technology. Carrefour, a global supermarket chain, has implemented a comparable system enabling consumers to scan product packaging to obtain comprehensive details regarding the product's origin, production methods, and environmental attributes. (Kouhizadeh & Sarkis, 2018) .

The implementation of collaborative logistics allows logistics firms to work together in serving a group of customers, resulting in reduced freight expenses and increased utilization of facilities. The collaboration between logistics firms has the potential to decrease energy consumption and greenhouse gases while simultaneously enhancing profitability. (Suzuki & Lu, 2017) Traditional collaborative logistics marketplaces face challenges in efficiently allocating logistics resources and duties because of unpredictable supply and demand variables. The establishment of a peer-to-peer (P2P) collaborative logistics market can be facilitated through the adoption of blockchain technology, enabling participants to engage in unrestricted trading. This application optimizes resource allocation and minimizes raw material consumption, thereby enhancing environmental sustainability, encouraging green supply chain development, and supporting sustainable growth. (Tan et al., 2020)

The slow adoption of blockchain in logistics can be attributed to several factors. These include the unpredictability of regulations, limited awareness among stakeholders, the intricate nature of blockchain systems, a lack of proficient professionals, governance challenges, limited internal technical expertise within firms, scalability issues, access to technology limitations, and uncertainties regarding safety and confidentiality. Therefore, the widespread implementation of blockchain technology in the logistics and supply chain management (SCM) industry is less likely to happen in the near future. (Rejeb et al., 2021).

A four-field matrix is used in conventional SWOT analysis, divided into internal and external sources and either favorable or adverse impacts, the components are then broken down into the various sectors of the matrix. While opportunities and threats relate to external elements, which include environmental, legal, economic, etc., that are beyond the control of the subject under investigation, strengths and weaknesses constitute controllable variables. Therefore, accurate identification and grouping of components into pertinent categories are essential for the evaluation, which in this instance is the evaluation of a technology-integrated green logistics framework. (Szum and Nazarko, 2020)

The results of the SWOT analysis indicate that the decentralized and enduring structure of blockchain assures the confidentiality and authenticity of logistics statistics, which subsequently encourages effective and collaborative logistics operations by simplifying paperwork alongside automating procedures to provide complete visibility and accountability in logistics.(Malyavkina et al., 2019; Jovic et al., 2020) However, there also exist significant constraints due to blockchain scaling inability to efficiently manage large volumes of data as well as transactions, which can have a negative influence on large-scale logistics activities. Furthermore, the lack of regulatory guidelines and structures that encourage and support blockchain adoption in logistics and a lack of competent workers in the blockchain industry, make blockchain-based technologies difficult to deploy. There are challenges to integrating blockchain technology into green logistics, promoting sustainable practices, enabling traceability of goods, and encouraging the circular economy, yet there additionally exist opportunities for growing, planning, and improving the regulatory structure along with advancements in R&D to address these issues. (Kayıkcı, 2020). Also, there are a number of threats, including high energy usage, the creation of a lot of electronic waste, and the incompatibility of blockchain networks with preexisting logistics infrastructure and networks, alongside technological constraints. Given their open and transparent nature, blockchain systems present significant safety and confidentiality risks, necessitating stringent safeguards for critical logistical data. (YONTAR, 2023).

3.3.2 Technology 4.0 driven sustainable warehousing.

The technological approaches of Industry 4.0 have rapidly integrated into internal logistics processes, facilitating the development of intelligent warehouses, also referred to as Warehouse 4.0. These warehouses adhere to the fundamentals of Industry 4.0, including connectivity, virtualization, decentralisation, real-time operations, versatility, and reconfigurability. (Tubis & Rohman, 2023) .The logistics sector has undergone significant changes due to the advancement of Industry 4.0. This era is characterized by the use of advanced technologies such as warehouse robots, the Internet of Things, Internet of Services (IoS), and cyber-augmented collaboration. These innovations have converted conventional warehouses into SMART warehouses or warehouses 4.0, resulting in improved sustainable performance. (Dusadeerungsikul et al., 2021) .

Cloud computing could link warehouse management via a transport management system for digital interactions between consumers, supplier networks, and transporters. The autonomous mobile robot (AMR) is capable of intelligent navigation and task execution in a storage facility, through its sensors and advanced computing capabilities. The AMRs' accurate actuators enable their application in tasks that are challenging, laborious, or dangerous for humans. For example Amazon's Kiva Systems are used in storage facilities for goods transportation and shelf organization. (Tikwayo & Mathaba, 2023) The implementation of 5G technology in warehouses can lead to improvements in planning and routing of vehicles (Dolgui & Ivanov, 2021). The integration of real-time location systems in warehouse management can enhance security as well as effectiveness in forklift placement, monitoring, and fulfillment in inventory (Halawa et al., 2020). The incorporation of blockchain technology in digital ledgers enhances accountability and traceability in warehouse activities, thus minimizing the risks associated with product tampering, shipment rejection, and financial losses. Intelligent robots can enhance the efficiency of warehouse material movement, reducing the risk of harm and economic losses. (Ali & Aboelmaged, 2021). The Ethereum blockchain is utilized for creating secure and unalterable documentation in a centralized warehouse management system, thereby enhancing customer trust. (Tikwayo & Mathaba, 2023)

IoT systems have the capability to regulate environmental conditions in warehouses using automated sensors. The use of IoT in communicating data and improving visibility during picking orders, loading, and transporting can decrease the occurrence of inaccuracies, losses, and rejections. This, in turn, eliminates the risk of resource wastage in product distribution. (Ding et al., 2020) . The implementation of IoT in warehouse management allows for continuous monitoring of operations through data generation. This facilitates optimized information sharing among various departments, leading to faster response times and quicker identification of issues (Tikwayo & Mathaba, 2023).

The Internet of Things (IoT) plays a significant role in Industry 4.0 and has implications for all Sustainable Development Goals (SDGs) in relation to warehousing. The adoption of IoT in warehouse management can have positive effects on economic, social, and environmental aspects. This includes minimising economic losses via monitoring inventory stocks, decreasing CO2 emissions via real-time detection, and promoting safety by preventing major accidents. The deployment of IoT in cold storage establishments helps reduce food wastage, monitor perishable food supplies, and maintain the frozen state of food supplies. This contributes to accomplishing sustainable growth, as outlined in SDG 2 of Zero Hunger. Also The Internet of Things (IoT) aids in addressing climate change by effectively monitoring and managing emissions from warehouses. This contributes to the fulfillment of Sustainable Development Goal 13, which focuses on taking steps to address climate change. (Aravindaraj & Rajan Chinna, 2022).

The implementation of IoT-enabled RFID technology can reduce operational mistakes, unforeseen losses, resource wastage, delay in processing, quality degradation, and waste in warehouse activities by facilitating real-time data exchange.(Poon et al., 2011). RFID and the Internet of Things (IoT) have the potential to alleviate delays in the conventional warehouse model caused by discrepancies in the state and condition of products during cargo receiving and dispatching. RFID technology enables complete control of goods flow inside a warehouse using digital tags incorporated into the products (Chen et al., 2013). RFID technology enhances inventory management by facilitating the accurate gathering of data on raw materials, storage in warehouses, and the shipment of final products across supply chains. RFID technology facilitates the automation of continual restocking or vendor-managed inventories. RFID consists of a reader and a tag that use radio waves to recognize objects. Tags are utilized for the purpose of identifying and monitoring objects. The tag acquires data from an object and subsequently transfers it to the reader. The readers collect tag data and transmit it to a server for analysis using software interfaces. RFID technology allows for efficient identification, inexpensive tracking, and inventory tracking in logistics. This leads to improved efficiency and the establishment of a sustainable competitive edge via product quality assurance. (Unhelkar et al., 2022) .This helps achieve SDG 12 of sustainable consumption and production. (Aravindaraj & Chinna, 2022).

Automation has had significant effects on information circulation within warehouses. Companies like Manhattan Associates, Oracle, and Blue Yonder utilize warehouse management systems to monitor and document their movements of merchandise. A contemporary Warehouse Management System (WMS) utilizes scanners and barcodes or RFID tags to collect information on goods arrival, storage place, and customer deliveries. The obtained data serves as a foundation for making demand forecasts and, in a broader sense, enhancing operational planning. (Mehta & Levy, 2020). This is related to eight sustainable warehousing concepts that consider different aspects of sustainability, including storage facility layout, design, inventory management, employees, processes, onsite facilities, management framework, and mechanical handling machinery. These concepts suggest a conceptual sustainable warehousing model that can be employed as a plan of action for establishing future objectives and targets to accomplish a greater degree of sustainable development within warehousing. (Malinowska, 2022) .

The implementation of autonomous vehicles within warehouses results in a 22% reduction in CO_2 emissions. Automated warehouses have contributed to environmental improvement by lowering emissions and promoting renewable energy, aligning with SDG 7 (Affordable and Clean Energy). Developing countries are adopting regulations that enable solar roof-top systems in warehouses as an alternative energy source. This initiative aims to promote climate resilience and the adoption of sustainable and energy-effective practices in warehousing. Additionally, it aligns with Sustainable Development Goal 7, which focuses on ensuring access to affordable, reliable, sustainable, and modern energy for all. (Aravindaraj & Chinna, 2022).Green energy plays a vital role in warehouse technologies by minimizing energy usage and adverse emissions.(Ali et al., 2022) The main forms of green energy include biomass, solar, and wind, which utilize recovered kinetic energy, air compressor heat, and refrigeration setups. (Oloruntobi et al., 2023) Green energies have effectively minimized warehouse carbon footprints and contributed to achieving zero carbon emissions. (Mashud et al., 2022).

Figure 3.3.2 - An Automated Storage and Retrieval System (ASRS) for automated warehousing. (Mehta & Levy, 2020)

The Environmental Impact Assessment (EIA), Building Research Establishment Environmental Assessment Method (BREEAM), and Leadership in Energy and Environmental Design (LEED) are popular certification systems for evaluating the environmental impact and sustainability of warehouse buildings. (Wu et al., 2020). The integration of these certifications with smart warehousing technologies could enable the development of highly technological and environmentally sustainable green warehousing. (Aravindaraj & Rajan Chinna, 2022)

In conclusion, Industry 4.0 technologies play an insufficient but significant role in promoting sustainable development and providing social advantages in the warehouse industry. (Ali & Phan, 2022) .Despite the potential benefits of RFID technology and the positive research findings, several obstacles are impeding the widespread implementation of RFID in sustainable warehousing. (Bose et al., 2009). These challenges can be categorized as internal and external. Internal obstacles in the warehouse include the decision to implement RFID systems depending on the return on investment (ROI), as well as issues related to integrating these systems with existing businesses' legacy systems like WMS, enterprise resource planning(ERP), and customer relationship management(CRM). External obstacles include unreliable performance outcomes and a lack of standardized global standards. Safety and confidentiality concerns encompass both internal as well as external obstacles. (Lim et al., 2013). The absence of an integrated IT network poses an obstacle to the implementation of technologies like RFID, which rely on connectivity to meet organizational objectives. The integration of technology necessitates the establishment of a comprehensive infrastructure to support all functions and processes. The utilization of an ERP system is recommended for integrating current interfaces with legacy systems, enabling them to share data concurrently and function as a unified system. (Tikwayo & Mathaba, 2023). Privacy concerns arise when RFID-collected data falls into the hands of hackers. This poses potential problems. Organizations face new cyber-security hazards that were not present in the past. (Abugabah et al., 2020). One potential privacy concern associated with blockchain technology is the public visibility of blockchain transactions. (Liu et al., 2018).

The results of a SWOT analysis reveal that the implementation of RFID technology, warehouse management systems, Internet of Things-driven systems, and automation to enhance operational effectiveness and reduce carbon footprints, consumption of energy, and waste in accordance with sustainable development goals is facilitated through the adoption of Technology 4.0 technologies in smart warehouses. However, these benefits aren't without drawbacks; for example, implementing new technologies may necessitate substantial expenditures in facilities, machinery, and training, which can strain a firm's finances and human resources. Workers' opposition is to be expected, as is the complexity of incorporating novel innovations into preexisting warehouse processes. (Orellano & Tiss, 2022). Nonetheless, businesses can improve warehouse productivity, environmental reliability, and customer satisfaction through the formation of collaborative arrangements with technology developers and logistics firms, which could lead to the attraction of mindful customers and suppliers and, ultimately, an edge over rivals. However, there are also risks associated with carrying out the sustainable warehousing 4.0 framework. For example, the introduction of autonomous robots within the warehouse could lead to the loss of job prospects for warehouse workers.(VASILEVA et al., 2022). Furthermore, in underdeveloped nations, the broad adoption of Technology 4.0 in sustainable warehousing might be hampered by the absence of global standards and compatibility across various systems.(Jovic et al., 2020).

3.3.3 Leveraging technology 4.0 for enhancing circular economy in logistics practices

The circular economy (CE) is a new concept that focuses on extending the value of resources utilized in the creation, production, and distribution of goods and services. (Genovese et al., 2017) conducted a study. The circular approach differs from the linear business model by shifting from a take-make-use-dispose strategy to a take-make-consume-reuse-recycle approach. This transformation enhances the efficiency and sustainability of the business model. (Den Hollander et al., 2017) .Three methods exist for adopting a circular economy that is implementing strategies such as reducing resource loops, designing long-life goods, and extending product-life, the duration of product utilization is prolonged, leading to a deceleration in the resource flow. Another strategy is to close resource loops by recycling, which creates a circular flow of resources between post-use and manufacturing. Additionally, resource effectiveness can be employed to reduce the amount of resources used per item. (Bocken et al., 2016). The circular economy is regarded as a sustainable manufacturing and consumption model that promotes sustained development. A circular economy is primarily associated with reverse logistics. The circular economy is significantly impacted by the emergence of Industry 4.0 technologies, which are applied in key areas of demand. Logistics operations contribute to resource effectiveness in the circular economy. The Internet of Things (IoT) can be utilized to create a structure that enhances efficiency by collecting real-time data on resource utilization, including natural resources while making informed decisions according to this data. This structure facilitates tracking and recognition of inefficient processes and provides recommendations for their optimization. Autonomous vehicles, typically equipped with electric drive systems, autonomously choose and navigate the most efficient routes without the need for human drivers. This technology plays a significant role in conserving natural resources, particularly fuel. Artificial intelligence, along with big data and data mining, can help identify opportunities for resource optimization in logistics processes such as transportation, inventory management, ordering, and warehousing. Efficient logistics planning minimizes energy usage and resource utilization, including personnel, finances, and time, by improving allocation and capacity planning. (Krstić et al., 2022).

Reverse logistics is a vital aspect of the circular economy as it involves the movement of products from customers to producers. Reverse logistics is an essential component of a closed-loop supply chain. Without it, the product flow usually ends with customers disposing of the goods in landfills. Reverse logistics is a crucial component in establishing a closed-loop system. (Govindan et al., 2015) . Nevertheless, a considerable amount of resources continue to be disposed of in landfills rather than being reclaimed. Industries are increasingly under pressure to tackle sustainability issues such as resource depletion, climate change, waste, and toxicity resulting from the linear economic system. As a result, companies now recognize the significance of implementing reverse logistics. (Mallick et al., 2023) . Big data analytics, smart products, and cyber-physical systems enable the evaluation of end-of-life (EOL) product recovery via steps like return, assessment, sorting, disposition, restoration, recycling, reuse, and remanufacturing. This enhances the circular economy and improves the efficacy of Logistics 4.0 by integrating technology and losing material loops within an economic system. (Strandhagen et al., 2017).

Artificial intelligence (AI) in reverse logistics has significant potential for positively transforming the circular economy. (Sun et al., 2022) Mechanical intelligence pertains to the capacity for automated execution of repetitive tasks. Although it may not seem particularly intelligent, it plays a crucial role in numerous mechanical operations. Mechanical intelligence refers to the capacity to carry out repetitive operations automatically. Although it may not be perceived as highly intelligent, artificial intelligence (AI) is crucial for various tasks due to its notable superiority over humans in terms of consistent performance. This is particularly evident in the case of service robots. Analytical intelligence refers to the capacity to effectively process data in order to solve challenges and acquire knowledge. This intelligence is necessary for executing intricate and methodical tasks, particularly ones that involve a significant amount of information and data. The primary analytical uses for AI include machine learning and data analytics. Intuitive intelligence refers to the capacity to engage in creative thinking and adapt successfully to unfamiliar circumstances. Recognizing is an essential aspect of intuitive AI that sets it apart from analytical AI. Empathetic intelligence refers to the capacity to perceive and comprehend the emotions of others, react in a suitable emotional manner, and impact the emotions of others. Empathetic AI represents the latest and most modern iteration of artificial intelligence, with very limited applications in the service sector. (Huang & Rust, 2018).

