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Doctoral Dissertation

Improving Waste Management Operations in the Oil and Gas Industry through Reverse Logistics

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1. Introduction

This thesis investigates the role of reverse logistics and waste management in the oil and gas industry, focusing on how companies can design, structure, and improve their practices to enhance both operational efficiency and environmental sustainability. The study was motivated by the recognition that oil and gas activities generate large and diverse waste streams, ranging from hazardous materials to recyclable products, and that the way these are managed has a direct impact on compliance, cost control, and corporate responsibility. Despite growing awareness of sustainability issues, gaps remain in how reverse logistics is implemented across the sector, especially in balancing regulatory requirements with practical constraints and opportunities for innovation.

Reverse logistics (RL) has evolved from being a supplementary business activity into a strategic component of modern supply chain management. Traditionally associated with the return of goods from customers to suppliers, RL is now widely recognised as a system for managing the backward flow of materials, products, and related information from the point of consumption to the point of origin, with the aim of reuse, recycling, remanufacturing, or environmentally responsible disposal (Rogers and Tibben-Lembke, 1999; De Brito and Dekker, 2004). Over the past two decades, its importance has grown significantly, driven by stricter environmental regulations, rising stakeholder expectations, and the economic potential of resource recovery (Presley et al., 2007; Pokharel and Mutha, 2009).

In the oil and gas industry, RL is not merely a logistical option but a necessity. The sector generates large volumes of both hazardous and non-hazardous waste, including drilling residues, production chemicals, and industrial packaging, all of which must be handled according to rigorous safety and environmental standards (Lebedev and Cherepovitsyn, 2024). Failures in waste management can lead to serious environmental harm, legal penalties, and reputational damage, making structured RL systems vital for operational continuity and corporate responsibility. The integration of RL within the industry’s supply chain offers opportunities to optimise waste handling, reduce costs, and strengthen compliance frameworks. Yet, despite its potential, RL remains underutilised in many oil and gas operations, especially in regions with limited infrastructure and fragmented regulatory oversight.

Existing research has examined RL in manufacturing, retail, and consumer goods sectors, but its application in oil and gas waste management has received comparatively little attention (Pokharel and Mutha, 2009; De Brito and Dekker, 2004). This gap is significant given the industry’s unique operational challenges, including geographically dispersed production sites, variable waste streams, and high environmental risk. There is a need for deeper empirical insights into how RL processes can be adapted to this context, how stakeholders can collaborate effectively, and how emerging technologies can enhance efficiency and sustainability.

Against this backdrop, the present study investigates how RL can be strategically integrated into waste management in the oil and gas sector, with a focus on both developed and developing country contexts. Using a mixed approach of systematic literature review, multiple case studies, and semi-structured interviews with industry experts, the research explores the drivers, barriers, process design considerations, performance metrics, outsourcing strategies, and technological enablers of RL. The study's aim is not only to contribute to academic theory but also to provide practical recommendations that can be applied by industry practitioners seeking to enhance their environmental performance and operational efficiency.

The significance of this research lies in its ability to address multiple dimensions of RL within a high-impact industry. By linking empirical findings to established theoretical perspectives, the thesis offers a grounded understanding of RL that is both conceptually robust and operationally relevant. It responds directly to identified theoretical, empirical, and methodological gaps, providing a comprehensive framework for RL implementation in oil and gas waste management. In doing so, this study positions RL as a central mechanism for achieving sustainable supply chain practices in the oil and gas sector, aligning economic performance with environmental stewardship.

To address the existing gaps, the thesis combined a systematic literature review with empirical research. Systematic literature review provided an overview of how reverse logistics has been conceptualized in academic research and revealed important limitations and research gaps in existing literature, including a lack of studies tailored to the specific challenges of oil and gas operations while implementing reverse logistics. Building on these insights, the empirical component of the study explored waste management and reverse logistics practices in oil and gas industry.

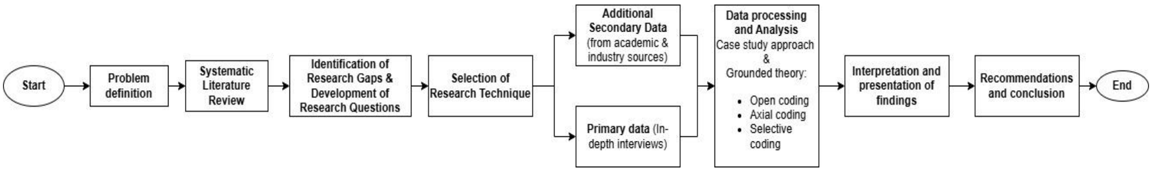
Primary data was collected through semi-structured interviews with managers and specialists from six oil and gas companies and one waste management solutions provider, all of whom were directly involved in reverse logistics and waste management activities. These interviews were complemented by a case study analysis of each company, enabling the study to capture both shared practices and context-specific variations, including distinctions between international oil majors and a national oil company operating in a developing-country environment. To analyse the qualitative data systematically, grounded-theory-inspired coding was employed, allowing the interview material to be organized and interpreted through an inductive, structured process. Using the core stages of open, axial, and selective coding, the analysis progressed from identifying initial concepts to establishing relationships between categories and, ultimately, integrating them into coherent thematic patterns aligned with the research questions. This analytical approach ensured that the findings were not only descriptively rich but also theoretically informed and methodologically robust, grounding practitioner insights within a clear and rigorous interpretive framework.

The research achieved several key outcomes. It provided an integrated framework for understanding how reverse logistics can be structured in oil and gas companies, highlighting the importance of mapping waste streams, establishing consolidation points, optimizing transportation, and integrating technology. It also showed that stakeholder collaboration and scalability are critical for effective system design. Importantly, the study revealed both strengths and shortcomings in current practices: while companies have made progress in recycling, reuse, and compliance, challenges remain in areas such as contractor engagement, infrastructure limitations, and the full integration of sustainability goals into logistics processes.

By combining theoretical insights with empirical findings, this thesis contributes to both academic and practical debates. It extends the literature on reverse logistics by tailoring concepts to the oil and gas sector and provides a step-by-step guideline for companies seeking to strengthen their systems.

Below presents the overall research process undertaken in this study. The flowchart outlines the sequential steps followed, beginning with the definition of the research problem and the execution of a systematic literature review. Based on the insights gained, key research gaps and questions were formulated, which guided the selection of appropriate research techniques. The study then proceeded with the collection of both secondary data from academic and industry sources, and primary data through in-depth interviews. The collected data were analysed using a grounded-theory-inspired coding approach involving open, axial, and selective coding stages and multi-case study was applied. The final stages involved interpreting the findings and formulating practical recommendations and conclusions. This structured approach ensured methodological coherence and alignment with the study's qualitative, exploratory nature.

Figure 1. Research Process



Source: Author's elaboration

1.1. Research Methodology

Multi-method qualitative research approach was chosen for the research, as it offers the depth and flexibility required to address the intricate nature of reverse logistics and waste management in the oil and gas industry (Köhler, 2024; Patton, 2002). Qualitative methods are particularly advantageous for research exploring **"how"** and **"why"** questions, providing nuanced insights into complex issues and processes that quantitative methods may oversimplify (Adamson et al., 2004). In this context, qualitative research facilitates a comprehensive understanding of the organizational motivations, challenges, and strategic approaches that underpin waste management practices, thereby aligning with the research objectives of this study.