AI can assist in designing a reverse logistics network. AI can offer more reliable and quantitative techniques for multi-criteria group decision-making approaches in situations where human evaluation is inaccurate, subjective, and prone to being biased. Intuitive AI applications can evaluate the need for outsourcing specific tasks and rank potential vendors accordingly. Intuitive AI applications were employed to evaluate and choose suitable third-party logistics (3PL) providers. The selection process for prospective providers involves evaluating various criteria such as specialization, cost, reliability, customer service, environmental considerations, and adaptability Return quantities are impacted by various factors, especially the cause for return (e.g., defective products or end-of-life returns), population density, and environmental consciousness. Analytical AI can enhance warehouse operations by predicting return quantity and providing better decision support for managing inventory, thus reducing uncertainty. Collaborative robots, known as cobots, equipped with machine learning features are currently being utilized in various warehousing environments. Cobots, from a reverse logistics standpoint, can benefit humans in multiple tasks such as pattern identification in product conditions, failure diagnosis, specific component detection, interpretation of testing equipment outcomes, and communication with other machinery and systems. Both analytical and intuitive AI depends on machine learning, which necessitates large data sets for optimal performance. However, acquiring such data sets can be challenging or even unattainable, especially during the initial stages of implementation. Additionally, the intricate nature of machine learning poses challenges in providing explanations for specific decisions or predictions. (Wilson et al., 2021).

The Internet of Things (IoT) offers potential improvements in waste management processes, which have historically been complicated and time-consuming for gathering, transporting, and recycling. (Garrido-Hidalgo et al., 2020). Industry 4.0 utilizes cloud-based resources and IoT technologies to gather data on societal behavior. This data is then used to enhance operational metrics and optimize resource utilization for improved economic and environmental outcomes. (Rymaszewska et al., 2017)The integration of IoT, CPS, and cloud services is essential for ensuring the sustainability of energy and materials in a circular economy. Sensors and RFID tags can enhance the effectiveness of reverse logistics operations by improving product monitoring, tracking, and transportation modes. Hence, components can be recovered through processes like reuse, remanufacture, and recycling. (Vanderroost et al., 2017) The integration of RFID, Bluetooth low energy (BLE), advanced sensors, and smart containers in a networked CPS enables real-time collection of data from reverse logistics processes. This data includes returned merchandise identification and categorization, local as well as global information. It can be utilized for enhanced control of inventory and environmental oversight of the entire process. (Garrido-Hidalgo et al., 2019) .

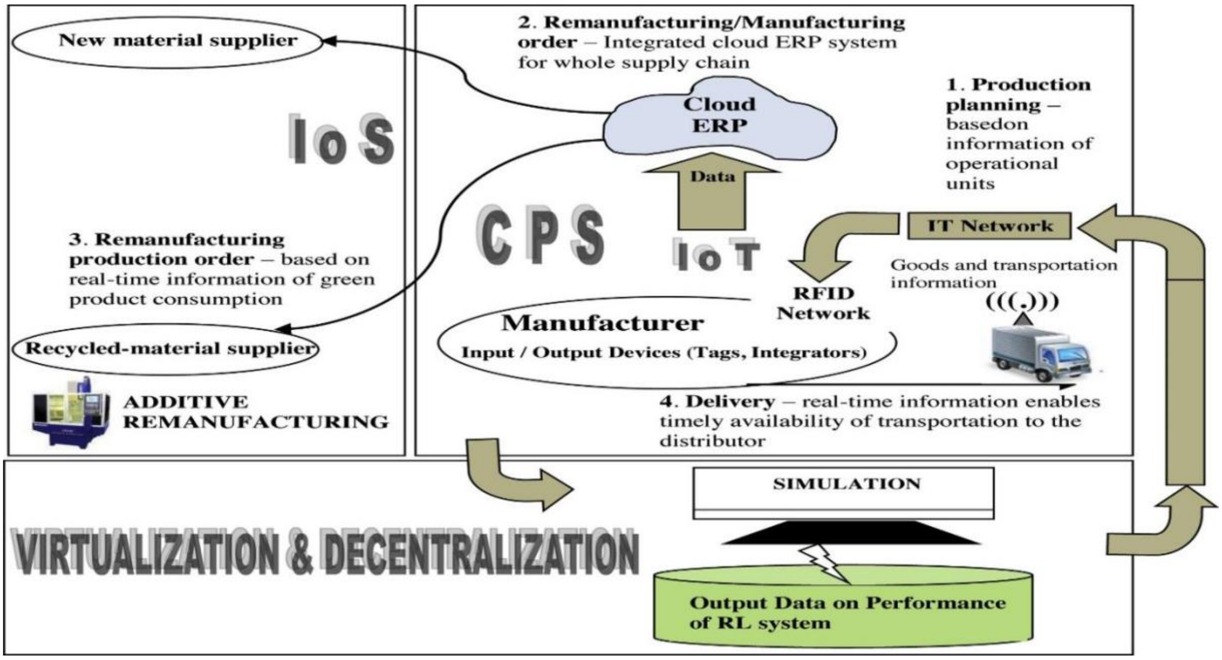


Figure 3.3.3 - Reverse logistics system for circular economy according to principles of Industry 4.0 (Dev et al., 2020)

An IoT-based system that can forecast and monitor waste levels in various sizes of existing collection bins. The system utilizes a smart neural network structure to evaluate and foresee waste generation patterns. It then sends updates to relevant personnel through a Firebase cloud messaging system. Additionally, it provides a dynamic web data dashboard. (John et al., 2021). A cloud-based automated system for revolutionary waste collection services is developed, where this system utilizes smart sensors, data, and optimization algorithms to create a smart CPS. Its purpose is to ensure real-time data transmission for end-of-life product collection in reverse logistics. Recent advancements in artificial intelligence (AI) and vision-based technologies have enabled intelligent robots to effectively identify and sort various recyclable materials. This technology has the potential to significantly impact reverse logistics activities. (Wilson et al., 2021).

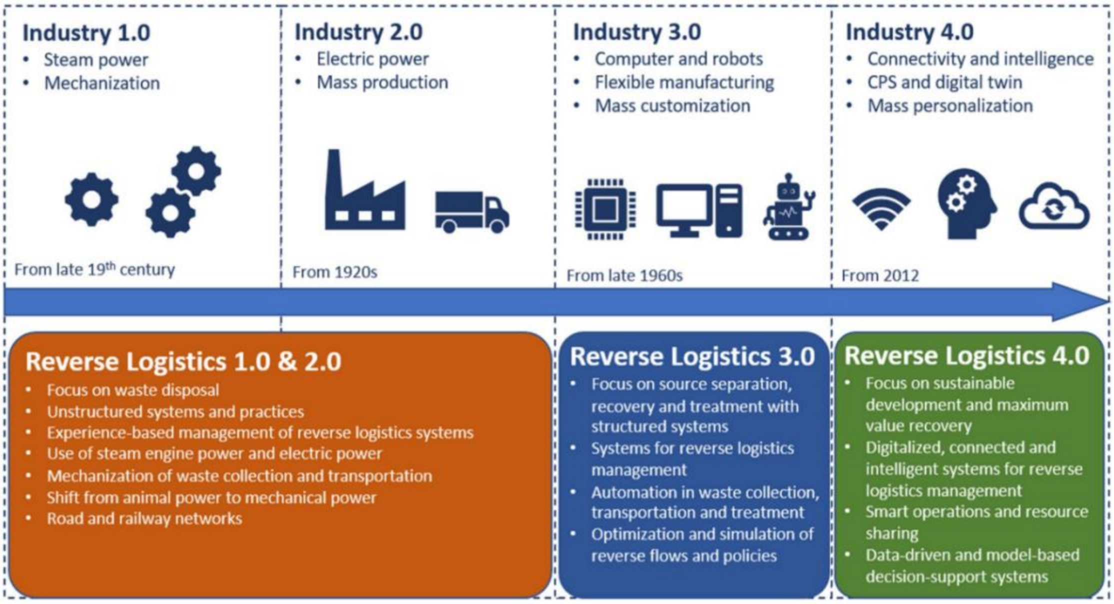


Figure 3.3.3.1 - Evolution of reverse logistics alongside each industrial revolution. (Sun et al., 2022)

IoT-based smart platforms are utilized for optimizing demand allocation and routing of transport vehicles. Real-time vehicle data is gathered from various sources such as GIS, IoT sensors, 4G/5G devices, RFID, and GPS devices. This data is subsequently analyzed to align with the task data provided by multiple businesses. The optimization of routing decisions aims to maximize the efficiency of vehicle utilization for numerous tasks across various companies.

The system can be optimized by incorporating real-time traffic data for dynamic route planning. This optimization aims to reduce fuel consumption, emissions, and traffic congestion. (Sun et al., 2022)

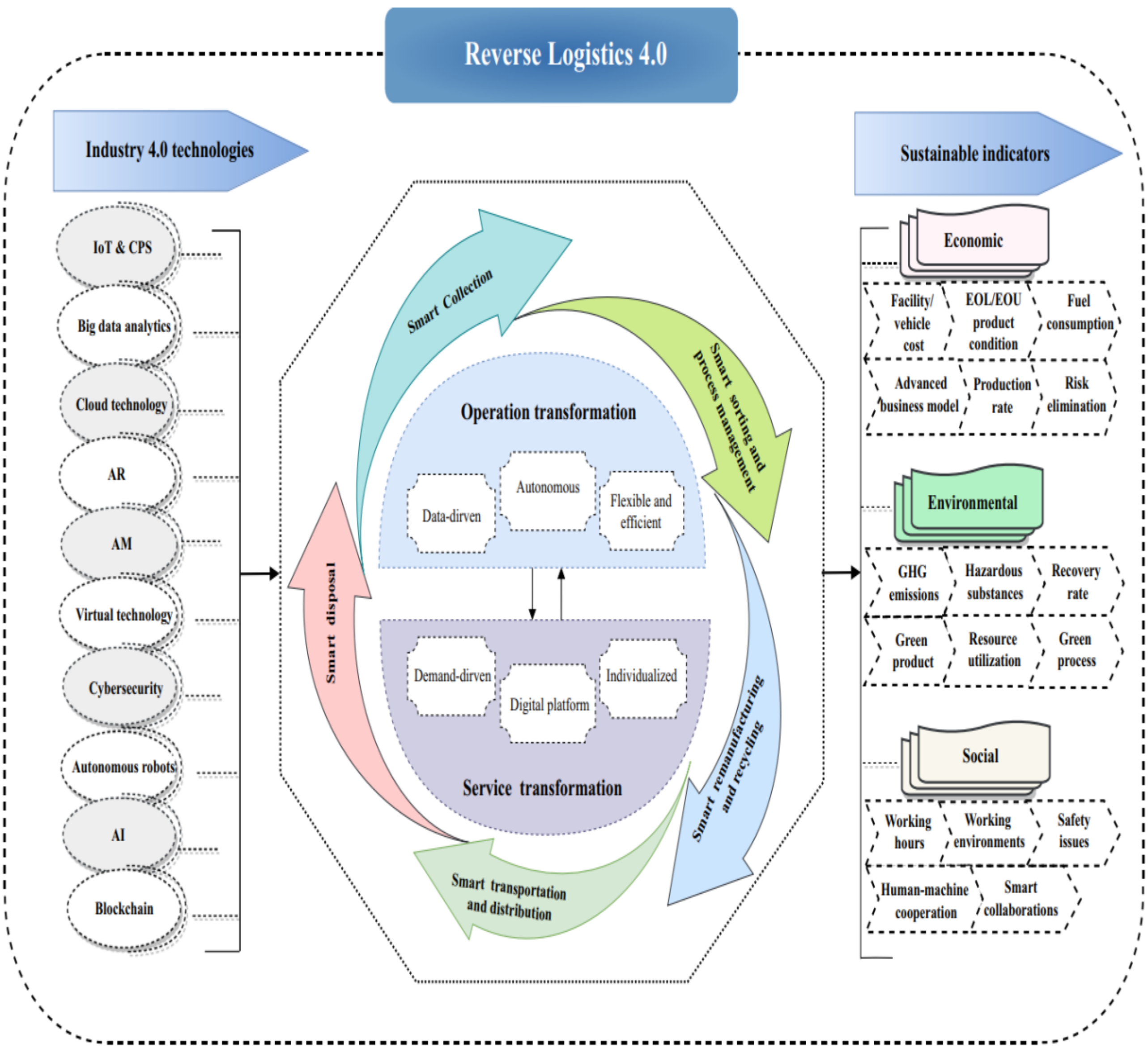


Figure 3.3.3.2 A conceptual framework of smart and sustainable reverse logistics transformation with Industry 4.0 technologies. (Sun et al., 2022)

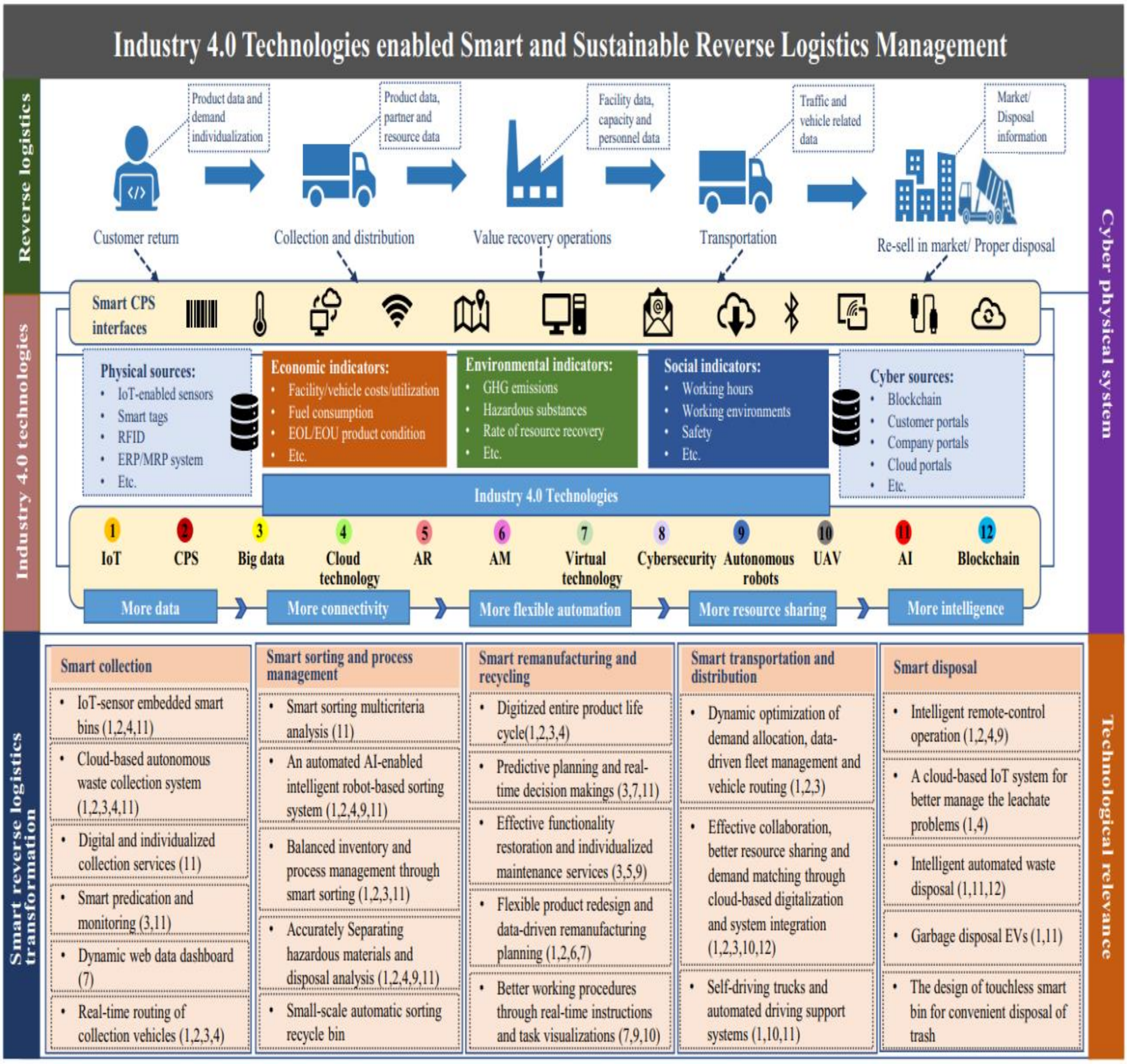


Figure 3.3.3.3 - Industry 4.0 Technologies enabled smart and sustainable reverse logistics management for circular economy. (Sun et al., 2022)