The complex and multifaceted nature of waste management practices in oil and gas-encompassing regulatory requirements, environmental impacts, and logistical challenges make qualitative methods especially appropriate. Qualitative research enables a flexible and adaptive framework to capture emergent themes and adapt to unforeseen findings, particularly valuable when examining specialist insights and diverse case studies in the industry (Köhler, 2024). This flexibility is important especially when studying industry-specific practices across different organizations and regions, where variations in regulations, environmental conditions, and operations are common (Hamilton and Finley, 2019). Unlike quantitative methods, which may miss the complexity of organizational motivations, qualitative interviews and case studies allow the gathering of rich, context-specific data that reveal the environmental priorities and corporate strategies guiding these practices (Bansal and Roth, 2000; Denzin and Lincoln, 2017). This depth of understanding is essential to achieve a holistic view of waste management and reverse logistics, given the intricate blend of operational, ethical, and regulatory factors involved.

The study began with a Systematic Literature Review (SLR) to establish the theoretical foundation and identify critical research gaps (RGs) that necessitated the primary data collection. Following established protocols (Tranfield et al., 2003), the SLR involved a rigorous search across databases (Scopus, Web of Science) using predefined inclusion and exclusion criteria. This process yielded a targeted sample of 35 articles focused on reverse logistics in the petroleum sector. The resulting body of literature was analysed using the 4W1H framework to code key elements-such as research motivation, methodology, and geographical scope-thereby providing a comprehensive overview of existing knowledge, highlighting limitations, and formally justifying the need for the empirical research questions. The SLR was thus integral to confirming the theoretical void this thesis addresses, specifically the absence of context-specific RL implementation models for the oil and gas industry.

The overall theoretical and conceptual foundation for this research is simultaneously validated by a rigorous body of 229 total sources, ensuring a comprehensive blend of academic theory and operational relevance. The quality of this foundation is confirmed by the following numerical breakdown of source types:

Table 1. Classification of Literature Sources by Publication Type (N=229)

Publication type	Count (N)
Journal Articles	191
Conference Proceedings	11
Books/Monographs	12
Book Chapters/ Encyclopedia Entries	4
Technical Reports	1
Web References/Corporate Reports	10

Source: Author’s elaboration

This structure demonstrates that the principal evidence is built upon 191 Journal Articles, guaranteeing a high degree of peer-validated knowledge. The inclusion of 12 Books/Monographs and 1 Technical Report provides essential methodological and foundational context. Furthermore, 10 Web References/Corporate Reports, comprising sustainability and ESG reports from key multinational companies, ensure the thesis is anchored in the latest official industry commitments and practices.

Primary data was collected through **semi-structured interviews**, a widely used qualitative research method that allows for in-depth exploration of participants’ experiences, opinions, and motivations (Adeoye-Olatunde and Olenik, 2021; Peters and Halcomb, 2015). This methodological choice was crucial for obtaining both structured and spontaneous insights from the participants. It offers flexibility and adaptability while maintaining focus on specific themes, making it more powerful than other interview types for qualitative research (Mashuri et al., n.d.). Semi-structured interviews allowed for the exploration of specific topics related to waste management, ensuring that key areas of interest were covered systematically. These topics included reverse logistics practices, challenges in waste management, vessel routing, key performance measurements, regulatory compliance, and innovative strategies employed within the oil and gas industry.

The flexibility of semi-structured interviews also permitted interviewees to introduce and elaborate on relevant issues from their own perspectives. This approach encouraged participants to share their unique experiences, challenges, and insights in a more natural and conversational manner. As a result, the interviews were not restricted to a predefined set of questions, allowing the discussion to flow according to the participants' expertise and areas of interest.

Overall, the semi-structured interview process was instrumental in gathering rich, qualitative data that provided valuable insights into the current practices, challenges, and opportunities in waste management within the oil and gas industry. The flexibility of this approach ensured that the research could adapt to the expertise and insights of the participants, enhancing the depth and relevance of the findings.

In the context of this thesis, **purposive sampling** was employed to identify and select interviewees from the oil and gas industry who work closely with waste management operations. Purposive sampling is a non-probability sampling technique specifically designed to select informants who possess certain knowledge or characteristics pertinent to the research study (Creswell, 2014; Palinkas et al., 2015; Tongco, 2007). Unlike convenience sampling, which involves selecting participants based on their easy accessibility, purposive sampling involves a deliberate selection process (Etikan et al., 2015). This approach ensured that the participants had specific and relevant expertise, thereby providing in-depth insights into current practices, challenges, and opportunities in reverse logistics and waste management within the industry. Purposive sampling is especially useful in qualitative research, where the depth of information is often more important than the total number of participants. By selecting professionals such as waste management experts, logistics planners, directors and senior managers, the study could capture a diverse range of perspectives and experiences, contributing to a comprehensive understanding of the subject matter. This targeted approach was essential for developing a robust theoretical framework grounded in real-world practices and insights. Andrade (2020) also highlighted that researchers must carefully consider the trade-offs between accessibility, relevance, and representativeness when employing these sampling methods. The careful selection of interviewees not only enhanced the relevance and richness of the data collected but also ensured that the findings could directly inform the development of strategies to improve waste management efficiency and sustainability in the oil and gas industry.

The interview process in this study was meticulously developed and structured using the five-phase framework proposed by Kallio et al. (2016), which has been shown to enhance the credibility, confirmability, and dependability of semi-structured interviews in qualitative research. Following this framework enabled a systematic approach to designing an effective interview guide that allowed for in-depth exploration of reverse logistics and waste management practices within the oil and gas industry.

Phase 1: Identifying the Prerequisites for Using Semi-Structured Interviews

In the first phase, a critical assessment was conducted to ensure that semi-structured interviews were the most suitable method for achieving the study's research objectives. Given the exploratory nature of the research questions, semi-structured interviews were deemed appropriate for capturing detailed insights into industry practices and participant experiences (Kallio et al., 2016). This phase involved confirming that the semi-structured format could provide the depth of understanding needed to explore complex logistical and environmental management issues effectively.

Phase 2: Retrieving and Utilizing Previous Knowledge

To ensure that the interview guide was well-informed and relevant, an extensive literature review was conducted, synthesizing previous studies on reverse logistics, waste management, and semi-structured interview methods. This review served as a foundation for the interview guide, mapping out key topics and themes to be covered during the interviews. Consulting both theoretical and empirical literature allowed the guide to reflect established concepts and identify areas that needed empirical validation through expert input.

Phase 3: Formulating the Preliminary Interview Guide

In developing the preliminary interview guide, particular attention was given to balancing broad, open-ended questions with specific follow-up prompts, ensuring that the guide could facilitate both structured and spontaneous insights. The main themes were chosen to cover core areas such as regulatory compliance, performance metrics, challenges in reverse logistics, and waste management innovations. Follow-up questions were designed to gently nudge participants if they had difficulty understanding the main questions, preventing leading biases and allowing for richer, more participant-driven responses.

Ethical considerations were integrated into this phase to ensure that the questions did not inadvertently cause distress or discomfort. This included revising the language of certain questions to maintain a neutral and professional tone.

Phase 4: Pilot Testing the Interview Guide

To enhance the reliability and clarity of the interview guide, a pilot test was conducted with a small sample of participants who had similar roles to those in the main study. This pilot test provided essential feedback on the content, structure, and clarity of the interview questions, which led to several adjustments in the phrasing and sequencing of questions to improve comprehension and flow. Additionally, feedback from other researchers familiar with qualitative methodologies was incorporated to address any issues related to interviewer bias or the guide's alignment with the study's objectives. This phase ensured that the interview guide was both comprehensive and practical for use in +the actual data collection process.

Phase 5: Presenting the Complete Interview Guide

After refining the interview guide based on pilot test results, the finalized version was used for the main data collection. The guide was presented in a clear, logical order, with main themes followed by optional follow-up prompts, enabling a systematic yet adaptable approach to data collection. As suggested by Kallio et al. (2016), presenting the complete guide helps to ensure the study's dependability, allowing future researchers to replicate the data collection method if desired. This structured process also aligns with the principles of confirmability, as the transparent development and piloting of the guide support the objectivity of the research.

Ensuring Trustworthiness of the Methodology

Applying this rigorous approach to interview guide development contributed significantly to the trustworthiness of the data collected. By following each phase as outlined by Kallio et al. (2016), the research was able to ensure that the interview methodology was both credible and reliable. The systematic design and testing process reduced the potential for researcher bias and increased the likelihood that the data collected accurately captured participants' perspectives and experiences in reverse logistics and waste management.

Complementing this, **grounded-theory-inspired coding** was used as a structured analytical technique to organise the interview data and develop empirically grounded themes and insights. Through a three-stage coding process-open coding, axial coding, and selective coding-emergent themes were identified, refined, and integrated into a core category. This methodological combination enables both exploratory depth and theoretical contribution, allowing the study to uncover practical patterns while simultaneously building a grounded, empirically derived model of reverse logistics implementation in the oil and gas sector. **Grounded theory** is an **inductive methodology** designed for theory generation. It helps researchers build a theoretical framework that reflects the core aspects of a topic, while grounding it in real-world data and observations (Martin and Turner, 1986). The approach is characterized by an iterative process of constant comparison between emerging theory, data, and existing literature. It focuses on uncovering social patterns that individuals may or may not be aware of (Edmonds and Kennedy, 2017). Unlike other approaches, it does not fit data into pre-existing theoretical frameworks but generates explanatory theories from the analysed data (Matavire and Brown, 2008). In this thesis, the value of grounded theory lies not in its structured coding logic, which supports systematic organization and interpretation of the interview data. By applying grounded-theory-inspired coding procedures, the analysis was able to identify recurring patterns and link operational practices across companies. This analytical structure helped to transform raw qualitative input into coherent themes that directly inform the development of the reverse logistics framework and the comparative insights across developed and developing contexts.

As a next step in the methodological process, the study adopted the **multiple-case study** method as a research approach to investigate the reverse logistics practices in the oil and gas industry. This method is particularly suitable for this research as it allows the examination of complex phenomena in a holistic and in-depth manner (Mills et al., 2010; Yin, 2003). Additionally, it enables the identification of common patterns and variations across different cases, thus providing a comprehensive understanding of the research topic.

Gentles et al. (2015) and Sarfo et al. (2021) recommend 4-15 cases for multiple case study designs, with Gentles et al. (2015) specifically suggesting 4-10 cases to ensure manageable engagement for the researcher and readers, as 15-30 cases may exceed comprehension capacity. This study involved the selection of six case companies, with one of them being an oil company from developing country - Azerbaijan. This company represented the context of emerging markets, where reverse logistics and waste management practices were examined to identify current approaches and potential areas for improvement. The remaining five companies, recognized for their advanced reverse logistics operations in the oil and gas sector, contributed comparative insights that collectively informed a broader understanding of best practices and improvement opportunities across different contexts.

The multiple case study method with the use of semi-structured interviews, allows for a thorough examination of the research topic and provides a comprehensive understanding of the reverse logistics practices in the oil and gas industry (Dubois and Gadde, 2002; Saepudin Mashuri et al., 2022). This approach incorporates insights from a diverse range of companies, including those operating in both developed and developing country contexts. By integrating perspectives from various organizational and geographical settings, the study identifies opportunities for improvement and highlights best practices in reverse logistics and waste management. This approach ensures the applicability and relevance of the study for practitioners and researchers in the field of reverse logistics in the oil and gas industry. To ensure the trustworthiness and analytical rigor of this multiple-case study design, a strategy of data triangulation was applied. By integrating the theoretical foundation established in the systematic literature review with secondary data from corporate reports and primary empirical insights from semi-structured interviews, the research facilitated the cross-verification of findings (Patton, 2002). This methodological triangulation minimized the potential biases inherent in single-source studies and ensured that the identified reverse logistics practices were corroborated across diverse operational contexts.

Mills et al. (2010) has described semi-structured interviews as it is a method which fall between structured and unstructured interviews, attempt to address a set of prepared topics or topic areas. Interviews were chosen as the primary data collection method to gather rich, detailed information directly from industry specialists involved in various aspects of reverse logistics, such as waste management, transportation, and logistics planning. This approach allows for an in-depth understanding of the practices and challenges faced in waste management and reverse logistics, which are often not fully captured through quantitative methods (Cassell et al., 2006; Patton, 2002; Yin, 2003). This method is highly effective in both qualitative and quantitative research contexts where the focus is on obtaining detailed and relevant data from knowledgeable sources (Guarte and Barrios, 2006; Tongco, 2007).

Finally, a comparative analysis of researched reverse logistics practices was introduced to deepen the understanding of variations across different operational environments. Since the interviewed companies operate in both developed and developing countries, the data offered a valuable opportunity to compare implementation approaches in diverse contexts. A comparative analysis was therefore conducted using the interview responses, focusing on key dimensions such as infrastructure, regulation, contractor management, stakeholder coordination, technology use, and performance monitoring. This enabled the identification of practical distinctions and shared challenges across regional settings, based solely on empirical input from respondents rather than generalized assumptions (Eisenhardt, 1989; Zartman, 2011). By drawing on grounded data, this step contributed to the study's aim of producing actionable insights that are both context-sensitive and applicable across varying economic and regulatory landscapes.

In parallel, the study also included a comparative lens focused on a national-level case by analyzing the reverse logistics practices of the national oil company operating within Azerbaijan. This analysis was compared with global experiences shared by interviewees from multinational oil companies operating in more developed markets. The purpose of this comparison was to highlight localized operational challenges, regulatory environments, and logistical constraints in contrast with globally standardized practices. The insights were derived strictly from interview responses rather than predefined assumptions. This additional layer of analysis enabled the identification of specific areas where national practices diverge from or align with global standards, offering a more nuanced understanding of reverse logistics implementation within both emerging and advanced operational contexts.

1.2. Research Objective

Reverse logistics (RL) refers to the process of planning, implementing, and controlling the backward flow of materials, goods, and associated information from the point of consumption back to the point of origin, typically for purposes such as reuse, recycling, remanufacturing, or environmentally responsible disposal (Rogers and Tibben-Lembke, 1999). Although it is traditionally seen as an extension of customer service, RL has evolved into a strategic function within supply chain management, contributing significantly to sustainability, regulatory compliance, and operational efficiency (Presley et al., 2007; Pokharel and Mutha, 2009b). De Brito and Dekker (2004) emphasize that RL is not limited to handling returns but is increasingly recognized as a critical enabler of environmentally sound practices and emission reduction.

In industries like oil and gas, where operations are complex and the environmental stakes are high, reverse logistics (RL) plays a significant role. The sector produces substantial volumes of hazardous and non-hazardous waste, which must be handled in accordance with strict environmental regulations and safety standards. Implementing structured reverse logistics systems in this context enables companies to improve waste tracking, ensure legal compliance, reduce operational costs, and align with broader sustainability goals (Corrêa and Xavier, 2013). However, despite its potential, the oil and gas industry still faces significant challenges in fully integrating RL into its operations, including technological limitations, infrastructure gaps, and coordination barriers. As such, exploring RL within this sector offers a valuable opportunity to advance both theoretical understanding and practical solutions for sustainable supply chain management.