Circular economy (CE) flows can have a negative environmental impact as they do not reduce the need for natural resources, energy, and water, regardless of their implementation. Another drawback of CE is its connection to the laws of thermodynamics. Recycling procedures necessitate energy and produce waste and by-products as a result of entropy. The circular utilization of materials can increase flows, leading to higher energy requirements and a decrease in the economic and environmental equilibrium of an ecosystem. Hence, the implementation of CE practices may lead to a higher rate of ecological depletion. (Korhonen et al., 2018) . The Internet of Things (IoT) aids in promoting sustainability by collecting real-time data, which facilitates the effective management of manufacturing systems. This, in turn, leads to improved proficiency in predicting demand and controlling inventory. Digital and virtual technologies can impact production lead times by decentralizing production. The distance between demand and supply can affect response duration and delivery credibility. (Chen et al., 2015).. Strategic concerns related to the combination of Industry 4.0 and circular economy principles involve political, regulatory, and societal factors. To address these concerns, management must demonstrate commitment to standardizing procedures, ensuring compliance, and driving growth through employee training and education on the strategic advantages. In addition, employees must adopt a proactive perspective and accept change without resistance. Streamlining these activities necessitates the initial dedication of the highest management. (Chauhan et al., 2019). . The economic barrier to adopting Industry 4.0 technologies for supporting a circular economy is the insufficient investment in capacity and expertise in the industrial sector regarding smart production and novel technologies. Additionally, there are concerns about the compatibility between the potential of industry 4.0 technologies and the establishment of innovative circular business models. (Cezarino et al., 2019). The use of sensors and robots in recycling facilities has been found to enhance sorting processes, leading to improved recycling rates, increased resource efficiency, and reduced costs. However, limited financial resources and technological infrastructure can hinder the positive correlation between the integration of Industry 4.0 technologies and a circular economy structure in terms of lowering expenses.(Lopes de Sousa Jabbour et al., 2022) The development of the circular economy faces several challenges that can be addressed by implementing industry 4.0 technologies. These challenges include supply chain complexity, lack of cooperation between businesses, insufficient information for product design processes, quality concessions, lengthy disassembly times, and elevated expenses. (Jaeger & Upadhyay, 2020). The interconnection between reverse logistics and the circular economy means that barriers to adopting reverse logistics 4.0 also hinder the development of the circular economy. Companies may face challenges in marketing recycled goods due to the limited availability of established recovery marketplaces and uncertainties regarding the quality and timing of returns. Customers are crucial in reverse logistics initiatives. However, a lack of consciousness or encouragement to return end-of-life products poses a significant obstacle to implementing reverse logistics and the circular economy. (Waqas et al., 2018; Prakash & Barua, 2016).

Using a SWOT analysis, we can see that the benefits of adopting industry 4.0 technologies include enhanced functioning, economic, and sustainable supply chain effectiveness; increased material flow; and decreased life cycle effects upon firms' ability to grow. Automation has the potential to increase human safety during the separation of hazardous waste while decreasing the occurrence of errors like accidents at work, both of which contribute to social sustainability as a whole. With the help of optimization algorithms, IoT-enabled platforms can provide real-time information on waste generation patterns and modes of transportation, allowing for more efficient logistical processes and a more sustainable circular economy. (Lu et al., 2022). Transport routes and even the degree of aggregation can be optimized with the use of advances like big data analytics and CPS, resulting in lower emissions and more support for environmental sustainability.(Strandhagen et al., 2017). . Businesses ought to be flexible throughout the process of adoption because there are some limitations, including the fact that implementing CE is time-consuming due to the time-consuming nature of collecting the necessary resources and customizing them according to business demand. (Bag et al., 2022). Both AI and ML require extensive data sets to function properly. Early adopters may find it difficult to get enough data on which to train their algorithms. The energy needed for recycling and processing could potentially cancel out a few of the environmental advantages of technology 4.0, which can improve resource effectiveness. Conservation of resources and reasonable use of energy requires careful balancing. (Lu et al., 2022). Opportunities to eliminate unethical behavior may also present themselves in the form of new developments. To increase consumer interest in recycled goods and boost consumers' environmental and ethical consciousness, businesses might launch marketing initiatives centered on the concept of resource circularity. Trusting suppliers and involving them in R&D initiatives connected to technology-integrated circular economy business structures is crucial. Because of this, CE purchasing policies will become more moral and accountable. (Bag et al., 2022). When businesses use the technologies of Industry 4.0, they may drastically increase material efficiency by eliminating material waste across the entire organization. By increasing data accountability all the way through the supply chain, smart green logistics helps businesses minimize carbon emissions and promote a more circular economy by decreasing wasteful processes like unneeded product flows, transportation, and distribution inaccuracies (Lu et al., 2022). Threats exist alongside opportunities because of the many resources needed to propel industry 4.0 technology-integrated CE business models, which necessitate substantial initial investments, breakthroughs, and strict monitoring to prevent unethical practices. (Bag et al., 2021)

3.3.4 Last-mile Logistics Challenges and mitigation strategies

More than $4.5 trillion are invested each year on e-commerce along with online retailing combined within worldwide. The last mile of product delivery to its end-user or location of purchase, also mentioned as the last-mile logistics, can often be considered as the most essential phase within the purchase fulfilment approach (Gevaers et al., 2011). Globalisation, economic growth, growing populations, urbanisation, and multichannel retailing are the key factors influencing the continuous rise in urban freight flow. As a result, there are more issues with transportation, including accidents on the roads, noise pollution, and the emission of greenhouse gases (Bosona, 2020). Similarly, due to some of the distinctive limitations of this operating environment, such as substantial amounts of congestion, increased regulation, and inadequate availability of targeted logistical facilities, last-mile deliveries in urban areas establish different levels of difficulties on the e-fulfilment process. Additionally, concerns about the viability of doorstep delivery services for online orders are raised by the ongoing e-commerce boom (Janjevic & Winkenbach, 2020). Reverse logistics is the operation of the transit of goods from consumers to manufacturers, suppliers, and retailers. Additionally, reverse logistics is becoming more difficult because of the increase in returns brought on by e-commerce, which leads to carbon emissions (Siegfried et al., 2021). In addition, the COVID-19 pandemic became an initiator that accelerated a pattern towards increasing the number of shipments from distribution and fulfilment centres to particular residences, substantially raising the requirement for last-mile logistics optimisation (Mehta & Levy, 2020). Due to the rise in personalised deliveries initiated by e-commerce, it is clear that the social and environmental effects of freight transportation chains are expanding. Given that last-mile logistics also led to transportation challenges and other environmental concerns in cities, it is important to assess their impact (Viu-Roig & Alvarez-Palau, 2020).

The latest technological advancements and innovations connected to Industry 4.0 have still provided businesses a new opportunity to improve their green logistics practises and preserve their organisational value by quickly and effectively responding every customer's requirement in a sustainable way (Paksoy & Deveci, 2023). Organisational, technology-enabled, and data-technique-enabled are the three types of last-mile innovations. In the first group, various crowdsourcing techniques or last-mile organisation methods can be utilised. Drones and autonomous vehicles are two additional important examples of current innovations in technology. Finally, data-supported innovations involve ideas using automation, big data, machine learning, data analytics, and other technologies 4.0 to optimise the last mile's logistics (Viu-Roig & Alvarez-Palau, 2020).

Industry 4.0 technologies consisting of the Internet of Things (IoT), artificial intelligence (AI), and cloud computing have the capability to be implemented in last-mile logistics processes because they support decision-making and process improvement and provide useful information for process optimisation. Smart logistics signifies an extended utilisation of ICT technologies in combination with industry 4.0 technologies. As a result, they are a vital resource to ensure maximum use of available resources and optimising logistical flows within business systems as well as throughout entire supply chains (Kolasińska-Morawska et al., 2022). For instance, the ability of decision-makers in businesses to assess various logistics plans for the long-term sustainable optimisation of logistics infrastructure by using green decision support systems (GDSS). The primary goals of green decision support systems is to create a balance sheet for the energy resources consumed during every task and the resulting environmental effects to be able to determine the impact of each ecologically adverse parameter. Using GDSS for automated planning and vehicle capacity use optimisation could be another approach to increase efficiencies in logistics (Gruchmann, 2018). Infrastructure and vehicles utilise Industry 4.0 technologies, enabling a new method of adaptability. With the help of IoT sensors, it is now possible to monitor on a variety of vehicles characteristics, including fuel usage, both while driving and while the car is parked. All this data can be processed to improve preventative maintenance and the economic, social performance, and environmental of last-mile logistics (Ranieri et al., 2018).

If logistics firms manage to provide both 3D printing and delivery services through their local 3D printing shops, they may be capable to create a new business possibility (Wieczorek, 2017). For instance, Amazon Technologies, Inc. has recently filed patent applications for mobile manufacturing that allow delivery companies equipped with 3D printers to simultaneously take and fill orders. By strategically utilising the process of delivery, which was once considered as an additional cost for final shipment, mobile manufacturing is predicted to provide a new method for reducing order lead times (Na et al., 2021). The current strict division between manufacturing and logistics will be eliminated by this innovative form of logistics, which will also offer an extensive amount of adaptation and competitiveness in supplying finished goods to customers (Boon & van Wee, 2017).

Current Industry 4.0 technology development is concentrated on advancing the use of driverless vehicles or autonomous modes of transportation within last-mile logistics (Dabic-Miletic, 2023). There are at present five categories of Autonomous driving, which has been assessed by Continental for more than 50 years. Three levels are currently utilised for the distribution of supplies, about the fourth level it is expected to be carried out in 2025 and full autonomy to the fifth extent envisioned by 2027. Levels 4 and 5 are anticipated to be fully utilised for last-mile logistics operations by 2030 (Fritschy & Spinler, 2019). Additionally, robots for delivery or unmanned ground vehicles (UGVs) can improve last-mile logistics efficiency in a sustainable manner. Combining UGVs and delivery vans can provide more environmentally friendly options than using only delivery vans as a feasible option. UGVs are free of any emissions because they operate by renewable energy. Starship Technologies had been experimenting with these autonomous delivery robots as assistants as a successful trial. The conventional delivery van serves the customer in their delivery system while also serving as a mothership for their robots. Robots can be sent to their aimed buyers once the van is parked, then they can come back to the same location to meet the mothership van (Demir et al., 2022). Automatic delivery robots (ADRs) come in two different kinds: road autonomous delivery robots (R-ADRs), which share the road with different motorised vehicles, and sidewalk autonomous delivery robots (S-ADRs), which only use walkways or bicycle paths (Engesser et al., 2023). Adopting either of them has barriers because S-ADRs do not satisfy the legal standards for motor vehicles and might call for additional caution in regard to governmental regulations (Hoffmann & Prause, 2018). However, if R-ADRs are added to the road without other vehicle types being replaced, congestion levels might rise rather than fall (Engesser et al., 2023).

Figure 3.3.4 - Sidewalk autonomous delivery robots: S-ADRs (left) and Road autonomous delivery robots: R-ADRs (right). (Engesser et al., 2023)

The last-mile delivery of goods, transportation, and city logistics are now thought to be particularly viable for electric-powered vehicles when used in conjunction with close to distribution facilities (Gruchmann, 2018). Hybrid and electric vehicles are now capable of taking the place of lighter transportation because they generally reduce greenhouse gas (GHG) emissions and improve the quality of the air in urban areas. Additionally, it has been demonstrated that these vehicles produce less noise pollution and could assist with urban logistics problems (El Moussaoui et al., 2022). Additionally, when compared to PHEVs and conventional vehicles, electric vehicles (EVs) emit significantly less carbon dioxide. Commercial EV purchase costs are three times higher than those of traditional diesel trucks, but traditional trucks' operating costs are nearly four times higher. Electric vehicles' limited range and lengthy battery recharge periods are the only drawbacks to their commercialization (Digiesi et al., 2017). Additionally, since this technology is so new, there aren't as many charging stations as there should be. However, there may also be ways to address this particular issue with EVs. The first is Sweden's implementation of an electrified road that will recharge the batteries of cars and trucks driving on it. The second solution also involves substituting graphene supercapacitors for the traditional Li-ion batteries currently found inside EVs. Because of their high energy performance and limited space, graphene supercapacitors enable quick charging while reducing overall vehicle weight. The automobile's projected range on one full charge is up to 310 miles, making it comparable to the range of a gasoline-powered car and nearly twice that of an electric car in use today. when compared to Li-ion batteries, these supercapacitors have the additional benefit of being less hazardous to the environment when eliminated Therefore, it would create a circular economy and pave the way for sustainable last-mile logistics (Awwad et al., 2018). The road network specifically designed for this form of transportation is still insufficient and has limitations, even though both the national and local governments are encouraging the implementation of electric cars for logistics service providers to reduce emission levels and improve air quality in cities (El Moussaoui et al., 2022).

3.4 Summary

This chapter emphasized the importance and applicability of Industry 4.0 technologies and green logistics separately. This study examined the integration of technology and sustainable logistics, establishing a basis for their application. This study examined the impact of blockchain technology on transparency and traceability in green logistics operations. The review examined how Industry 4.0 technologies contribute to enhancing green warehousing and supporting circular practices via improved reverse logistics processes. This study thoroughly examined the obstacles of last-mile logistics and explores potential approaches for mitigating these challenges. Theoretical evidence from this literature review would guide the following chapter, which will include case studies from the real world. This study aims to identify research gaps within the implementation of Industry 4.0 technologies in green logistics through contrasting case studies with theoretical results.

CHAPTER 4. DATA COLLECTION AND ANALYSIS

4.1 Introduction

In the last chapter, we analyzed the prospective benefits and drawbacks of combining Industry 4.0 and green logistics in great detail. However, looking at real-world instances that illustrate the practical ramifications of this integrated framework is crucial for a thorough comprehension of the research thesis. Therefore, this chapter examines two separate case studies of successful corporations: DHL, a worldwide logistics service, and Ocado Group, a top British retail giant. This section examines in depth the approaches taken by these companies to apply the integrated framework in order to revolutionize their last-mile solutions, optimize their warehousing procedures, and improve the efficiency of their reverse logistics operations. Moreover, doing an in-depth examination of these case studies will provide a comparative evaluation of the two organizations, encompassing an assessment of their best practices as well as the problems they encountered. The utilization of a comparative strategy in this study will establish a connection between theoretical research and practical execution. This technique will enable the identification of greater insights and gaps, which will be further examined in the subsequent chapter.

4.2 Case Study 1 - DHL

DHL is recognized as the largest global postal and logistics firm, with a presence spanning around 220 nations and territories. The organization has significantly transformed the field of logistics through its proactive adoption of industry 4.0 technology, in conjunction with the implementation of sustainable logistics practices.(DHL, At a glance). The strategic plan of Deutsche Post DHL Group (DPDHL Group) for the year 2025 aims to achieve superiority in a digital environment. To accomplish this, the company has allocated more than €2 billion towards digital transformation initiatives. These initiatives involve the implementation of Radio Frequency Identification (RFID) sensor-based Internet of Things (IoT) technologies, automation, artificial intelligence (AI) robots, and big data analytics. The primary objective of these investments is to enhance the satisfaction of both customers and employees, while simultaneously improving operational efficiency and sustainability within the organization's operations. DHL has utilized Big data analytics and the expertise of Predictive analytics in the Advanced Quality Control Centre system (AQCC), which is driven by AI. This system aims to track the flow of shipments, promptly detect any issues, and determine substitute flight or network routes. The objective is to improve transparency in DHL's global logistics operations. The AQCC system incorporates Artificial Intelligence (AI) and machine learning algorithms to effectively detect probable underlying factors contributing to blockages and provide suggestions for ongoing enhancement. (DHL, How Digitalisation has transformed DHL Express' operations - DHL Express Australia Hub 2021). The process of warehouse order fulfillment and order picking necessitates a substantial degree of physical exertion and the performance of recurring duties. DHL employs automated technological procedures, like smart picking robots or collaborative robots (cobots), as well as drones, to augment the efficacy of warehouse management. (DHL, Digital Supply Chain: What exactly is Logistics 4.0 all about?: DHL Express 2022)

The company has implemented the utilisation of DHLBot, an automated flyer sorting system that was collaboratively developed by the company and Dorabot, a provider of AI-powered robotic solutions. The DHLBot is an artificial intelligence-driven robotic arm designed to streamline the process of parcel sortation. Cutting-edge 3D and barcode cameras are employed to scan the airway bill affixed to each box, accurately determining its intended destination as it traverses the conveyor belt. The DHLBot, an artificial intelligence (AI) system, is strategically located at the termination point of the conveyor belt. It is designed to acquire comprehensive data about the package, including its destination, and afterward employs its intelligent capabilities to effectively categorize the package into specific delivery bins. These bins are situated on racks around the robot, with each bin corresponding to a distinct courier route. The implementation of this complete procedure resulted in a decrease in reliance on the manual reading of waybills and manual sorting of packages by workers, so enabling them to allocate additional time towards route planning. Furthermore, the implementation of the DHLBot has enhanced the process of manually sorting smaller packages and has facilitated the handling of larger quantities at hubs and gateways, particularly during periods of high demand. This has resulted in a notable improvement in overall operational efficiency, with an increase of at least 40 percent. The DHLBot demonstrates a remarkable capacity to sort a high volume of small parcels, exceeding 1,000 per hour, while maintaining an impressive accuracy rate of 99 percent. This advanced sorting capability has effectively minimized the occurrence of mis-sorting, eliminating the necessity for secondary sorting processes. Consequently, the use of DHLBot has resulted in a substantial enhancement of both parcel sortation efficiency and service quality.(DHL, DHL Express deploys AI-powered sorting robot 2021).