This study aims to explore how reverse logistics can be strategically integrated to improve waste management in the oil and gas industry, while also addressing key challenges and identify research gaps that still exist in this area. The central goal of this research is to offer a comprehensive and novel exploration into the significance, challenges, and opportunities linked with reverse logistics and its pivotal role within the supply chain dynamics of the oil and gas sector. By closely examining the benefits and practical strategies for implementing reverse logistics, this study aims to offer new insights that can help to improve waste management processes and boost the overall efficiency of supply chain operations in the oil and gas industry. Moreover, this research seeks to investigate the potential barriers and challenges that enterprises may encounter while implementing reverse logistics strategies and subsequently propose effective strategies to overcome these hurdles successfully.

Additionally, this study aims to examine the role and significance of emerging Industry 4.0 technologies and software applications in streamlining waste management operations and reverse logistics processes within the supply chain of the oil and gas industry. To achieve these aims, the study begins with a **systematic literature review** to establish the theoretical foundation and identify key research gaps, problems and questions. This is followed by a qualitative empirical investigation, utilizing a case study approach supported by **semi-structured interviews** and **coding process** inspired by **grounded theory** to enable systematic theme development and theoretical insight.

A preliminary **Systematic Literature Review (SLR)** enabled the study to map existing research on reverse logistics and waste management within the oil and gas industry. While the literature acknowledges the increasing importance of reverse logistics in advancing sustainability goals, the review also highlighted several critical **research problems**, **gaps**, and **unanswered questions**. These findings helped to shape the direction of this study and informed the development of the core research focus. The following section outlines the identified research gaps, problems and questions which will be examined in depth in the subsequent chapters.

Overall, this research aims to offer insights and recommendations, supporting a sustainable approach to waste management and reverse logistics while cultivating a more streamlined, efficient, and ecologically conscious supply chain landscape for the oil and gas industry.

1.3. Research Gaps (RG)

Based on the Systematic Literature Review conducted, presented in Chapter 3, the importance of reverse logistics in enhancing waste management operations within the oil and gas industry is increasingly recognized, while critical research gaps remain that call for further exploration. These gaps, categorized into theoretical, empirical, and methodological dimensions, have guided the development of this study's core focus, which will be addressed in detail in the subsequent chapters. The following subsections outline the specific research gaps, providing a foundation for targeted investigation to advance knowledge in this field.

Theoretical gaps:

RG1 - The existing literature lacks comprehensive coverage on implementing reverse logistics during waste management operations in the oil and gas sector.

RG2 - There is limited research about the place that reverse logistics takes part in supply chain in oil and gas industry.

RG3 - There is a shortage in literature about the role and engagement of supply chain parties in reverse logistics and waste management activities realized in oil and gas sector.

RG4 - Insufficient analysis of outsourcing opportunities for reverse logistics and waste management activities in the petroleum industry.

RG5 - A gap in the existing research landscape is the need for a comprehensive exploration of how Industry 4.0 technologies can be effectively harnessed to optimize waste management operations and streamline reverse logistics processes within the oil and gas industry's supply chain management.

Empirical gaps:

RG6 - The lack of empirical primary data, validation and limited sample size hinders understanding the practical implementation of reverse logistics during waste management in the oil and gas industry, potentially leading to incomplete insights into effective practices.

RG7 - The literature is almost silent about designing reverse logistics network tailored for oil and gas industry.

Methodological gaps:

RG8 - The need for more comprehensive approaches that consider multiple variables in reverse logistics for oil and gas waste management.

RG9 - Lack of a structured framework to assess outsourcing decisions in reverse logistics and waste management, including criteria for partner selection, compliance assurance, and performance monitoring in the oil and gas sector.

1.4. Research Problems (RP):

Building on the research gaps identified earlier, this section highlights the practical and theoretical challenges that impede the advancement of reverse logistics and waste management operations within the oil and gas industry. These research problems reflect critical issues such as limited awareness, decentralized processes, and underutilized opportunities, which hinder the effective integration of reverse logistics to improve waste management. The problems listed below provide a foundation for addressing these barriers, guiding the development of this study's empirical and analytical efforts to offer actionable insights and solutions in the subsequent chapters.

RP1 - Oil companies miss the opportunities of reverse logistics raising from lack of awareness about its benefits and implementation methods.

RP2 - Waste Management operations are not centralized because of a lack of reverse logistics activities in most businesses.

RP3 - Lack of theoretical and empirical research on petroleum oil from reverse logistics perspective compared to other sectors.

RP4 - There is a lack of literature about the place of reverse logistics in supply chain of oil and gas industry.

RP5 - Limited research on participation of supply chain parties in reverse logistics/waste management activities.

RP6 - Outsourcing opportunities within reverse logistics operations in petroleum industry are not fully discovered by companies.

RP7 - Shortage on literature about barriers and challenges companies can face during reverse logistics/waste management operations.

RP8 - The research gap lies in the absence of a comprehensive investigation into the effective integration of Industry 4.0 technologies to optimize waste management and streamline reverse logistics in the oil and gas industry’s Supply Chain Management.

1.5. Research Questions (RQ):

Following the identification of research gaps and problems, this section presents a set of research questions designed to address the critical challenges and underexplored areas in reverse logistics and waste management within the oil and gas industry. These questions focus on the importance and implementation of reverse logistics, process design, stakeholder coordination, outsourcing strategies, barriers, and the role of technology, aligning with the study’s aim of improving waste management operations. Developed from the theoretical, empirical, and methodological gaps, as well as the practical issues outlined previously, these questions provide a structured framework for the empirical investigation in the subsequent chapters. The research questions listed below will guide the analysis, offering insights to enhance both academic understanding and industry practices.

RQ1 - What is the importance, role, and main drivers of implementing reverse logistics/waste management in the oil and gas industry as a part of supply chain management?

RQ2 - How should the reverse logistics/waste management processes and activities be designed within supply chain to increase the efficiency of operations in oil and gas industry?

RQ3 - How to improve the quality of processes and activities between stakeholders within supply chain during reverse logistics/waste management activities in oil sector?

RQ4 - How should outsourcing decisions be taken to increase RL efficiency and what are the steps to follow?

RQ5 - What barriers would companies face while implementing reverse logistics and how to overcome them?

RQ6 - What is the role and significance of technology and software` in enhancing reverse logistics/waste management within the oil and gas industry’s supply chain management?

The following matrix visually maps each research question (RQ) to the specific research gaps (RG) it addresses. This presentation illustrates the interdisciplinary and interconnected nature of the identified gaps, where multiple research questions contribute to addressing a single gap, and some questions are designed to cover several gaps simultaneously. This table complements the detailed descriptions provided earlier and offers a concise view for clarity.

Table 2. Mapping Research Questions to Research Gaps

Research Gap/Research Question	**RQ1**	**RQ2**	**RQ3**	**RQ4**	**RQ5**	**RQ6**
RG1 - The existing literature lacks comprehensive coverage on implementing reverse logistics during waste management operations in the oil and gas sector, and further research is required to address various kinds of risks and uncertainties in this context.	✓				✓	
RG2 - There is limited research about the place that reverse logistics takes part in supply chain in oil and gas industry.	✓	✓				
RG3 - There is a shortage in literature about the role and engagement of Supply Chain parties in reverse logistics and waste management activities realized in oil and gas sector.			✓			
RG4 - Insufficient analysis of outsourcing opportunities for reverse logistics and waste management activities in the petroleum industry.				✓		
RG5 - A gap in the existing research landscape is the need for a comprehensive exploration of how Industry 4.0 technologies can be effectively harnessed to optimize waste management operations and streamline reverse logistics processes within the oil and gas industry's supply chain management.						✓
RG6 - The lack of empirical primary data, validation and limited sample size hinders understanding the practical implementation of reverse logistics during waste management in the oil and gas industry, potentially leading to incomplete insights into effective practices.		✓			✓	
RG7 - The literature is almost silent about designing reverse logistics network tailored for oil and gas industry.		✓				
RG8 - Need for more comprehensive and validated models considering a wider range of variables for reverse logistics during waste management in the oil and gas sector.		✓				
RG9 - Absence of a structured analytical methodology to assess and determine the				✓		

Research Gap/Research Question	RQ1	RQ2	RQ3	RQ4	RQ5	RQ6
viability, efficiency, and potential benefits of outsourcing reverse logistics and waste management tasks in petroleum industry.						