Stationary robots can be categorized into two distinct types: collaborative robots, which are specifically engineered to perform versatile tasks that involve human interaction, and industrial robots, primarily utilized in applications demanding substantial payload capacity, extensive operational range, and high velocity. Typically, industrial robots function within enclosed spaces, restricted off by security fences. DHL, a global logistics company, has implemented stationary robotics in its operations. EffiBOT is a consequence resulting from the implementation of DHL's advanced artificial intelligence and sensor technology. EffiBOT is a collaborative robot, sometimes referred to as a cobot, that has made notable advancements in the field of collaborative automated order picking. This technology represents a huge stride forward in enhancing warehouse operations. The implementation of this system enhances the efficiency and ergonomics of the warehouse picking process. (DHL, What's behind the robot boom in warehousing? 2021; DHL, Logistics 4.0: Interlinking the supply chain 2021). DHL foresees certain potential hurdles in the deployment of stationary robots in warehouses, which mostly revolve around the technical framework required and the associated costs of implementing such a widespread stationary robot infrastructure. Despite the ongoing advancement of automation in various processes, the presence of human oversight and support remains essential for applications. Consequently, achieving total automation without human supervision in the foreseeable future is improbable. Moreover, the scarcity of skilled personnel would provide a significant obstacle to the widespread adoption of such automation. The introduction of stationary robots or any other form of automation investment in warehouse facilities would necessitate an increase in safety infrastructure. Consequently, there would be a need to reevaluate the existing infrastructure and incur significant additional costs.(DHL, Stationary robotics). DHL utilizes Automated Guided Vehicles (AGVs) to effectively detect, convey, and arrange goods within the warehouse. These devices are designed to autonomously navigate the warehouse and carry out duties that were previously executed by human laborers. Furthermore, drones are employed for the purpose of conducting inventory audits, facilitating stocktaking processes, and locating misplaced objects within warehouse facilities.(DHL, Digital Supply Chain: What exactly is Logistics 4.0 all about?: DHL Express 2022)

DHL has adopted environmentally sustainable warehousing practices, as evidenced by the company's pledge to attain complete net zero-carbon warehousing by the year 2025. The organization has employed the usage of environmentally friendly electricity derived from sustainable and renewable energies in order to facilitate the energy operations of the warehouse. The organization has additionally utilized digital technologies and intelligent building management systems, resulting in decreased energy usage and thus contributing to the sustainable development objectives established by the United Nations. (DHL, Sustainability reports 2022)

DHL has transformed urban logistics through the implementation of electric vehicles for last-mile delivery, resulting in a more environmentally friendly and efficient system. DHL has significantly reduced its carbon footprint in last-mile logistics by implementing electric vehicles (EVs), including electric vans and cargo e-bikes, for urban pick-ups and deliveries. This has resulted in a reduction of approximately twenty-nine million tonnes of greenhouse gas emissions. Moreover, the efficiency of their movements in urban areas is further enhanced by utilizing smart route optimization software that is informed by real-time traffic data. The business has made investments in electric cargo planes to mitigate greenhouse gas emissions in its air fleet. (DHL, Sustainability reports 2022; DHL, Green Logistics is being assisted by this route optimization algorithm). The company has deployed approximately 15,000 battery electric trucks and 19,000 charging stations in an effort to decrease carbon emissions related to last-mile logistics. Sustainability initiatives have been implemented in Berlin, Sweden, the Netherlands, and the United Kingdom. (Adam, DHL: Pioneer in the use of Battery Electric Commercial Vehicles 2021). DHL foresees future obstacles in implementing electrified alternatives due to their limited availability for all vehicles and devices. Consequently, until these alternatives become more widely accessible, additional measures to reduce carbon emissions are necessary. The data used for calculating product carbon footprints (PCFs) and logistics emissions is frequently unreliable, generalized, decentralized, and translucent throughout supply chains. This lack of uniformity poses challenges in evaluating and comparing these values. Decarbonization solutions, like electric vehicles, typically necessitate substantial initial investments due to the need for chargers, specialized repair machinery, and staff retraining. Moreover, there may be potential downtime during the implementation process. As logistics providers invest in decarbonization approaches to meet demand, consumers may experience increased costs for products and services. (DHL, The challenging logistics of last-mile delivery; DHL, Decarbonization)

DHL and Formula 1 have collaborated to enhance sustainable logistics through the introduction of their initial truck fleet powered by biofuel, a recognized sustainable fuel. This technological advancement is a component of DHL's alternative fuel technology, which is being executed as part of their efforts to reduce carbon emissions and achieve NetZero status by 2030. DHL and Formula 1 intend to increase the deployment of sustainable trucks in the future, acknowledging their substantial sustainability benefits. (DHL, Launching a first truck fleet powered by biofuel to reduce carbon footprint 2023)

DHL has partnered with Tetra Pak in Singapore to set up an extensive smart warehouse, which is one of the first of its kind in the Asia-Pacific region. This facility also functions as a digital twin system. DHL has implemented digital twin technology in its warehouse operations through the use of IoT platforms and sensors. These tools provide real-time information to constantly update the digital twin. Industrial trucks are also commonly fitted with IoT sensors. DHL Supply Chain integrates these sensors with additional warehouse data to create a virtual representation which is then evaluated using digital twin technology. The implementation of these measures has led to reduced congestion within DHL's warehouse, as well as improvements in planning and workload allocation. It assisted live site access monitoring and real-time monitoring of environmental temperature systems, allowing for informed decision-making and improvements in operational and sustainable performance.(DHL, Smart warehouse with internet-of-things technology 2019). DHL foresees potential obstacles related to digital twin technology, specifically regarding the availability and reliability of real-time, high-quality data. Limitations in accessing data and adverse field conditions can hinder the acquisition of data and compromise the quality of a digital twin. Moreover, the implementation of digital twins necessitates substantial investments in sensor technology, model development, platforms, and meticulous maintenance. Moreover, the integration of digital twins with physical objects presents a security concern as it could provide cyber criminals with an additional avenue for disrupting a firm's operations. (DHL, Digital Twins).

DHL, in collaboration with Cranfield University, has recognized the significant role of logistics in addressing challenges related to the circular economy. This recognition is based on the involvement of member companies from the Ellen MacArthur Foundation's CE100, who are leaders in the field of circular economy. DHL has created the Reverse Logistics Maturity Model (RLMM) to evaluate and enhance return management in support of a circular economy. This model has helped DHL allocate resources and capabilities to enhance reverse logistics, specifically by prioritizing the 5Rs: returns, repairing, reselling, repackaging, and recycling.(DHL, Circular economy; DHL, A guide to reverse logistics – DHL Express 2022).DHL foresees potential obstacles in implementing circular practices in their logistics operations due to the limited design of products for reuse and recycling, which hinders the achievement of circularity principles. One challenge is the technical immaturity of waste capture and recycling technologies, despite their advancing nature. Recycling can be costlier than utilizing primary raw materials due to the limited availability of smart and affordable return solutions in certain areas. The inhibiting threshold for end customers to change their habits and fully embrace circularity is high.(DHL, Circularity).

4.3 Case Study 2 - Ocado

The Ocado Group is a prominent British-based online grocery retail business. Ocado Retail Limited has established a partnership with Mark & Spencer and is currently revolutionizing the online grocery industry through the implementation of the Ocado Smart Platform (OSP). OSP is a comprehensive eCommerce, fulfillment, and logistics system that leverages Industry 4.0 technologies to transform warehouse operations and last-mile logistics. Additionally, it contributes to the reduction of food waste throughout the supply chain of the business.(Ocado, Who we are).

The Ocado Smart Platform (OSP) encompasses the integration of six distinct technologies, namely Digital Twins, Big Data, Artificial Intelligence (AI), Robotics, Internet of Things (IoT), and Cloud Computing. The scope of OSP includes both automated warehouses and technical solutions aimed at achieving fully optimized and sustainable last-mile logistics. The demand forecasting algorithm employed by Ocado has the capability to accurately anticipate the sales figures for the extensive range of over 58,000 distinct products available for purchase on their online platform. The implementation of this approach has effectively enhanced the quality and accessibility of their products for their clientele, while concurrently reducing waste and inventory levels. Consequently, this initiative has made a significant contribution to the establishment of a circular economy. Ocado employs sophisticated routing and forecasting algorithms to effectively optimize their routing and planning processes, leveraging extensive data analysis. The aforementioned technologies perform around 14 million routing calculations and 600,000 modifications every second whenever a customer initiates or modifies an order. The route planning software possesses the ability to adjust promptly and effectively to various factors such as fluctuating road conditions, traffic patterns, and fuel levels. This software has demonstrated a reduction in energy usage and subsequently, a decrease in carbon dioxide emissions. Consequently, it has enhanced the efficiency of last-mile logistics operations with a sustainable approach.(DHL, Technology behind the Ocado Smart Platform).

The Ocado Group operates technologically advanced warehouses, commonly referred to as Customer Fulfilment Centres (CFCs). The CFCs mentioned refer to computerized facilities that are equipped with automated warehouses. These warehouses are operated by robotic systems that continuously gather data, around 5,000 data points per second, while connected to the power grid. The data collected by the bots is utilized for self-monitoring and alerting engineers about the need for repair, hence enhancing the efficiency of addressing unexpected downtime by proactively reducing it. Moreover, demand forecasting engines that utilize artificial intelligence (AI) have the capability to anticipate the potential orders that customers are expected to make throughout various time periods such as weekly, monthly, or yearly. These predictions are made by analyzing extensive volumes of recorded data and employing powerful pattern recognition techniques. This practice has facilitated the effective management of CFC's inventory, resulting in a significant reduction in food waste. The observed rate of 0.4% is significantly lower when juxtaposed with the prevailing industry average range of 2-3%.(Ocado, What is an automated ocado CFC? ; Marr, 2020).The grid employs machine learning techniques to dynamically re-optimize its operations in response to future demand forecasts for individual products, thereby contributing to the reduction of lead time.(Ocado, 2018)

Ocado has implemented simulations to create "digital twins" of their Customer Fulfilment Centres (CFCs) and identify operational efficiencies in their warehouse operations. This initiative has resulted in the recovery of over two million hours of warehouse run time. An automated Ocado Customer Fulfilment Centre (CFC) refers to a facility that utilizes advanced technology and robotics to automate the process of fulfilling customer orders. The utilization of digital twins has facilitated Ocado in the design and optimization of highly automated systems. Ocado employs simulations to produce data for training their Machine Learning models prior to the availability of actual data. Ocado employs digital twins beyond its storage facilities or CFCs. Digital twins are employed both upstream for customer demand forecasting and downstream for algorithmic modeling of vehicle routing. This enables the creation of a comprehensive digital replica of our e-commerce, fulfillment, and logistics system.(DHL, Our competencies)

Ocado employs artificial intelligence (AI) to optimize the timing of stock delivery to their warehouse, aligning it with the unpacking process. This approach minimizes the risk of fresh and frozen food spoiling while waiting to be loaded, thus promoting zero waste to landfill while upholding circular economy principles. Artificial intelligence (AI) is utilized for identifying the proximity of stock to its expiration date. Discounts or donations can help expedite the sale of the stock and contribute to achieving Sustainable Development Goal 2 of Zero Hunger. (Ocado, How we use AI explained; Marr, 2020).

4.4 Summary

Case study results show how DHL has implemented Internet of Things (IoT) platforms, sensors, and AI-powered systems to enhance its logistics and warehousing operations. DHL's efforts to cut its carbon footprint and pave the path towards a greener future include electrifying its last-mile logistics and using bio-fuel-powered vehicle fleets. Finally, the Reverse Logistics Maturity Model (RLMM) is DHL's primary tool for putting circular economy principles into practice. However, Ocado has taken advantage of Big Data, AI, robots, and the Internet of Things (IoT) with its Ocado Smart Platform (OSP). Warehouse management, demand prediction, and logistics route optimization have all been significantly improved thanks to this one platform. Ocado has minimized food loss by optimizing its automated warehouses with the help of Digital Twins and simulations. In conclusion, by completely accepting Industry 4.0 innovations and environmentally friendly logistics practices, both DHL and Ocado have proven their dedication to sustainability and innovation. There may be discrepancies between the theoretical conclusions outlined in the literature review and the practical use of the integrated framework, and these case studies have provided a unique opportunity to investigate these possibilities. To better evaluate the implications and the viability of adopting the integrated framework in various logistics situations, the next chapter will focus on identifying and critically analyzing these gaps, with a view that filling them will lead to the improvement and verification of the research findings.

CHAPTER 5. DISCUSSIONS & SOLUTIONS

5.1 Introduction

The primary goal of this chapter is to integrate the findings of the research with the knowledge gained through the literature review. The following section seeks to achieve just that by comparing the literature's theoretical knowledge of integrating Industry 4.0 technologies in green logistics with the real-world application observed in case studies, with the goal of highlighting any discrepancies that may occur. In addition, this section will provide ways to address the disconnect between theory and practice. Based on the findings of the case studies, these recommendations will help businesses better integrate Industry 4.0 technologies approaches into sustainable logistics.

5.2 Key Findings

The "Blockchain Technology for Green Logistics" literature review illuminated the prospective advantages and uses of blockchain technology in the context of green logistics. DHL and Ocado both were least inclined to adopt Blockchain technology in their logistics processes, as demonstrated by the case studies. As a result, the provided literature study can help shape a plan to integrate blockchain technology into logistics at both firms, thereby improving their environmental footprint. The literature assessment has focused on how blockchain technology has the potential to increase supply chain visibility by allowing for complete product tracking from manufacturer to consumer. This acceptance can facilitate the use of blockchain-based technologies by DHL and Ocado to monitor the flow of commodities throughout their supply chains. Because blockchain technology provides complete transparency into the logistics business, DHL and Ocado would be able to more effectively handle the physical state of shipments and ensure that they are in accordance with environmental requirements.

DHL and Ocado could improve logistics efficiency and minimize delays through the optimization of documentation and automation of processes. DHL and Ocado have the potential to enhance collaboration with stakeholders in their supply chains by utilizing blockchain technology. Greater collaboration could encourage the reuse and traceability of packaging materials, promoting sustainable and socially responsible practices. This can enhance transparency, and economic viability, and contribute to the circular economy. The integration of blockchain technology in green logistics enables enhanced product and material traceability, granting customers access to comprehensive information regarding the origin, production methods, and environmental attributes of their purchased goods. Transparency can enhance customer empowerment in making educated choices and selecting environmentally friendly goods and services, in line with the business's dedication to sustainable growth and environmental responsibility, fostering a sustainable culture.

The decentralized framework of blockchain technology enables all stakeholders in logistics, such as consumers, vendors, and logistics providers, to contribute to the network and access verified and reconciled information, as supported by the literature review. Implementing blockchain technology in the operations of DHL and Ocado might improve security measures and safeguard against illegal practices, such as false responsibility and data manipulation. This is crucial for maintaining the authenticity of green logistics processes.