Source: Author's elaboration

1.6. Structure and Content of the Thesis

The structure of this dissertation is designed to provide a coherent progression from foundational concepts toward empirical investigation and the development of an applied framework for reverse logistics and waste management in the oil and gas sector. Each chapter contributes a distinct layer of analysis, collectively addressing the research gaps identified in the literature and responding to the study's research questions. The chapters are arranged to guide the reader systematically through the conceptual underpinnings, methodological design, empirical findings, and practical outcomes of the research.

Chapter 1 introduces the central themes and motivation of the dissertation, establishing the importance of reverse logistics and waste management in the oil and gas industry. It highlights the growing operational, environmental, and regulatory pressures faced by petroleum companies and explains why effective and well-structured reverse logistics systems are essential for compliance, cost efficiency, and sustainable performance. The chapter outlines the complexity of petroleum waste flows, the critical role of contractors and service providers, and the increasing need for integrated, digitally supported RL processes. These challenges frame the overarching problem driving the study: despite the strategic relevance of waste-related operations, the sector still lacks a comprehensive, empirically grounded framework for implementing and managing reverse logistics across organizational and supply chain boundaries.

The chapter then introduces the research methodology underpinning the study. It presents the philosophical orientation and multi-method qualitative strategy adopted to investigate complex industrial practices and explains how the combination of a systematic literature review, semi-structured interviews, and multi-company case studies enables an in-depth examination of organizational processes. The methodological discussion clarifies the sampling logic, data collection procedures, coding and analytical steps, and the measures taken to ensure reliability, validity, and ethical compliance. This foundation demonstrates how research design supports the generation of credible, contextually rich insights into reverse logistics and waste management.

Following this methodological framing, the chapter outlines the research objectives, which translate the broader motivation of the study into a series of clearly defined aims. These objectives centre on understanding current industry practices, identifying operational challenges, analyzing organizational and technological influences on RL performance, and developing an applied reverse logistics network framework tailored to the oil and gas sector.

The chapter then presents the nine research gaps derived from the systematic literature review. These gaps highlight key theoretical, empirical, and methodological shortcomings in existing scholarship, including fragmented perspectives, limited multi-company analysis, insufficient attention to supply chain integration, underexplored contractor coordination, and a lack of research on the digital transformation of RL processes. Together, these gaps justify the need for a comprehensive and practice-oriented investigation of reverse logistics in petroleum operations.

Building on these gaps, the chapter formulates the research problems that define the core industry challenges addressed by the dissertation. These problems reflect issues such as fragmented waste flows, inconsistent data availability, unclear coordination mechanisms, and the absence of unified performance evaluation and design principles for reverse logistics networks.

From these problem statements, the chapter sets out the research questions that guide the empirical inquiry. These questions steer the investigation toward understanding existing RL practices, identifying operational bottlenecks, evaluating contractor roles and digital tools, and determining how reverse logistics networks can be structured to improve efficiency, compliance, and sustainability in the oil and gas industry.

The chapter concludes with an explanation of how the remainder of the dissertation is organized. It outlines how each subsequent chapter builds upon the conceptual foundations, methodological approach, empirical findings, and analytical insights, ultimately leading to the development of a practical framework for reverse logistics network design. By presenting this structure, Chapter 1 provides a clear roadmap for how the dissertation systematically addresses its research questions and responds to the gaps identified in the existing literature.

Following Chapter 1, **Chapter 2** provides the conceptual foundation of the study by presenting key themes related to reverse logistics and waste management in the oil and gas sector. The chapter begins with a description of reverse logistics and its role in supply chain management, outlining how RL supports environmental compliance, cost efficiency, and material recovery. It then examines the drivers and barriers of reverse logistics processes and activities, discussing regulatory pressures, sustainability requirements, cost factors, and operational constraints that influence RL adoption. The chapter continues with an overview of the types of wastes in the oil and gas industry, classifying both hazardous and non-hazardous waste streams and explaining their implications for handling, transportation, and treatment.

Building on this foundation, the chapter discusses outsourcing reverse logistics practices, describing the widespread use of contractors in waste operations, the reasons for outsourcing, and the challenges associated with contractor performance and oversight. It then moves to performance measurement in reverse logistics, outlining the criteria and indicators commonly used to evaluate RL efficiency, compliance, and cost-effectiveness. The chapter concludes with a review of technological innovations in waste management and reverse logistics, highlighting digital tools and systems that support waste tracking, process optimization, and regulatory reporting. Together, these sections establish the conceptual background needed to interpret the findings of the systematic literature review presented in the next chapter.

Chapter 3 provides a structured and comprehensive systematic literature review of the academic literature on reverse logistics and waste management in the oil and gas industry. This chapter explains the systematic procedure used to collect, screen, and analyse peer-reviewed studies, including the database selection, search strings, inclusion and exclusion criteria, and the step-by-step filtering process. By following a transparent and replicable approach, the chapter establishes the academic rigor of the review and ensures that the resulting findings are grounded in a credible evidence base.

The chapter then presents the thematic synthesis of the reviewed studies, highlighting the fragmented nature of existing research and demonstrating how current scholarship tends to focus on isolated topics rather than offering integrated perspectives on reverse logistics in petroleum supply chains. Through this synthesis, the chapter identifies clear limitations in theoretical development, empirical investigation, and methodological approaches.

A core contribution of Chapter 3 is the articulation of the nine research gaps (RG1-RG9) revealed through the systematic literature review, covering insufficient theoretical coverage of RL implementation, limited understanding of supply chain roles and outsourcing, the lack of empirical data and network design studies, and methodological shortcomings related to multi-variable analysis and decision-making frameworks. These gaps directly inform the research questions and justify the need for the empirical study that follows.

Following the research gaps identified in Chapter 3, **Chapter 4** explains how primary data were collected and analysed to gain practical insights into reverse logistics and waste management operations in the oil and gas industry. The chapter begins by outlining the interview process, including the selection of participating companies, the criteria for choosing respondents, and the use of purposive sampling to reach specialists directly involved in waste handling, logistics coordination and environmental compliance. It also describes the development of the semi-structured interview guide, which was informed by the themes emerging from the literature review, ensuring alignment between the interview questions and the study's research objectives.

The chapter then summarizes how interviews were conducted, recorded, transcribed, and anonymized to maintain confidentiality and ethical integrity. It explains the practical considerations encountered during the data collection process, such as scheduling constraints, the availability of technical experts, and differences in organizational structures across companies.

Chapter 4 proceeds to describe the analytical approach, outlining how the interview transcripts were examined using open, axial, and selective coding to identify key themes, relationships, and recurring patterns within the data. This section explains how the coding process enabled the transformation of raw interview material into meaningful categories that reflect real-world practices, challenges, and decision-making processes in reverse logistics.