The literature review concludes by discussing some of the obstacles that have been brought to light in regard to the widespread implementation of blockchain technology. DHL and Ocado can avoid these pitfalls in the creation of their blockchain infrastructure if they are conscious of them. The SWOT analysis included in the literature study provides an in-depth look at the positives and negatives of using blockchain technology for green logistics. DHL and Ocado can utilize this evaluation to determine the possible benefits and obstacles to integrating blockchain technology into their respective logistical processes.

The literature evaluation guides DHL and Ocado towards a more well-rounded and effective framework for incorporating blockchain technology into green logistics. DHL and Ocado might improve their sustainability efforts, have a smaller environmental effect, and advance circular economy practices by utilizing blockchain's accountability, safety, and effectiveness in logistics. Through gradual implementation, the revolutionary blockchain technology outlined in this road map will revolutionize the future of green logistics. DHL and Ocado's adoption of this paradigm would not only contribute to the achievement of Sustainable Development Goal 9 (Industry, Innovation, and Infrastructure) and Sustainable Development Goal 12 (Responsible Consumption and Production), but it would additionally address the two research questions (RQ1, RQ2) posed by the thesis.

DHL and Ocado are two organizations whose case studies show how automation and AI are used to boost warehouse efficiency, with both businesses also adopting renewable energy sources to sustain warehouse operations and therefore cut down on carbon emissions. However, there is insufficient data on whether the warehouse was built and operates in accordance with sustainable design and construction practices. Accordingly, it takes into consideration a globally recognized sustainability standard that must be set throughout the construction and operation of a warehouse, and this might be accomplished through LEED or BREEAM certification, as noted by the literature research.

The findings of the literature research highlight the importance of establishing a sustainable standard for warehouse building and management. Warehouse sustainability may be evaluated and enhanced using both the LEED and BREEAM certifications, which are both well-recognized and regarded in the industry. The design, layout, inventory management, energy conservation, and waste reduction of a building are only a few of the many facets of sustainability that are covered by these certifications. (Gladkih et al., 2019). DHL and Ocado could assure that their storage facilities are sustainable by obtaining LEED or BREEAM certification, respectively. These standards cover more than just technology developments, including environmentally friendly building layouts, effective use of materials, and ethical business practices. Their dedication to sustainable growth and their ability to promote good environmental impact might be strengthened by complying to such criteria.For example, (McKinnon et al., 2016)

It is essential for DHL and Ocado to enhance their initiatives by adopting recognized sustainable standards like LEED or BREEAM, despite the fact that they have accomplished tremendous achievements in employing artificial intelligence and automation to improve warehouse productivity and green energy to minimize energy usage. Both businesses would benefit from a more all-encompassing strategy for sustainable warehousing if they worked together on issues like operational efficiency, green warehouse layout, and the incorporation of Industry 4.0 technological tools. The third objective of the research thesis will be attained if they adopt this all-encompassing strategy, as it will strengthen their dedication to sustainability and make significant contributions to Sustainable Development Goal 9: Industry Innovation and Infrastructure; Sustainable Development Goal 7: Affordable Clean Energy; Sustainable Development Goal 12: Responsible Consumption and Production; Sustainable Development Goal 13: Climate Change; and Sustainable Development Goal 11: Sustainable Cities and Communities.

The literature study emphasizes the importance of incorporating Industry 4.0 technologies in conjunction with green logistics, with a particular focus on transitioning from a linear to a circular approach in order to attain sustainable practices. Although both DHL and Ocado use circular practices in their logistics operations, there is a scarcity of proof indicating their complete adoption of Industry 4.0 capabilities to effectively bolster these endeavors. While the case studies acknowledge the utilization and investment in IoT and AI technology for logistics processes, there is less empirical data to support the implementation of IoT and AI in the businesses' reverse logistics operations. The literature analysis offers significant insights into the adoption of Industry 4.0 technologies in reverse logistics and circular practices, facilitating the development of a strategic plan for attaining sustainable outcomes.

The literature evaluation clarifies the prospective influence of artificial intelligence (AI) on reverse logistics operations. DHL and Ocado have the potential to enhance their reverse logistics operations, encompassing activities such as return management, examination, sorting, repair, recycling, and reuse, through the implementation of artificial intelligence (AI)-based decision-making systems. By leveraging artificial intelligence algorithms to optimize such procedures, both companies have the potential to improve their resource efficiency, minimize waste generation, and augment the circularity of resources. The literature analysis also highlights the application of Internet of Things (IoT) technology in waste management, with a specific focus on its utilization in the areas of waste collection, transportation, and recovery. DHL and Ocado have the potential to integrate Internet of Things (IoT) enabled intelligent systems in order to enhance the efficiency of demand allocation and routing for their transportation trucks. The implementation of real-time optimization has the potential to provide several benefits, including but not limited to the reduction of fuel consumption, greenhouse gas emissions, and traffic congestion. These positive outcomes align with the principles of circular practices in the field of green logistics. Moreover, the integration of intelligent cyber-physical systems (CPS) and advanced robotic technology has the potential to greatly enhance recycling processes. DHL and Ocado may consider investigating the potential integration of intelligent Cyber-Physical Systems (CPS) within their recycling facilities, with the aim of automating the identification and segregation processes for various categories of recyclable materials. The implementation of intelligent robotic waste containers has the potential to optimize recycling procedures, enhance recycling rates, and enhance the overall efficiency of resource utilization within the circular economy. The findings derived from the examination of existing literature offer valuable guidance for DHL and Ocado in their adoption of advanced technologies to effectively pursue their circular economy objectives. By doing so, these companies can contribute to the fulfillment of Sustainable Development Goal 12, while also ensuring their sustained competitiveness within the dynamic logistics sector. Consequently, this approach aligns with the attainment of objectives 3 and 5, as well as addressing research questions 3 and 5.

The integration of Green Decision Support Systems (GDSS) into the logistics functions of DHL and Ocado has the potential to greatly augment their sustainability endeavors in the domain of last-mile logistics. The GDSS is a sophisticated technological solution that utilizes Information and Communication Technology (ICT) and Industry 4.0 technologies to assess and enhance last-mile logistics strategies with the goal of achieving long-term sustainability. By employing GDSS these organizations may make well-informed decisions aimed at minimizing energy usage, mitigating environmental impacts, and optimizing resource utilization across their logistics operations. The implementation of GDSS would provide numerous advantages for both DHL and Ocado. At the outset, this would facilitate the assessment of different logistics strategies with an emphasis on sustainability. The organization would develop the potential to evaluate the energy resources utilized in every operation and analyze the subsequent ecological impacts. Through a comprehensive understanding of ecological impact criteria, DHL can effectively detect specific locations where enhancements can be implemented to mitigate the environmental consequences associated with last-mile logistics. Additionally, GDSS has the potential to aid both DHL and Ocado in the automation of planning and optimization processes related to the utilization of vehicle capacities. Furthermore, GDSS enables DHL and Ocado to access up-to-date information regarding vehicle performance, facilitating the ability to make informed decisions in a timely manner pertaining to maintenance and operational enhancements. The system additionally has the capability to offer analysis and recommendations about the choice of environmentally sustainable last-mile transportation alternatives, including e-bikes, e-trucks, or drones, based on the specific needs of the company. Integrating Group Decision Support Systems (GDSS) into the logistical operations of both DHL and Ocado would provide these organizations with the ability to make better informed and environmentally conscious judgements. This integration would also align with Sustainable Development Goals (SDG) 7 and 13, so accomplishing objectives 1 and 3, as well as addressing research questions 3, 4, and 5.

CHAPTER 6. CONCLUSION & FUTURE RECOMMENDATIONS

6.1 Introduction

The concluding chapter of this research thesis presents a complete outline of the whole research study, spanning numerous chapters like the literature review, research methodology, real-world case studies, and concise analyses of the results of the research. This part clarifies the extent to which each chapter of the research thesis has contributed towards the attainment of the predetermined objectives and the resolution of the research questions as specified at the commencement of the study. In light of the existing research deficiencies, ithis section also suggest that future initiatives should focus on the adoption of the Triple Bottom Line (TBL) Framework and Life Cycle Assessment (LCA) to augment the evaluation and quantification of the efficacy of Industry 4.0 technologies within a green logistics framework.

6.2 Conclusions

Section 3.3 of the literature analysis provides an overview of the practices pertaining to the integration of green logistics with Industry 4.0 technologies. The study effectively addressed research objectives 2 and 3 andas well as research questions 1 and 3. It demonstrated that the utilization of Industry 4.0 technologies holds the potential in facilitating sustainable green practices within the logistics sector. These practices encompass efficient allocation of resources, reduced energy usage, waste minimization, and adherence to circular economy principles. Furthermore, the integration of Industry 4.0 technologies has the potential to contribute to a range of sustainable development goals. RQ2 was further examined by providing illustrations of how big data analytics and other technological advancements have contributed to the improvement of transparency and traceability in the context of green logistics operations.

In section 3.3.1 of the literature study, an analysis was conducted on the characteristics of blockchain technology, including transparency, traceability, and security. These properties were found to contribute to the improved efficiency and long-term viability of logistics operations, hence aligning with the research objectives outlined in objectives 1 and 2. This part further demonstrated that the utilization of blockchain technology for recording product and material data allowed customers to obtain pertinent information regarding the origin, quality, and environmental attributes of items. This accessibility empowered customers to make informed choices in favor of sustainable solutions, thereby effectively addressing RQ2.

The literature review in section 3.3.2 supports the use of Industry 4.0 technologies in green warehousing. This combination has resulted in enhanced operational effectiveness and reductions in carbon emissions, energy usage, and waste. This integration was in line with the green logistics KPIs, which greatly contributed to the achievement of Objective 1. The review highlighted the role of blockchain and RFID technologies in enhancing transparency and traceability in warehouse activities, thereby accomplishing objective 2. Furthermore, the study emphasized that IoT systems effectively regulate environmental conditions, minimizing waste and resource consumption. Additionally, the adoption of RFID technology enhances inventory management and facilitates continual restocking, thereby promoting closed-loop supply chains and waste reduction. These findings demonstrate that the incorporation of these technologies in warehouses aligns with the principles of the circular economy, solving RQ3 and RQ5.

Section 3.3.3 of the literature review examined how the adoption of Industry 4.0 technologies could boost circular practices. It was found that innovations like IoT, AI, and big data analytics could be used in green logistics to improve circular economy principles and achieve objectives 2 and 5. The utilization of IoT, CPS, and cloud services was essential in promoting circularity in logistics operations. These technologies provided real-time data on waste generation trends, transportation modes, and product conditions. As a result, they facilitated improved inventory control, a decrease in waste, and resource recovery in reverse logistics processes, effectively addressing RQ3. AI and machine learning have shown effectiveness in optimizing travel paths, waste collection offerings, and resource allocation. This has resulted in reduced energy consumption, emission levels, and waste in logistics operations, thereby addressing RQ5.

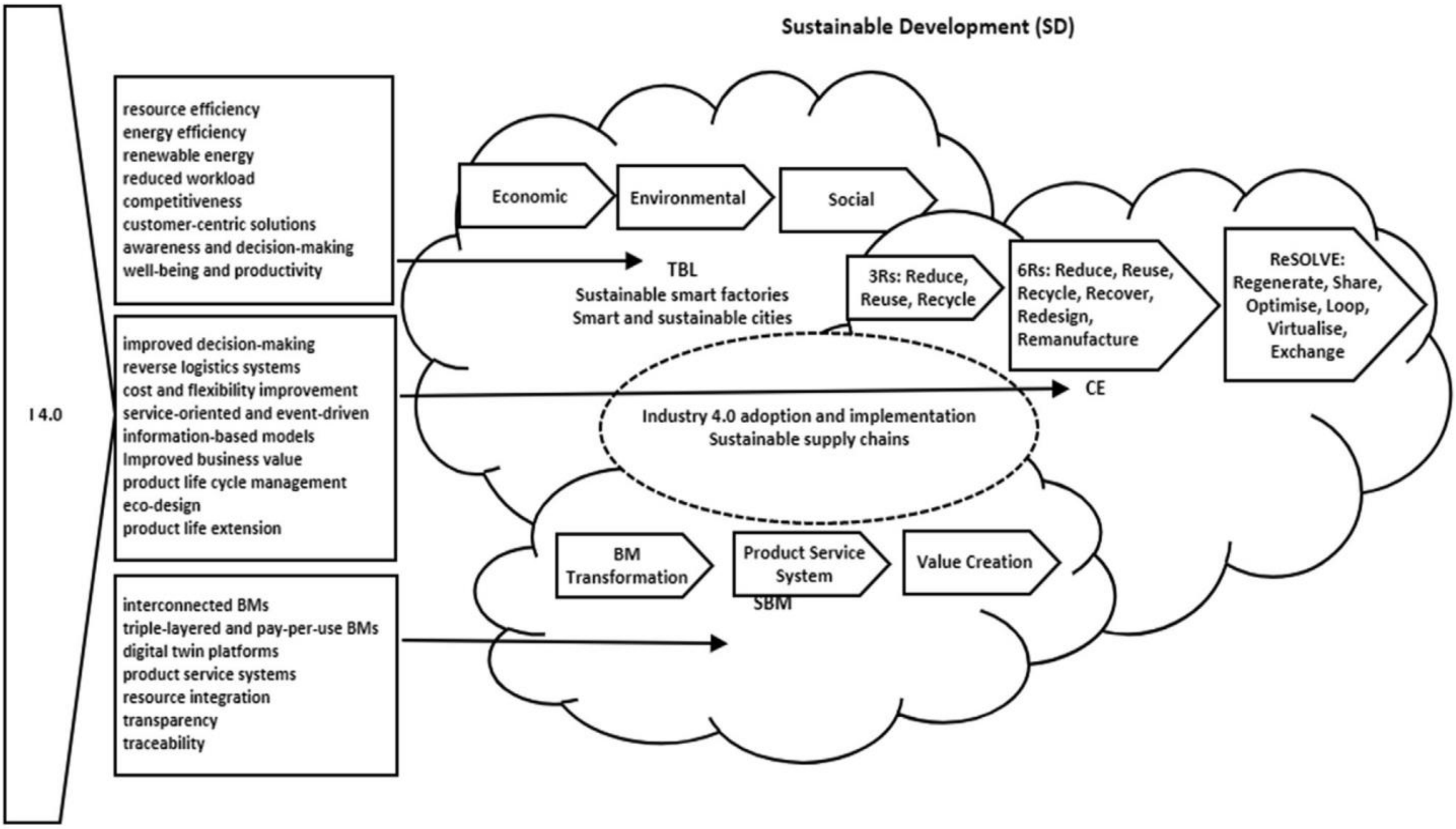
Section 3.3.4 of the literature review thoroughly examined the difficulties related to last-mile logistics in urban settings. The study examined the implementation and justification of technological innovations such as autonomous vehicles, delivery robots, and electric vehicles. These innovations were considered as possible ways to enhance the sustainability and effectiveness of last-mile deliveries, thereby mitigating the environmental effects of freight distribution networks. This contributed to the accomplishment of objectives 1 and 2, as well as research question 4. The integration of IoT, AI, and cloud computing has enhanced green logistics activities, resulting in improved power consumption and decreased environmental effects in last-mile transportation. This is achieved through the utilization of intelligent logistics and green decision support systems. This finding provided a response to RQ5.

The research philosophy, process, methodology, and data collection methods were essential in leading the dissertation toward accomplishing its objectives and addressing the research questions. The selection of interpretivism as the research philosophy in section 2.2.1 was crucial for comprehending the way businesses interpret and make sense of the integration of Industry 4.0 technologies within the realm of green logistics. Interpretivism facilitates the examination of the intricate and dynamic characteristics of the subject matter, enabling the capture of distinctive perspectives and the attainment of a more profound comprehension of the contextual elements that impact the integration of technology. Additionally, the utilization of the inductive approach discussed in section 2.2.2 greatly aided in achieving a thorough comprehension of the scenarios, while also capturing the complexities and variations inherent to the topic. It facilitated the development of new ideas, strengthening the theoretical basis of the study. The inductive approach is valuable for studying the evolving field of Technology 4.0 integrated green logistics, as pre-existing theories may not fully capture the complexities and emerging trends. Section 2.2.3 discussed the use of qualitative research methodology, which proved advantageous in the research process by enabling the investigation of subjective experiences. Qualitative analysis's versatility enabled the adaptation of research methods to incorporate arising perspectives, maintaining a strict and flexible investigation of the topic. The data collection method in section 2.2.4 involved the use of secondary data through case studies, which supported the qualitative research approach. Secondary data facilitated a comprehensive examination, verification of findings, and enhanced understanding of the historical development and previous obstacles encountered in the integration of Technology 4.0 in green logistics. The examination of specific instances involving DHL and Ocado offers a thorough comprehension of the intricacies and diversities in the implementation of Technology 4.0 in green logistics. By examining these real-world instances, we have identified practical implications for professionals in the logistics sector. The utilization of secondary data addresses the ethical issues associated with primary data collection. This is because secondary data has already been confidential and made accessible to everyone, thereby enhancing the ethical compliance of the investigative process.

6.3 Future Recommendations

The successful integration of Industry 4.0 technology with a green logistics framework requires the development of performance measurement tools, such as specific Key Performance Indicators (KPIs), to accurately review, track, and evaluate its effects. This emphasizes the significance of implementing a holistic framework that can assess the social, economic, and environmental aspects of sustainability within the realm of new technologies.

Figure: Industry 4.0, circular economy and TBL framework (Khan et al., 2021)



The triple bottom line (TBL) is widely regarded as the most contemporary and pertinent assessment framework for sustainable development. The Triple Bottom Line (TBL) encompasses three fundamental dimensions: economic sustainability, which focuses on maintaining financial stability and generating revenue; social sustainability, which contributes to the advancement of human and societal well-being; and environmental sustainability, which pertains to the responsible utilization of renewable and non-renewable resources. These three pillars, when collectively implemented, can contribute to the long-term viability of an organization. The integration of Key Performance Indicators (KPIs) derived from the Triple Bottom Line (TBL) inside this structure has the potential to yield several advantageous outcomes. These include enhanced utilization of resources, greater energy savings, alleviated workload, heightened competition and consciousness, enhanced decision-making abilities, and also bolstered employee well-being and performance. (Khan et al., 2021). Incorporating the Triple Bottom Line (TBL) framework into the measurement of Key Performance Indicators (KPIs) would ensure that the assessment of the combined technologies' effectiveness takes into account the three aspects of sustainability. In addition, the implementation of the Team-Based Learning (TBL) framework will effectively facilitate the achievement of equitable trade-offs. This implies that whereas specific technologies may provide benefits in one domain, they have the potential to create obstacles in another. One illustration of the impact of blockchain technology is its ability to augment transparency and traceability within green logistics operations. However, it is important to note that this technology also generates a substantial quantity of electronic trash. The TBL Framework enables enterprises to efficiently navigate these trade-offs by concurrently assessing several variables. This method promotes the identification of alternatives that maximize sustainability across the three areas. (Jayashree et al., 2021).

However, despite the fulfillment of the three objectives of the Triple Bottom Line (TBL) by Industry 4.0 technology, the aspect of social sustainability is frequently disregarded. The societal ramifications of intelligent technologies are insufficiently examined in relation to their accompanying economic advantages. As an illustration, the implementation of autonomous and semi-autonomous robots in substitution of human laborers for physical tasks ensures the provision of a safer working environment. However, it is important to acknowledge that this phenomenon will inevitably result in a reduction in employment opportunities, thereby exerting a detrimental impact on the social aspect of the Triple Bottom Line (TBL).(Ferraro et al., 2023).The integration of green logistics with recent advances in technology can be evaluated using the TBL Framework to determine its potential in contributing to broader sustainability goals, such as the United Nations' Sustainable Development Goals (SDGs). This evaluation can provide valuable insights for stakeholders and align with objective number 3. (Favi et al., 2022)

In addition, alongside the Triple Bottom Line (TBL), the Life Cycle Assessment (LCA) method serves as an additional comprehensive strategy or instrument utilized for the sustainable examination of goods, services, energy usage, and environmental effect. (Favi et al., 2022). Life cycle assessment (LCA) is a comprehensive method used for environmental accounting as well as management. It takes into consideration every facet of resource utilization and environmental emissions. LCA can be utilized to analyze the ecological impact of Industry 4.0 technologies in the context of green logistics. This assessment helps in understanding and evaluating the phases of integration that have the greatest adverse environmental effects. Therefore, the utilization of Life Cycle Assessment (LCA) enables a systematic evaluation of the environmental consequences associated with many alternative technologies. This assessment aids in the identification of advantages and favorable compromises among different possibilities. (Sartal et al., 2020). Life Cycle Assessment (LCA) is a comprehensive method used to assess the potential impacts of products all over their entire life cycle. It aids in identifying these impacts and can be instrumental in establishing targets and key performance indicators for measuring and promoting circular principles. This is particularly important when considering the integration of Industry 4.0 technologies within a green logistics framework. This also demonstrates a correlation and can be viewed as a possible guide to the literature discussed in Chapter 2, namely in section 3.3.3, while also addressing Research Question 3. (Ávila-Gutiérrez et al., 2019)

CHAPTER-7 REFERENCES

Abdirad, M., & Krishnan, K. (2020). Industry 4.0 in logistics and Supply Chain Management: A systematic literature review. *Engineering Management Journal*, *33*(3), 187–201. https://doi.org/10.1080/10429247.2020.1783935

Abugabah, A., Nizamuddin, N., & Abuqabbeh, A. (2020). A review of challenges and barriers implementing RFID technology in the Healthcare Sector. *Procedia Computer Science*, *170*, 1003–1010. https://doi.org/10.1016/j.procs.2020.03.094

Adams, J., A., K. H. T., & Raeside, R. (2014). *Research methods for business and Social Science Students*. SAGE Response.

Adam, T.-M. (2021, September 16). *DHL: Pioneer in the use of Battery Electric Commercial Vehicles*. DHL Freight Connections. https://dhl-freight-connections.com/en/sustainability/dhl-pioneer-in-the-use-of-battery-electric-commercial-vehicles/

Alharahsheh, H. H., & Pius, A. (2020). A Review of key paradigms: positivism VS interpretivism. *Global Academic Journal of Humanities and Social Sciences*, *2*(2), 39–43. https://doi.org/10.36348/gajhss.2020.v02i03.001

Aliakbarian, D. B. (2020, May 4). *Smart packaging: Challenges and opportunities in the supply chain*. CSCMPs Supply Chain Quarterly RSS. Retrieved June 5, 2023, from https://www.supplychainquarterly.com/articles/1853-smart-packaging-challenges-and-opportunities-in-the-supply-chain.

Ali, I., & Phan, H. M. (2022). Industry 4.0 technologies and sustainable warehousing: A systematic literature review and future research agenda. *The International Journal of Logistics Management*, *33*(2), 644–662. https://doi.org/10.1108/ijlm-05-2021-0277

Ali, S. S., Kaur, R., & Khan, S. (2022). Evaluating sustainability initiatives in warehouse for measuring sustainability performance: An emerging economy perspective. *Annals of Operations Research*, *324*(1–2), 461–500. https://doi.org/10.1007/s10479-021-04454-w

Allen, S. D., Zhu, Q., & Sarkis, J. (2021). Expanding conceptual boundaries of the Sustainable Supply Chain Management and Circular Economy Nexus. *Cleaner Logistics and Supply Chain*, *2*, 100011. https://doi.org/10.1016/j.clscn.2021.100011

Angreani, L. S., Vijaya, A., & Wicaksono, H. (2020). Systematic literature review of Industry 4.0 maturity model for manufacturing and logistics sectors. *Procedia Manufacturing*, *52*, 337–343. https://doi.org/10.1016/j.promfg.2020.11.056

Aravindaraj, K., & Rajan Chinna, P. (2022). A systematic literature review of integration of Industry 4.0 and warehouse management to achieve Sustainable Development Goals (sdgs). *Cleaner Logistics and Supply Chain*, *5*, 100072. https://doi.org/10.1016/j.clscn.2022.100072

Åsvoll, H. (2013). Abduction, deduction and induction: Can these concepts be used for an understanding of methodological processes in interpretative case studies? *International Journal of Qualitative Studies in Education*, *27*(3), 289–307. https://doi.org/10.1080/09518398.2012.759296

Ávila-Gutiérrez, M. J., Martín-Gómez, A., Aguayo-González, F., & Córdoba-Roldán, A. (2019). Standardization framework for sustainability from Circular Economy 4.0. *Sustainability*, *11*(22), 6490. https://doi.org/10.3390/su11226490

Awaworyi Churchill, S., Inekwe, J., Ivanovski, K., & Smyth, R. (2021). Transport infrastructure and CO2 emissions in the OECD over the Long Run. *Transportation Research Part D: Transport and Environment*, *95*, 102857. https://doi.org/10.1016/j.trd.2021.102857

Awwad, M. A., Shekhar, A., & Iyer, A. S. (2018). In *International Conference on Industrial Engineering and Operations Management*. Washington DC. Retrieved July 10, 2023, from https://www.researchgate.net/publication/336474432_Sustainable_Last-Mile_Logistics_Operation_in_the_Era_of_E-_Commerce.

Bag, S., Yadav, G., Dhamija, P., & Kataria, K. K. (2021). Key Resources for Industry 4.0 adoption and its effect on sustainable production and Circular Economy: An Empirical Study. *Journal of Cleaner Production*, *281*, 125233. https://doi.org/10.1016/j.jclepro.2020.125233

Bai, C., Dallasega, P., Orzes, G., & Sarkis, J. (2020). Industry 4.0 technologies assessment: A sustainability perspective. *International Journal of Production Economics*, *229*, 2. https://doi.org/10.1016/j.ijpe.2020.107776

Bai, C., & Sarkis, J. (2019). A supply chain transparency and sustainability technology appraisal model for blockchain technology. *Academy of Management Proceedings*, *2019*(1), 16069. https://doi.org/10.5465/ambpp.2019.16069abstract

Bányai, T., & Zaher Akkad, M. (2021). The impact of Industry 4.0 on the future of Green Supply Chain. *Green Supply Chain - Competitiveness and Sustainability*. https://doi.org/10.5772/intechopen.98366

Bluhm, D. J., Harman, W., Lee, T. W., & Mitchell, T. R. (2011). Qualitative Research in Management: A Decade of Progress. *Journal of Management Studies*, *48*(8), 1866–1891. https://doi.org/10.1111/j.1467-6486.2010.00972.x

Böckel, A., Nuzum, A.-K., & Weissbrod, I. (2021). Blockchain for the Circular Economy: Analysis of the Research-Practice Gap. *Sustainable Production and Consumption*, *25*, 525–539. https://doi.org/10.1016/j.spc.2020.12.006

Bocken, N. M., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Boon, W., & van Wee, B. (2017). Influence of 3D printing on transport: A theory and experts judgment based conceptual model. *Transport Reviews*, *38*(5), 556–575. https://doi.org/10.1080/01441647.2017.1370036

Bose, I., Ngai, E. W., Teo, T. S., & Spiekermann, S. (2009). Managing RFID projects in organizations. *European Journal of Information Systems*, *18*(6), 534–540. https://doi.org/10.1057/ejis.2009.43

Bosona, T. (2020). Urban freight last Mile Logistics—challenges and opportunities to improve sustainability: A literature review. *Sustainability*, *12*(21), 8769. https://doi.org/10.3390/su12218769

Cannavacciuolo, L., Ferraro, G., Ponsiglione, C., Primario, S., & Quinto, I. (2023). Technological Innovation-Enabling Industry 4.0 Paradigm: A systematic literature review. *Technovation*, *124*, 9–11. https://doi.org/10.1016/j.technovation.2023.102733

Chauhan, C., Sharma, A., & Singh, A. (2019). A sap-lap linkages framework for integrating industry 4.0 and circular economy. *Benchmarking: An International Journal*, *28*(5), 1638–1664. https://doi.org/10.1108/bij-10-2018-0310

Chen, D., Heyer, S., Ibbotson, S., Salonitis, K., Steingrímsson, J. G., & Thiede, S. (2015). Direct digital manufacturing: Definition, evolution, and Sustainability Implications. *Journal of Cleaner Production*, *107*, 615–625. https://doi.org/10.1016/j.jclepro.2015.05.009

Chen, J. C., Cheng, C.-H., Huang, P. B., Wang, K.-J., Huang, C.-J., & Ting, T.-C. (2013). Warehouse management with Lean and RFID application: A case study. *The International Journal of Advanced Manufacturing Technology*, *69*(1–4), 531–542. https://doi.org/10.1007/s00170-013-5016-8

Cezarino, L. O., Liboni, L. B., Oliveira Stefanelli, N., Oliveira, B. G., & Stocco, L. C. (2019). Diving into emerging economies bottleneck: Industry 4.0 and implications for circular economy. *Management Decision*, *59*(8), 1841–1862. https://doi.org/10.1108/md-10-2018-1084

Ching, N. T., Ghobakhloo, M., Iranmanesh, M., Maroufkhani, P., & Asadi, S. (2022). Industry 4.0 applications for Sustainable Manufacturing: A systematic literature review and a roadmap to Sustainable Development. *Journal of Cleaner Production*, *334*, 2–6. https://doi.org/10.1016/j.jclepro.2021.130133

Chung, S.-H. (2021). Applications of smart technologies in Logistics and transport: A Review. *Transportation Research Part E: Logistics and Transportation Review*, *153*, 102455. https://doi.org/10.1016/j.tre.2021.102455

Cotet, C. E., Deac, G. C., Deac, C. N., & Popa, C. L. (2020). An Innovative Industry 4.0 cloud data transfer method for an automated waste collection system. *Sustainability*, *12*(5), 1839. https://doi.org/10.3390/su12051839

Cowling, M. A. (2016). Navigating the path between positivism and interpretivism for the technology academic completing education research. *Constructing Methodology for Qualitative Research*, 45–58. https://doi.org/10.1057/978-1-137-59943-8_4

Dabic-Miletic, S. (2023). Autonomous vehicles as an essential component of Industry 4.0 for meeting last-mile logistics requirements. *Journal of Industrial Intelligence*, *1*(1), 55–62. https://doi.org/10.56578/jii010104

Demir, E., Syntetos, A. and van Woensel, T. (2022) ‘Last Mile Logistics: Research Trends and needs’, *IMA Journal of Management Mathematics*, 33(4), pp. 549–561. doi:10.1093/imaman/dpac006.