Building on the interview findings presented in Chapter 4, **Chapter 5** offers a detailed examination of reverse logistics and waste management practices across six major oil and gas companies included in the study. This chapter presents each company as an individual case, summarizing its operational context, waste management approach, outsourcing arrangements, technological capabilities, and compliance practices. The aim is to show how reverse logistics functions in real industry settings and to highlight both common challenges and company-specific approaches.

Each case study draws on interview insights, company reports, and publicly available documents to provide a concise but comprehensive overview of how waste is generated, collected, transported, processed, and monitored within the organization. The chapter illustrates the infrastructure, contractor management practices, coordination mechanisms, and level of digitalization observed within each company, showing how geographical location, regulatory environments, and organizational structures shape the way reverse logistics operations are carried out.

By organizing the cases systematically, Chapter 5 reveals recurring issues-such as reliance on contractors, capacity constraints, variable technology use, and communication gaps while also identifying effective practices, including centralized coordination systems, digital tracking tools, and structured waste categorization methods. These comparative insights form the empirical foundation for the cross-case analysis and the development of the guiding framework.

Chapter 6 synthesizes the findings from the interviews and case studies, presenting the overall results of the research and discussing their implications in relation to the research questions and the gaps identified in Chapter 3. The chapter brings together the main operational themes that emerged across the participating companies, including waste generation patterns, consolidation practices, transportation difficulties, outsourcing and contractor challenges, coordination issues, and the uneven adoption of technological tools. These findings are discussed to show how current reverse logistics practices function in reality and where significant inefficiencies or structural weaknesses persist.

In addition to analysing these results, the chapter incorporates the section *"Recommendations for Designing a Reverse Logistics Network in Oil and Gas Companies"*. This part translates the empirical insights into a structured, practice-oriented guideline that outlines the key steps companies should follow when developing or improving their reverse logistics networks. The recommendations cover waste mapping, the creation of consolidation points, strategic facility selection, transportation optimization, technology integration, stakeholder collaboration, and designing systems capable of scaling with operational demands. These recommendations directly address the weaknesses identified in the study and provide a practical model for enhancing RL performance in the sector. By combining the empirical discussion with clear, actionable recommendations, Chapter 6 not only explains what the findings reveal about current practice but also offers a structured pathway for improvement.

Following the results and discussion presented in Chapter 6, **Chapter 7** outlines the limitations of the study to provide a transparent assessment of the research boundaries and factors that may influence the interpretation of the findings. The chapter acknowledges the constraints associated with the qualitative research design, including the reliance on interview data from a limited number of companies and specialists. While the participating organizations represent significant players in the oil and gas industry, the findings may not capture the full diversity of practices across all regions or company sizes.

The chapter also notes limitations related to data availability, as some operational details, performance indicators, and contractual arrangements could not be fully accessed due to confidentiality and company policies. Additionally, the study focuses on specific aspects of reverse logistics and waste management that align with the research questions, which means certain technical, financial, or regulatory dimensions may fall outside the scope of the analysis.

Methodological limitations such as the subjective nature of qualitative coding, potential biases in participant responses, and the absence of quantitative modelling are discussed to ensure clarity about the study's analytical parameters. Despite these constraints, the chapter emphasizes that the findings remain robust and meaningful due to methodological triangulation and the depth of practitioner insights. These limitations also highlight opportunities for further research.

After the main body of the dissertation, the thesis concludes with a final synthesis of the research findings, reflecting on their theoretical, methodological, and practical implications for reverse logistics and waste management in the oil and gas sector. This is followed by a complete list of literature sources and web references used throughout the study, ensuring transparency and traceability of all cited material. The dissertation also includes a List of Tables and a List of Figures to support navigation and enhance the clarity of the presented data. Finally, Appendix A provides the semi-structured interview questions employed during the empirical research, offering additional methodological transparency and enabling replication or adaptation in future studies.

2. Reverse Logistics and Waste Management in Oil and Gas Industry

2.1. Description of Reverse Logistics and its Role in Supply Chain Management

Gomes, n.d. (2010) described reverse logistics as logistics in reverse direction which is dealing with products from the point of consumption back to the point of origin to restore the value of the returned product. In the study of de Brito and Dekker (2004), one of the definitions cited for reverse logistics characterizes it as a broad term encompassing the logistics management and disposal of hazardous or non-hazardous waste from packaging and products. This definition also includes reverse distribution, a process causing goods and information to move in the opposite direction of normal logistics activities. Reverse logistics contains planning, implementing, and controlling the flow of products and storage of used materials and information in a reversive direction with the purpose of reusing, recycling, repairing, and disposing correctly (Pokharel and Mutha, 2009). Presley et al. (2007) observed that reverse logistics, traditionally confined to customer service departments, dealt primarily with customers returning warranted or defective products to suppliers. However, it has evolved into a source of organizational competitive advantage, elevating its status as a strategic decision. In contemporary strategic perspectives, reverse logistics plays a crucial role in "closing the loop" for supply chain management (Blumberg, 2004; Kumar and Kumar, 2013; Mishra et al., 2022). The forms it takes vary based on the reasons for return, encompassing simple returns of consumer products to the shelf or broader management of returns for purposes like reuse or repair.

The concept of "reverse logistics" encompasses the logistical processes associated with recycling, disposal, and material management. It involves a comprehensive approach that includes activities aimed at reducing emissions, promoting recycling, exploring alternative solutions, facilitating reuse, and managing disposal (de Brito and Dekker, 2004; Dowlatshahi, 2000; Dr. Dale S. Rogers and Dr. Ronald S. Tibben-Lembke, 1999; Pokharel and Mutha, 2009). Rogers and Tibben-Lembke (2001) explained the purpose of reverse logistics and gave the most widely accepted definition of it as "reverse logistics is the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal".

Ye et al. (2013) present a classification of reverse logistics definitions, dividing them into two distinct structures. Initially, it is delineated as encompassing activities such as transportation, warehousing, and inventory management within the reverse supply chain. This focuses on extracting value from products or materials returned by customers, regardless of the alignment with the initial forward supply chain. In a broader sense, the second definition includes all processes related to the reverse supply chain. This extends to collection, disassembly, reassembly, distribution, and the sale of recycled materials or reconditioned products. The author underscores that reverse logistics comprises two fundamental concepts: product return and product recovery. Product return involves the physical transportation of used or defective goods from the consumption point back to the origin for purposes such as remanufacturing, reuse, or destruction. Product recovery, on the other hand, refers to taking back used or defective goods and finding ways to recover value from them, whether through repair, recycling, or other forms of reprocessing (Fleischmann et al., 2001; Sasikumar and Kannan, 2008).

Reverse logistics has got increasing interest from researchers and practitioners due to its potential benefits such as increasing profit, reducing costs, gaining competitiveness, saving nature and creating green social image, while it has remained under the shadow of forward logistics and supply chain management and was ignored for years (Jayant, 2012; Plaza-Úbeda et al., 2020; Rogers and Tibben-Lembke, 2001). Additionally, businesses have discovered that an improved understanding of product returns and effective reinforcement learning may provide a competitive edge (Agrawal et al., 2015). Reverse logistics is a growing trend in logistics management that involves the recovery, recycling, or reuse of end-of-life products (Olariu and Vasile, 2013). This process collects returned products from consumers, disassembles them, and reuses parts that can be returned to the product life cycle (Wong et al., 2016). Environmental concerns and opportunities for cost savings and revenue generation have led to increased research in this area (Hashemi, 2021). Thus, reverse logistics is now commonly linked with waste management, driven by growing social awareness and concerns for the environment. However, reverse logistics, as distinguished in de Brito and Dekker (2004) research, stands apart from waste management, which primarily involves collecting and processing waste without new utility. The distinction lies in the focus on recovering value and integrating the outcome into a new supply chain. Unlike green logistics, which encompasses environmental aspects in all logistics activities, reverse logistics concentrates on recovering value from used products and their reintegration into the supply chain (Burnard et al., 2015; Rubio and Jiménez-Parra, 2014). This process aligns with the principles of sustainable development, by ensuring the efficient and effective use of the value embedded in products, contributing to societal and environmental sustainability (Sarkis et al., 2010).