Den Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product design in a circular economy: Development of a typology of key concepts and terms. *Journal of Industrial Ecology*, *21*(3), 517–525. https://doi.org/10.1111/jiec.12610

Dev, N. K., Shankar, R., & Qaiser, F. H. (2020). Industry 4.0 and circular economy: Operational excellence for sustainable reverse supply chain performance. *Resources, Conservation and Recycling*, *153*, 104583. https://doi.org/10.1016/j.resconrec.2019.104583

DHL. (2022, July 26). *A Guide To Reverse Logistics – DHL Express*. dhl. https://www.dhl.com/discover/en-au/logistics-advice/logistics-insights/guide-to-reverse-logistics

DHL. (n.d.). *At a glance*. dpdhl. https://www.dpdhl.com/en/about-us/at-a-glance.html

DHL. (n.d.-b). *Circularity*. dhl. https://www.dhl.com/global-en/home/insights-and-innovation/thought-leadership/trend-reports/circularity-reverse-logistics.html

DHL. (n.d.-a). *Circular economy*. dpdhl. https://www.dpdhl.com/en/trends-in-logistics/studies/circular_economy.html

DHL. (n.d.-a). *Decarbonization*. dhl. https://www.dhl.com/global-en/home/insights-and-innovation/thought-leadership/trend-reports/supply-chain-decarbonization.html

DHL. (2022, February 14). *Digital Supply Chain: What exactly is Logistics 4.0 all about?: DHL Express*. dhl. https://www.dhl.com/discover/en-au/logistics-advice/logistics-insights/what-exactly-is-logistics-4-0-all-about

DHL. (n.d.-c). *Digital Twins*. dhl. https://www.dhl.com/global-en/home/insights-and-innovation/thought-leadership/trend-reports/digital-twins-supply-chain.html

DHL Express deploys AI-powered sorting robot. dhl. (2021, September 7). https://www.dhl.com/au-en/home/press/press-archive/2021/dhl-express-deploys-ai-powered-sorting-robot.html

DHL. (n.d.-b). *Green Logistics is being assisted by this route optimization algorithm*. dhl. https://www.dhl.com/global-en/delivered/sustainability/route-optimization-algorithm.html

DHL. (2021, June 15). *How Digitalisation has transformed DHL Express' operations - DHL Express Australia Hub*. How digitalisation has transformed DHL Express' operations - DHL Express Australia Hub. https://www.dhl.com/discover/en-au/logistics-advice/logistics-insights/digitalisation-transformation-operations

DHL. (n.d.-b). *Stationary robotics*. dhl. https://www.dhl.com/global-en/home/insights-and-innovation/thought-leadership/trend-reports/robotics-and-automation-logistics.html

DHL. (2019, July 30). *Smart warehouse with internet-of-things technology*. DHL Freight Connections. https://dhl-freight-connections.com/en/solutions/smart-warehouse-with-internet-of-things-technology/

DHL. (2022a). *Sustainability reports*. dpdhl. https://www.dpdhl.com/en/sustainability/our-approach/sustainability-reports.html

DHL. (n.d.-b). *The challenging logistics of last-mile delivery*. dhl. https://www.dhl.com/global-en/delivered/ecommerce/challenging-logistics-of-last-mile-delivery.html

DHL. (2021b, June 18). *What's behind the robot boom in warehousing?* DHL Freight Connections. https://dhl-freight-connections.com/en/business/whats-behind-the-robot-boom-in-warehousing/

Digiesi, S., Fanti, M. P., Mummolo, G., & Silvestri, B. (2017). Externalities reduction strategies in Last Mile Logistics: A Review. *2017 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI)*. https://doi.org/10.1109/soli.2017.8121002

Ding, Y., Jin, M., Li, S., & Feng, D. (2020). Smart Logistics based on the Internet of Things Technology: An overview. *International Journal of Logistics Research and Applications*, *24*(4), 323–345. https://doi.org/10.1080/13675567.2020.1757053

Dobrovnik, M., Herold, D., Fürst, E., & Kummer, S. (2018). Blockchain for and in logistics: What to adopt and where to start. *Logistics*, *2*(3), 18. https://doi.org/10.3390/logistics2030018

Dolgui, A., & Ivanov, D. (2021). 5G in digital supply chain and Operations Management: Fostering flexibility, end-to-end connectivity and real-time visibility through internet-of-everything. *International Journal of Production Research*, *60*(2), 442–451. https://doi.org/10.1080/00207543.2021.2002969

Dusadeerungsikul, P. O., He, X., Sreeram, M., & Nof, S. Y. (2021). Multi-agent system optimisation in FACTORIES OF THE FUTURE: Cyber Collaborative Warehouse Study. *International Journal of Production Research*, *60*(20), 6072–6086. https://doi.org/10.1080/00207543.2021.1979680

El-Berishy, N., Rügge, I., & Scholz-Reiter, B. (2013a). The interrelation between sustainability and green logistics. *IFAC Proceedings Volumes*, *46*(24), 527–531. https://doi.org/10.3182/20130911-3-br-3021.00067

El Moussaoui, A. E., Benbba, B., Jaegler, A., El Andaloussi, Z., & El Amrani, L. (2022). Last mile logistics: Challenges & Improvement Ways. *2022 14th International Colloquium of Logistics and Supply Chain Management (LOGISTIQUA)*, 1–7. https://doi.org/10.1109/logistiqua55056.2022.9938101

Engesser, V., Rombaut, E., Vanhaverbeke, L., & Lebeau, P. (2023). Autonomous Delivery Solutions for last-Mile Logistics Operations: A literature review and research agenda. *Sustainability*, *15*(3), 2774. https://doi.org/10.3390/su15032774

Favi, C., Marconi, M., Mandolini, M., & Germani, M. (2022). Sustainable life cycle and energy management of discrete manufacturing plants in the industry 4.0 framework. *Applied Energy*, *312*, 118671. https://doi.org/10.1016/j.apenergy.2022.118671

Ferraro, S., Cantini, A., Leoni, L., & De Carlo, F. (2023). Sustainable Logistics 4.0: A study on selecting the best technology for Internal Material Handling. *Sustainability*, *15*(9), 7067. https://doi.org/10.3390/su15097067

Fritschy, C., & Spinler, S. (2019). The impact of autonomous trucks on business models in the automotive and logistics industry–a Delphi-based scenario study. *Technological Forecasting and Social Change*, *148*, 119736. https://doi.org/10.1016/j.techfore.2019.119736

Garrido-Hidalgo, C., Olivares, T., Ramirez, F. J., & Roda-Sanchez, L. (2019). An end-to-end internet of things solution for Reverse Supply Chain Management in industry 4.0. *Computers in Industry*, *112*, 103127. https://doi.org/10.1016/j.compind.2019.103127

Garrido-Hidalgo, C., Ramirez, F. J., Olivares, T., & Roda-Sanchez, L. (2020). The adoption of internet of things in a circular supply chain framework for the recovery of WEEE: The case of lithium-ion electric vehicle battery packs. *Waste Management*, *103*, 32–44. https://doi.org/10.1016/j.wasman.2019.09.045

Genovese, A., Acquaye, A. A., Figueroa, A., & Koh, S. C. L. (2017). Sustainable Supply Chain Management and the transition towards a circular economy: Evidence and some applications. *Omega*, *66*, 344–357. https://doi.org/10.1016/j.omega.2015.05.015

Gevaers, R., Van de Voorde, E., & Vanelslander, T. (2011). Characteristics and typology of last-mile logistics from an innovation perspective in an urban context. *City Distribution and Urban Freight Transport*. https://doi.org/10.4337/9780857932754.00009

Gladkih, A. M., Yu Konyuhov, V., Galyautdinov, I. I., & Shchadova, E. I. (2019). Green building as a tool of energy saving. *IOP Conference Series: Earth and Environmental Science*, *350*(1), 012032. https://doi.org/10.1088/1755-1315/350/1/012032

Goldkuhl, G. (2012). Pragmatism vs interpretivism in Qualitative Information Systems Research. *European Journal of Information Systems*, *21*(2), 135–146. https://doi.org/10.1057/ejis.2011.54

Govindan, K., Soleimani, H., & Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A Comprehensive Review to explore the future. *European Journal of Operational Research*, *240*(3), 603–626. https://doi.org/10.1016/j.ejor.2014.07.012

Greeff, W. J. (2015). Organizational diversity: Making the case for Contextual Interpretivism. *Equality, Diversity and Inclusion: An International Journal*, *34*(6), 496–509. https://doi.org/10.1108/edi-02-2014-0010

Gruchmann, T. (2018) “Advanced Green Logistics Strategies and Technologies,” *Operations, Logistics and Supply Chain Management*, pp. 663–686. Available at: https://doi.org/10.1007/978-3-319-92447-2_29.

Guercini, S. (2014). New qualitative research methodologies in management. *Management Decision*, *52*(4), 662–674. https://doi.org/10.1108/md-11-2013-0592

Gupta, H., Kumar, A., & Wasan, P. (2021). Industry 4.0, cleaner production and Circular Economy: An Integrative Framework for evaluating ethical and sustainable business performance of Manufacturing Organizations. *Journal of Cleaner Production*, *295*, 126253. https://doi.org/10.1016/j.jclepro.2021.126253

Halawa, F., Dauod, H., Lee, I. G., Li, Y., Yoon, S. W., & Chung, S. H. (2020). Introduction of a real time location system to enhance the warehouse safety and operational efficiency. *International Journal of Production Economics*, *224*, 107541. https://doi.org/10.1016/j.ijpe.2019.107541

Hauer, G., Harte, P., & Kacemi, J. (2018, August 31). *An exploration of the impact of industry 4.0 approach on corporate communication in the German Manufacturing Industry*. International Journal of Supply Chain Management. https://napier-repository.worktribe.com/output/1321154/an-exploration-of-the-impact-of-industry-40-approach-on-corporate-communication-in-the-german-manufacturing-industry

Hoffmann, T. and Prause, G. (2018) ‘On the regulatory framework for last-Mile Delivery Robots’, *Machines*, 6(3), p. 33. doi:10.3390/machines6030033.

How online grocer ocado is automating warehouses using swarms of robots - sponsor content from Ocado. Harvard Business Review. (2018, May 22). https://hbr.org/sponsored/2018/05/how-online-grocer-ocado-is-automating-warehouses-using-swarms-of-robots

How we use AI explained. Ocado Group. (n.d.-a). https://www.ocadogroup.com/about-us/what-we-do/how-we-use-ai/

Hox, J. J., & Boeije, H. R. (2005). Data collection, primary vs. secondary. *Encyclopedia of Social Measurement*, 593–599. https://doi.org/10.1016/b0-12-369398-5/00041-4

Huang, M.-H., & Rust, R. T. (2018). Artificial Intelligence in service. *Journal of Service Research*, *21*(2), 155–172. https://doi.org/10.1177/1094670517752459

Jaeger, B., & Upadhyay, A. (2020). Understanding barriers to circular economy: Cases from the manufacturing industry. *Journal of Enterprise Information Management*, *33*(4), 729–745. https://doi.org/10.1108/jeim-02-2019-0047

Janjevic, M., & Winkenbach, M. (2020). Characterizing urban last-mile distribution strategies in mature and emerging e-commerce markets. *Transportation Research Part A: Policy and Practice*, *133*, 164–196. https://doi.org/10.1016/j.tra.2020.01.003

Jayashree, S., Reza, M. N., Malarvizhi, C. A., & Mohiuddin, M. (2021). Industry 4.0 implementation and triple bottom line sustainability: An empirical study on small and medium manufacturing firms. *Heliyon*, *7*(8), 2–14. https://doi.org/10.1016/j.heliyon.2021.e07753

John, J., Varkey, M. S., Podder, R. S., Sensarma, N., Selvi, M., Santhosh Kumar, S. V., & Kannan, A. (2021). Smart prediction and monitoring of waste disposal system using IOT and cloud for IOT based Smart Cities. *Wireless Personal Communications*, *122*(1), 243–275. https://doi.org/10.1007/s11277-021-08897-z

Jovic, M., Tijan, E., Zgaljic, D., & Karanikic, P. (2020). SWOT analysis of selected digital technologies in Transport Economics. *2020 43rd International Convention on Information, Communication and Electronic Technology (MIPRO)*, 1361–1366. https://doi.org/10.23919/mipro48935.2020.9245401

Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. (2018). Sustainable Industry 4.0 Framework: A systematic literature review identifying the current trends and future perspectives. *Process Safety and Environmental Protection*, *117*, 417–418. https://doi.org/10.1016/j.psep.2018.05.009

Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. (2018a). Sustainable Industry 4.0 Framework: A systematic literature review identifying the current trends and future perspectives. *Process Safety and Environmental Protection*, *117*, 418–422. https://doi.org/10.1016/j.psep.2018.05.009

Kayıkcı, Y. (2020). Blockchain Driven Supply Chain Management. *Logistics 4.0*, 146–155. https://doi.org/10.1201/9780429327636-16

Khan, I. S., Ahmad, M. O., & Majava, J. (2021). Industry 4.0 and sustainable development: A systematic mapping of triple bottom line, circular economy and sustainable business models perspectives. *Journal of Cleaner Production*, *297*, 126655. https://doi.org/10.1016/j.jclepro.2021.126655

Kolasińska-Morawska, K., Sułkowski, Ł., Buła, P., Brzozowska, M., & Morawski, P. (2022). Smart Logistics—sustainable technological innovations in customer service at the last-mile stage: The Polish perspective. *Energies*, *15*(17), 6395. https://doi.org/10.3390/en15176395

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

Kouhizadeh, M., & Sarkis, J. (2018). Blockchain practices, potentials, and perspectives in Greening Supply Chains. *Sustainability*, *10*(10), 3652. https://doi.org/10.3390/su10103652

Krstić, M., Agnusdei, G. P., Miglietta, P. P., & Tadić, S. (2022). Logistics 4.0 toward circular economy in the Agri-Food Sector. *Sustainable Futures*, *4*, 100097. https://doi.org/10.1016/j.sftr.2022.100097

Kuada, J. (2012). *Research Methodology*. *ProQuest Ebook Central*. Samfundslitteratur. Retrieved July 1, 2023, from https://ebookcentral.proquest.com/lib/coventry/detail.action?docID=3400854.

Kumar, A. (2015). Green Logistics for sustainable development: an analytical review. *International Journal of Business*, *1*(1), 7–13.

Lai, Y., Sun, H., & Ren, J. (2018). Understanding the determinants of Big Data Analytics (BDA) adoption in logistics and Supply Chain Management. *The International Journal of Logistics Management*, *29*(2), 676–703. https://doi.org/10.1108/ijlm-06-2017-0153

Launching a first truck fleet powered by biofuel to reduce carbon footprint. (2023, June 1). *Dpdhl*. Retrieved July 5, 2023, from https://www.dpdhl.com/en/media-relations/press-releases/2023/dhl-launching-a-first-truck-fleet-powered-by-biofuel.html.

Lim, M. K., Bahr, W., & Leung, S. C. H. (2013). RFID in the warehouse: A literature analysis (1995–2010) of its applications, benefits, challenges and future trends. *International Journal of Production Economics*, *145*(1), 409–430. https://doi.org/10.1016/j.ijpe.2013.05.006

Liu, X., Cao, J., Yang, Y., & Jiang, S. (2018). CPS-based Smart Warehouse for Industry 4.0: A survey of the underlying technologies. *Computers*, *7*(1), 13. https://doi.org/10.3390/computers7010013

Logistics 4.0: Interlinking the supply chain. DHL Freight Connections. (2021, December 10). https://dhl-freight-connections.com/en/business/logistics-4-0-interlinking-the-supply-chain/

Long, H. (2014). An empirical review of research methodologies and methods in creativity studies (2003–2012). *Creativity Research Journal*, *26*(4), 427–438. https://doi.org/10.1080/10400419.2014.961781

Lopes de Sousa Jabbour, A. B., Chiappetta Jabbour, C. J., Choi, T.-M., & Latan, H. (2022). ‘better together’: Evidence on the joint adoption of Circular Economy and Industry 4.0 Technologies. *International Journal of Production Economics*, *252*, 108581. https://doi.org/10.1016/j.ijpe.2022.108581

Lu, H., Zhao, G., & Liu, S. (2022). Integrating circular economy and industry 4.0 for Sustainable Supply Chain Management: A dynamic capability view. *Production Planning & Control*, 1–17. https://doi.org/10.1080/09537287.2022.2063198

Maji, I. K., Mohd Saudi, N. S., & Yusuf, M. (2023). An assessment of Green Logistics and Environmental Sustainability: Evidence from Bauchi. *Cleaner Logistics and Supply Chain*, *6*, 100097. https://doi.org/10.1016/j.clscn.2023.100097

Malinowska, M. (2022). The concept of decision support system to increase the level of sustainable warehousing. *Procedia Computer Science*, *207*, 4046–4054. https://doi.org/10.1016/j.procs.2022.09.467

Mallick, P. K., Salling, K. B., Pigosso, D. C. A., & McAloone, T. C. (2023). Closing the loop: Establishing reverse logistics for a circular economy, a systematic review. *Journal of Environmental Management*, *328*, 117017. https://doi.org/10.1016/j.jenvman.2022.117017

Malyavkina, L. I., Savina, A. G., & Parshutina, I. G. (2019). Blockchain technology as the basis for digital transformation of the supply chain management system: Benefits and implementation challenges. *Proceedings of the 1st International Scientific Conference "Modern Management Trends and the Digital Economy: From Regional Development to Global Economic Growth" (MTDE 2019)*. https://doi.org/10.2991/mtde-19.2019.3

Marr, B. (2020, October 30). *The amazing ways ocado uses artificial intelligence and Tech to transform the grocery industry*. Forbes. https://www.forbes.com/sites/bernardmarr/2020/10/30/the-amazing-ways-ocado-uses-artificial-intelligence-and-tech-to-transform-the-grocery-industry/?sh=1e14f7044797

Mashud, A. H., Roy, D., Chakrabortty, R. K., Tseng, M.-L., & Pervin, M. (2022). An optimum balance among the reduction in ordering cost, product deterioration and carbon emissions: A Sustainable Green Warehouse. *Environmental Science and Pollution Research*, *29*(51), 78029–78051. https://doi.org/10.1007/s11356-022-21008-0

Mazhar, S. A., Anjum, R., Anwar, A. I., & Khan, A. A. K. (2021). Methods of data collection: A fundamental tool of research. *Journal of Integrated Community Health*, *10*(01), 6–10. https://doi.org/10.24321/2319.9113.202101

McBeath, A., & Bager-Charleson, S. (2020). Introduction: Considering qualitative, quantitative and mixed methods research. *Enjoying Research in Counselling and Psychotherapy*, 1–12. https://doi.org/10.1007/978-3-030-55127-8_1

Mckinnon, A., Browne, M., Piecyk, M., & Whiteing, A. (2010). Environmental sustainability: A new priority for logistics managers. In *Green logistics: Improving the environmental sustainability of Logistics* (pp. 4–6). essay, Kogan Page.