As highlighted by Prajapati et al. (2021), the implementation of reverse logistics can provide cost and environmental benefits, minimize risks of government regulation, and improve corporate image. The study identified 13 criteria to evaluate reverse logistics alternatives, with government policy and regulations given the highest priority. Additionally, knowledge of reverse logistics risks and technical expertise are crucial for successful implementation, and companies must develop a specific location and routing equation to reduce transportation costs (Vaz et al., 2013). To stay competitive, companies need to build reverse logistics systems that are not only cost-effective and efficient but also meet customer expectations just as well as traditional supply chain methods (Vaz et al., 2013). As noted by Fernández et al., (2008), reverse logistics stands out as a complex process, demanding dynamic decision-making and meticulous planning, involving the assessment of returned product properties, selection of recovery options, transportation management, warehouse handling, and comprehensive information gathering about the returned product, among other related aspects. Successful implementation of reverse logistics requires firms to comprehend the driving factors and benefits, as well as to navigate the challenges and barriers that might impede reverse logistics activities (Nakiboglu, 2019).

The management decisions within RL are fundamentally guided by the waste hierarchy, which prioritizes actions from the most preferred to the least, namely:

Prevention which involves minimizing the volume and toxicity of waste before it is generated, often through design and upstream management decisions, and then Reduction, Reuse, Recycling, Energy Recovery (Goodship V., 2010). Rao et. al., (2017) also highlighted the importance of waste minimization thus waste minimization, or reduction at source, represents the most desirable activity within the waste hierarchy because it offers both economic and safety benefits by eliminating the expenditure associated with handling, recycling, and disposing of waste that is never created.

Reverse logistics involves two primary types of decision-making: strategic decisions focused on establishing network facilities, and tactical decisions centred around material flow, inventory management, backorders, shortages, and outsourcing (Azizi et al., 2020). Higher supply uncertainties make it more complicated to design reverse logistics networks than forward logistics networks (Alshamsi and Diabat, 2015). During the design phase of reverse production, companies face significant risks as they make decisions, primarily due to the substantial expenses related to transportation, potential facility placements, and various other factors which affect subsequent decisions about the locations of main infrastructures and transportation layout. Reddy et al., (2020) mentioned the importance of considering carbon emissions during planning reverse logistics network. Thus, the increase in carbon emissions and transportation costs causes companies to lose money by decreasing their total profit and to mitigate this, companies should increase the capacity of inventories, remanufacturing centres, inspection centres and the amount of used products carried. There is empirical evidence suggesting that fuel consumption and emissions can be influenced by multiple factors, including road inclination (Tavares et al., 2008) and traffic disturbances (Ericsson et al., 2006). It is essential to examine the importance of fuel efficiency since empirical studies have demonstrated that the most economical or shortest distance routes may not always be the best options for minimizing fuel consumption and emissions in practical applications (Naveed Wassan et al., 2019). The authors also highlighted the importance of utilizing empty returning vehicles which could be used for collecting demand and minimizing fuel cost.

2.2. Drivers and Barriers of Reverse Logistics Processes and Activities

2.2.1. Drivers of Reverse Logistics Processes

There are several drivers that motivate organizations to engage in reverse logistics activities. Chileshe et al. (2018) investigated categories of drivers - economic, environmental and social - in the construction sector and stated that main drivers that affect reverse logistics practices are cost of salvaged items and primacy of business objectives while societal factors have uncertain influence. Hsu et al. (2013) proposed 4 environmentally focused drivers of green supply chain management which pursues reverse logistics which are regulatory measures, customer pressures, competitor pressures and socio-cultural responsibility. Eltayeb et al. (2010) mentioned some additional drivers that would initiate green operations such as supplier pressure, market demand, community pressures, social responsibility and expected business benefits and highlighted the importance of waste management in reverse logistics. Drivers of green supply chain management can be grouped into external and internal drivers. Huang et al. (2017) cited clear environmental vision and policy statement, commitment resource of green supply chain initiatives and support action and interpretations of the importance of environmental issues as internal drivers. Lau and Wang (2009) highlighted various drivers influencing reverse logistics. These include environmental legislation, extended producer responsibility, economic considerations, achieving material reuse and energy conservation, increasing competitiveness and improving customer service. The integration of forward and reverse logistics in closed-loop supply chains positively enhances organizational performance across multiple dimensions and impacts logistics, marketing, and financial performance (Krikke et al., 2004; Mondragon et al., 2011). Studies emphasize the strategic importance of aligning supply chain strategies with environmental goals to optimize reverse logistics and foster sustainable business practices.

According to Govindan and Bouzon (2018) reverse logistics drivers, which motivate companies to implement RL initiatives, can be classified into eight clusters: policy-related issues, governance and supply chain process-related issues, management-related issues, market and competitor-related issues, technology and infrastructure-related issues, economic-related issues, knowledge-related issues, and social-related issues. Among these drivers, regulatory pressure for environmental initiatives is the most prominent, followed by green consumerism and economic viability. In their comprehensive exploration of reverse logistics, Pokharel and Mutha (2009) delve into the multifaceted drivers shaping the reverse logistics system. Their focal points include the significant influence of legislation and directives, with a particular emphasis on early producer responsibility (EPR) and its role in fostering green design and manufacturing practices. The authors further distinguish between reverse logistics system designs tailored for a single product type and those accommodating multiple product types, showcasing the adaptable nature of reverse logistics configurations. Highlighting the broader significance of reverse logistics, Pokharel and Mutha (2009) stress its growing attention, attributed to the potential for extracting value from used products. Beyond legislative frameworks, their analysis underscores the pivotal role of consumer awareness and societal responsibilities toward the environment as crucial drivers within the reverse logistics paradigm. This nuanced approach contributes to a more comprehensive understanding of the diverse factors influencing the dynamics of reverse logistics systems.

De Brito and Dekker (2004) identified three key drivers for reverse logistics: economics, legislation, and corporate citizenship. Companies engage in reverse logistics for direct economic gains like material savings and value-added recovery, as well as indirect benefits such as preparing for legislation and cultivating a green image. Legislation plays a crucial role, with legal requirements compelling companies to participate in reverse logistics (Veiga, 2013). Corporate citizenship reflects a commitment to responsible engagement, aligning with values that prioritize social and environmental concerns. This driving triangle illustrates the interconnected nature of these motivations, emphasizing their overlap in practice.

Economic drivers in reverse logistics encompass various aspects such as the reuse of product materials, recovering product value, reducing disposal costs, and generating indirect benefits like a green image, enhanced competitiveness, and strategic advantages Bouzon et al. (2015). The authors concluded that primary influence factor is not the government and legislation drivers but economic drivers and the actions of refurbishes in the aftermarket. They also highlighted that green image enhanced by reverse logistics application also helps companies to gain market share and make profit. Building on this perspective, authors have further identified key driving forces behind the implementation of reverse logistics. Bouzon et al. (2015) cited that governmental regulations form a critical legal framework, while economic considerations drive financial benefits and cost reduction. Changing consumer expectations and corporate citizenship contribute to reverse logistics adoption, aligning practices with societal values. Market-driven factors and stakeholder pressures, including supply chain capabilities, costs, and environmental impact, further shape reverse logistics decisions. The findings offer nuanced insights into the multifaceted influences guiding organizations in embracing reverse logistics practices.