McKinnon, A., Browne, M., Whiteing, A., & Piecyk, M. (2010). Chapter 8 - Reducing the environmental impact of warehousing. In *Green logistics improving the environmental sustainability of Logistics* (pp. 167–175). essay, Kogan Page.

McKinsey & Company. (2022, January 18). *Road Freight Global Pathways Report*. McKinsey & Company. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/road-freight-global-pathways-report

Mehta, A., & Levy, F. (2020, November 17). *Warehousing, Trucking, and technology: The future of work in Logistics*. MIT Work of the Future. Retrieved April 5, 2023, from https://workofthefuture.mit.edu/research-post/warehousing/.

Melnikovas, A. (2018). Towards an Explicit Research Methodology: Adapting Research Onion Model for Futures Studies. *Journal of Future Studies*, *23*(2), 29–44. https://doi.org/10.6531/JFS.201812_23(2).0003

Mohsin, A. K. M., Tushar, H., Abid Hossain, S. F., Shams Chisty, K. K., Masum Iqbal, M., Kamruzzaman, Md., & Rahman, S. (2022). Green Logistics and environment, economic growth in the context of the belt and road initiative. *Heliyon*, *8*(6). https://doi.org/10.1016/j.heliyon.2022.e09641

Mooney, R. J. (2000). Integrating abduction and induction in Machine Learning. *Applied Logic Series*, *18*, 181–191. https://doi.org/10.1007/978-94-017-0606-3_12

Na, H. S., Kweon, S. J., & Park, K. (2021). Characterization and design for last mile logistics: A review of the State of the art and Future Directions. *Applied Sciences*, *12*(1), 118. https://doi.org/10.3390/app12010118

Oloruntobi, O., Mokhtar, K., Mohd Rozar, N., Gohari, A., Asif, S., & Chuah, L. F. (2023). Effective technologies and practices for reducing pollution in warehouses - A Review. *Cleaner Engineering and Technology*, *13*, 100622. https://doi.org/10.1016/j.clet.2023.100622

Orellano, M., & Tiss, S. (2022). Impacts of digital transformation on Supply Chain Sustainability: A systematic literature review and expert assessment. *Collaborative Networks in Digitalization and Society 5.0*, 399–402. https://doi.org/10.1007/978-3-031-14844-6_32

Orji, I. J., & Ojadi, F. (2022). Application of blockchain technologies in circular supply chains. *The Circular Supply Chain*, 163–180. https://doi.org/10.1201/9781003252016-12

Our competencies. Ocado Group. (n.d.-a). https://www.ocadogroup.com/technology/competencies/

Oztemel, E., & Gursev, S. (2018). Literature Review of Industry 4.0 and Related Technologies. *Journal of Intelligent Manufacturing*, *31*(1), 141–146. https://doi.org/10.1007/s10845-018-1433-8

Paksoy, T. and Deveci, M. (2023) *Smart and sustainable operations and Supply Chain Management in industry 4.0*. 1st edn. Boca Raton: CRC Press.

Parhi, S., Joshi, K., & Akarte, M. (2020). Smart manufacturing: A Framework for managing performance. *International Journal of Computer Integrated Manufacturing*, *34*(3), 227–256. https://doi.org/10.1080/0951192x.2020.1858506

Parhi, S., Joshi, K., Gunasekaran, A., & Sethuraman, K. (2022). Reflecting on an empirical study of the digitalization initiatives for sustainability on logistics: The Concept of Sustainable Logistics 4.0. *Cleaner Logistics and Supply Chain*, *4*, 100058. https://doi.org/10.1016/j.clscn.2022.100058

Patyal, V. S., Sarma, P. R. S., Modgil, S., Nag, T., & Dennehy, D. (2022). Mapping the links between industry 4.0, Circular Economy and Sustainability: A Systematic Literature Review. *Journal of Enterprise Information Management*, *35*(1), 1–35. https://doi.org/10.1108/jeim-05-2021-0197

Pham, L. (2018). *A Review of Key Paradigms: Positivism, Interpretivism and Critical Inquiry.* https://doi.org/10.13140/RG.2.2.13995.54569

Poon, T. C., Choy, K. L., Chan, F. T. S., Ho, G. T. S., Gunasekaran, A., Lau, H. C. W., & Chow, H. K. H. (2011). A real-time warehouse operations planning system for Small Batch replenishment problems in production environment. *Expert Systems with Applications*, *38*(7), 8524–8537. https://doi.org/10.1016/j.eswa.2011.01.053

Prakash, C., & Barua, M. K. (2016). A multi-criteria decision-making approach for prioritizing reverse logistics adoption barriers under fuzzy environment: Case of Indian Electronics Industry. *Global Business Review*, *17*(5), 1107–1124. https://doi.org/10.1177/0972150916656667

Rabianski, J. S. (2003). *Primary and Secondary Data: Concepts, Concerns, Errors, and Issues* , *77*(1), 43–55. https://www.proquest.com/openview/68bfe6580297494936f0126ed5d3d017/1?pq-origsite=gscholar&cbl=35147

Rahi, S. (2017). Research design and methods: A systematic review of research paradigms, sampling issues, and instruments development. *International Journal of Economics & Management Sciences*, *06*(02). https://doi.org/10.4172/2162-6359.1000403

Raji, I. O., Shevtshenko, E., Rossi, T., & Strozzi, F. (2021). Modelling the relationship of Digital Technologies with Lean and Agile Strategies. *Supply Chain Forum: An International Journal*, *22*(4), 323–346. https://doi.org/10.1080/16258312.2021.1925583

Ranieri, L., Digiesi, S., Silvestri, B., & Roccotelli, M. (2018). A review of Last Mile Logistics Innovations in an externalities cost reduction vision. *Sustainability*, *10*(3), 782. https://doi.org/10.3390/su10030782

Rehman Khan, S. A., Yu, Z., Sarwat, S., Godil, D. I., Amin, S., & Shujaat, S. (2021). The role of block chain technology in circular economy practices to improve organisational performance. *International Journal of Logistics Research and Applications*, *25*(4–5), 605–622. https://doi.org/10.1080/13675567.2021.1872512

Reichertz, J. (2014). Induction, deduction, abduction. *The SAGE Handbook of Qualitative Data Analysis*, 123–135. https://doi.org/10.4135/9781446282243.n9

Ren, R., Hu, W., Dong, J., Sun, B., Chen, Y., & Chen, Z. (2019). A systematic literature review of Green and Sustainable Logistics: Bibliometric Analysis, research trend and knowledge taxonomy. *International Journal of Environmental Research and Public Health*, *17*(1), 261. https://doi.org/10.3390/ijerph17010261

Rejeb, A., Rejeb, K., Simske, S., & Treiblmaier, H. (2021). Blockchain technologies in logistics and Supply Chain Management: A bibliometric review. *Logistics*, *5*(4), 72. https://doi.org/10.3390/logistics5040072

Rosa, P., Sassanelli, C., Urbinati, A., Chiaroni, D., & Terzi, S. (2019). Assessing relations between Circular Economy and Industry 4.0: A systematic literature review. *International Journal of Production Research*, *58*(6), 1662–1687. https://doi.org/10.1080/00207543.2019.1680896

Rymaszewska, A., Helo, P., & Gunasekaran, A. (2017). IOT powered servitization of manufacturing – an exploratory case study. *International Journal of Production Economics*, *192*, 92–105. https://doi.org/10.1016/j.ijpe.2017.02.016

Sachdeva, J. K. (2009). *Business research methodology*. *ProQuest Ebook Central*. Himalaya Pub. House. Retrieved July 1, 2023, from https://ebookcentral.proquest.com/lib/coventry/detail.action?docID=3011363.

Saini, N., Malik, K., & Sharma, S. (2023). Transformation of Supply Chain Management to Green Supply Chain Management: Certain investigations for research and applications. *Cleaner Materials*, *7*, 100172. https://doi.org/10.1016/j.clema.2023.100172

Sartal, A., Bellas, R., Mejías, A. M., & García-Collado, A. (2020). The sustainable manufacturing concept, evolution and opportunities within industry 4.0: A literature review. *Advances in Mechanical Engineering*, *12*(5), 168781402092523. https://doi.org/10.1177/1687814020925232

Saunders, M., Lewis, P., & Thornhill, A. (2016). *Research methods for business students*. *ProQuest Ebook Central*. Pearson Education Limited. Retrieved July 1, 2023, from https://ebookcentral.proquest.com/lib/coventry/detail.action?docID=7219451.

Seroka-Stolka, O. (2014). The development of Green Logistics for Implementation Sustainable Development Strategy in companies. *Procedia - Social and Behavioural Sciences*, *151*, 302–309. https://doi.org/10.1016/j.sbspro.2014.10.028

Sharma, A., & Pandey, H. (2019). Big Data and analytics in industry 4.0. *A Roadmap to Industry 4.0: Smart Production, Sharp Business and Sustainable Development*, 7. https://doi.org/10.1007/978-3-030-14544-6_4

Siegfried, P., Michel, A., Tänzler, J., & Jiyuan Zhang, J. (2021). Analyzing sustainability issues in urban logistics in the context of growth of e-commerce. *Journal of Social Sciences*, *IV*(1), 6–11. https://doi.org/10.52326/jss.utm.2021.4(1).01

Strandhagen, J. O., Vallandingham, L. R., Fragapane, G., Strandhagen, J. W., Stangeland, A. B., & Sharma, N. (2017). Logistics 4.0 and emerging sustainable business models. *Advances in Manufacturing*, *5*(4), 359–369. https://doi.org/10.1007/s40436-017-0198-1

Soosay, C. and Kannusamy, R. (2018) 'The Road to a Digitalized Supply Chain Management: Smart and Digital Solutions for Supply Chain Management', in *Proceedings of the Hamburg International Conference of Logistics (HICL)*. Available at: https://www.econstor.eu/handle/10419/209342 (Accessed: June 2023).

Sun, X., Yu, H., Solvang, W. D., Wang, Y., & Wang, K. (2021). The application of Industry 4.0 Technologies in Sustainable Logistics: A systematic literature review (2012–2020) to explore future research opportunities. *Environmental Science and Pollution Research*, *29*(7), 9560–9591. https://doi.org/10.1007/s11356-021-17693-y

Sun, X., Yu, H., & Solvang, W. D. (2022). Towards the smart and sustainable transformation of Reverse Logistics 4.0: A conceptualization and research agenda. *Environmental Science and Pollution Research*, *29*(46), 69275–69293. https://doi.org/10.1007/s11356-022-22473-3

Suzuki, Y., & Lu, S.-H. (2017). Economies of product diversity in Collaborative Logistics. *Journal of Business Logistics*, *38*(2), 115–129. https://doi.org/10.1111/jbl.12153

Szum, K., & Nazarko, J. (2020). Exploring the determinants of Industry 4.0 development using an extended SWOT Analysis: A regional study. *Energies*, *13*(22), 5972. https://doi.org/10.3390/en13225972

Tan, B. Q., Wang, F., Liu, J., Kang, K., & Costa, F. (2020). A blockchain-based framework for Green Logistics in supply chains. *Sustainability*, *12*(11), 4656. https://doi.org/10.3390/su12114656

Tang, C. S., & Veelenturf, L. P. (2019). The strategic role of logistics in the Industry 4.0 Era. *Transportation Research Part E: Logistics and Transportation Review*, *129*, 1–11. https://doi.org/10.1016/j.tre.2019.06.004

Technology behind the Ocado Smart Platform. Ocado Group. (n.d.-a). https://www.ocadogroup.com/technology/powering-osp/

Thanh, N. C., & Thanh, T. T. L. (2015). The Interconnection Between Interpretivist Paradigm and Qualitative Methods in Education. *American Journal of Educational Science*, *1*(2), 24–27.

Tijan, E., Aksentijević, S., Ivanić, K., & Jardas, M. (2019). Blockchain technology implementation in Logistics. *Sustainability*, *11*(4), 1185. https://doi.org/10.3390/su11041185

Tikwayo, L. N., & Mathaba, T. N. (2023). Applications of industry 4.0 technologies in warehouse management: A systematic literature review. *Logistics*, *7*(2), 24. https://doi.org/10.3390/logistics7020024

Tubis, A. A., & Rohman, J. (2023). Intelligent Warehouse in industry 4.0—systematic literature review. *Sensors*, *23*(8), 4105. https://doi.org/10.3390/s23084105

Umar, M., Khan, S. A., Zia-ul-haq, H. M., Yusliza, M. Y., & Farooq, K. (2021). The role of emerging technologies in implementing green practices to achieve sustainable operations. *The TQM Journal*, *34*(2), 232–249. https://doi.org/10.1108/tqm-06-2021-0172

Unhelkar, B., Joshi, S., Sharma, M., Prakash, S., Mani, A. K., & Prasad, M. (2022). Enhancing supply chain performance using RFID technology and decision support systems in the industry 4.0–A systematic literature review. *International Journal of Information Management Data Insights*, *2*(2), 100084. https://doi.org/10.1016/j.jjimei.2022.100084

Vanderroost, M., Ragaert, P., Verwaeren, J., De Meulenaer, B., De Baets, B., & Devlieghere, F. (2017). The digitization of a food package's life cycle: Existing and emerging computer systems in the pre-logistics phase. *Computers in Industry*, *87*, 1–14. https://doi.org/10.1016/j.compind.2017.02.002

VASILEVA, A., LAZAREVSKA, A. M., & JAKIMOVSKA, K. (2022). Appropriate criteria for a transition from conventional to sustainable warehousing. *Logistics, Supply Chain, Sustainability and Global Challenges*, *13*(1), 19–31. https://doi.org/10.2478/jlst-2023-0002

Vienažindienė, M., Tamulienė, V., & Zaleckienė, J. (2021). Green logistics practices seeking development of sustainability: Evidence from Lithuanian transportation and logistics companies. *Energies*, *14*(22), 7500. https://doi.org/10.3390/en14227500

Viu-Roig, M., & Alvarez-Palau, E. J. (2020). The impact of e-commerce-related last-mile logistics on cities: A systematic literature review. *Sustainability*, *12*(16), 6492. https://doi.org/10.3390/su12166492

Wang, S., Liang, Y. C., Li, W. D., & Cai, X. T. (2018). Big data enabled intelligent immune system for energy efficient manufacturing management. *Journal of Cleaner Production*, *195*, 507–520. https://doi.org/10.1016/j.jclepro.2018.05.203

Waqas, M., Dong, Q., Ahmad, N., Zhu, Y., & Nadeem, M. (2018). Critical barriers to implementation of reverse logistics in the manufacturing industry: A case study of a developing country. *Sustainability*, *10*(11), 4202. https://doi.org/10.3390/su10114202

What is an automated ocado CFC?. Ocado Group. (n.d.). https://www.ocadogroup.com/about-us/what-we-do/automated-ocado-customer-fulfilment-centre/

Who we are. Ocado Group. https://www.ocadogroup.com/about-us/who-we-are/

Wieczorek, A. (2017). Impact of 3D printing on Logistics. *Research in Logistics and Production*, *7*(5), 443–450. https://doi.org/10.21008/j.2083-4950.2017.7.5.5

Wilson, M., Paschen, J., & Pitt, L. (2021). The Circular Economy Meets Artificial Intelligence (AI): Understanding the opportunities of AI for reverse logistics. *Management of Environmental Quality: An International Journal*, *33*(1), 9–25. https://doi.org/10.1108/meq-10-2020-0222

Wu, Z., Yu, A. T. W., & Poon, C. S. (2020). Promoting effective construction and demolition waste management towards Sustainable Development: A case study of hong kong. *Sustainable Development*, *28*(6), 1713–1724. https://doi.org/10.1002/sd.2119

Xu, L. D., & Duan, L. (2018). Big data for Cyber Physical Systems in industry 4.0: A survey. *Enterprise Information Systems*, *13*(2), 148–169. https://doi.org/10.1080/17517575.2018.1442934

YONTAR, E. (2023). Challenges, threats and advantages of using blockchain technology in the framework of sustainability of the logistics sector. *Turkish Journal of Engineering*, *7*(3), 186–195. https://doi.org/10.31127/tuje.1094375

Zhang, G., & Zhao, Z. (2012). Green Packaging Management of Logistics Enterprises. *Physics Procedia*, *24*, 900–905. https://doi.org/10.1016/j.phpro.2012.02.135