Another key driver of reverse logistics practices is competitive drivers. Thus, by efficiently managing product recovery and refurbishment, organizations can optimize their resource allocation and minimize expenses related to inventory storage and management. This cost-saving measure allows organizations to allocate their resources more effectively and potentially improve their profit margins, contributing to their overall competitiveness in the market (Andrade et al., 2014; Bentamar and Ourahou, 2020; Hsiao, 2014; Li and Olorunniwo, 2008; Meyer et al., 2017). The author also mentions operational performance drivers as effective reverse logistics practices can help companies reduce several operational costs such as transportation, waste disposal and inventory carrying costs and generate additional revenue. Chileshe et al. (2018) explores the drivers behind implementing reverse logistics a departure from traditional supply chain models. Reverse logistics prioritizes resource efficiency, quality improvement of secondary materials, and minimizing waste. Initiatives, especially in construction, address environmental concerns, product durability, and financial savings. Transitioning to reverse logistics in construction involves changes in design, business models, waste utilization, and consumer behavior. Chileshe et al. (2018) categorizes reverse logistics drivers into economic, environmental, and social subgroups, emphasizing cost considerations, environmental regulations, and community values. These drivers contribute to enhancing organizations' images and aligning with social justice and equity principles.

Ravi and Shankar (2015) underscores the significance of the volume of products in the return stream as a primary driver influencing reverse logistics activities. Research results indicate that organizations managing a larger volume of returned products tend to cultivate expertise in optimizing their reverse logistics programs. The authors highlight economic, ecological, and legislative considerations as the key factors prompting companies to engage in reverse logistics initiatives. Sorkun and Onay (2018) discuss the diverse motivations driving companies to adopt reverse logistics, including marketing, competition, environmental, social, and legislative factors. These incentives can be categorized as initiative-taking (voluntary adoption for benefits like cost savings and improved image) and reactive (compliance with legislative requirements). Institutional pressures, including government regulations, customer expectations, and competitive dynamics, drive the adoption of reverse logistics. The authors listed various motivations driving companies to engage in reverse logistics, including enhancing customer repurchasing behavior, building a positive corporate social image, exploiting financial opportunities (e.g., second-hand market sales or extracting valuable items like gold), complying with government regulations, benefiting from preferential subsidies and tax policies, reducing raw material costs, minimizing inventory, cutting transportation costs, improving product quality, and reducing the carbon footprint within the supply chain.

2.2.2. Barriers of Reverse Logistics Processes

While implementing reverse logistics and green activities, companies face various barriers such as, insufficient commitment from top management, lack of environmental professional knowledge and information, technological systems, costly human resources, insufficient stakeholder pressure (Huang et al., 2017; Mallick et al., 2023; Sirisawat and Kiatcharoenpol, 2018). Meyer et al. (2017) grouped barriers into internal and external barriers. According to the authors internal barriers are lack of functional integration while collaborative work among different functions of organizations is vital, top managements posture on reverse logistics, financial barriers like lack of initial capital and investment funds for reverse logistics operations, and lack of sufficient information systems. External barriers listed are supply chain partners' integration as with poor integration between stakeholders the cost of the return system may increase, lack of accurate forecasting, and finally lack of government support and well-established environmental laws.

Nakiboglu (2019) highlights several challenges in the execution of reverse logistics. These encompass limited recognition of benefits in emerging economies, with factors like the absence of environmental laws acting as barriers. Challenges include consumer perception, lack of awareness, and societal acceptance. Top management support is crucial, and its absence, along with resistance to change, impacts program implementation (Abbas, 2018; S. Senthil, 2014; Subramanian et al., 2014). Limited information flow, restrictive company policies, and quality concerns affect reverse logistics. Financial constraints, lack of standardized systems, technological inadequacies, and insufficient collaboration with supply chain partners also impede effective reverse logistics. Legal issues, unidentified returns, competitive problems, and forecasting difficulties further contribute to barriers in reverse logistics implementation (Silva et al., 2025; Waqas et al., 2018).

Ravi and Shankar (2015) emphasize various barriers in reverse logistics management. Identified hurdles include issues with information and technological systems, product quality, company policies, resistance to change, lack of performance metrics, inadequate training, financial constraints, top management commitment, awareness gaps, and strategic planning deficiencies. Financial constraints are underscored as a major barrier. In the Indian context, survey results reveal key barriers: financial constraints, lack of awareness, product quality concerns, absence of performance metrics, and insufficient top management commitment.

Chan et al. (2012) identifies key barriers to implementing reverse logistics in the automobile industry, categorizing them into management, technical, and perspective barriers. In the management aspect, the complexity of automobile supply chains poses challenges in controlling reverse logistics activities, especially with the involvement of multiple parties. The technical barrier involves challenges in recycling due to the intricate disassembly of vehicles and the lack of efficient technological solutions. Perspective barriers relate to differing views between customers and original equipment manufacturers regarding the reuse of materials, influenced by safety concerns (González-

Torre et al., 2010). Despite growing environmental awareness, some companies prioritize cost over reverse logistics needs.

Research of Bouzon et al. (2018) on reverse logistics barriers in the Brazilian context reveals a comprehensive multi-perspective framework for evaluating these impediments. The study underscores the importance of understanding complex relationships among stakeholders and addresses both general and managerial implications. Stakeholders influencing reverse logistics barriers include the government, customers, society/NGOs, market/competitors, suppliers, organization, employees, and media. The authors formulated a multi-perspective framework for reverse logistics barriers, categorized based on stakeholders, provides an in-depth understanding of the challenges associated with reverse logistics. The barriers, analysed from governmental, organizational, and customers' perspectives, reveal critical insights into the complexities of RL implementation:

Governmental Perspective:

From a government standpoint, barriers encompass the absence of specific laws, inadequate waste management practices, lack of inter-ministerial communication, deficiency in motivation laws, misuse of environmental regulations, and challenges related to extended producer responsibility across countries.

Organizational Perspective:

Examining barriers from an organizational viewpoint highlights internal challenges. These include a shortage of personnel technical skills, absence of IT systems standards, lack of latest technologies, technology and R&D issues related to product recovery, inconsistent product quality, absence of appropriate performance management systems, lack of initial capital, limited taxation knowledge on returned products, company policies against RL, perception of a poorer quality product, low importance of RL relative to other issues, and low involvement of top management and strategic planning.

Customers' Perspective:

Customers' perspectives introduce barriers such as difficulties with supply chain members, limited forecasting and planning, and the perception of a poorer quality product.

The research highlights that internal barriers dominate, with organizations holding 10 out of 13 key barriers. This suggests a strategic approach to reverse logistics implementation by initially addressing internal obstacles. The findings are valuable not only for companies but also for various reverse logistics stakeholders, including policymakers, industry practitioners, and researchers. The multi-perspective framework aids in identifying priority actions and developing a holistic industry strategy for successful reverse logistics implementation.

Gardas et al. (2018) highlighted some barriers which make reverse logistics implementation challenging such as lack of routine service pick up. Distance increases the cost of oily waste collection and results in improper disposal. Some other barriers were also mentioned in the research-lack of knowledge and awareness about the environmental impacts, the high cost of legal disposal of oil which leads to illegal oil dumping or selling to illegal buyers, insufficient government policies, lack of top management commitment, lack of integration between some stakeholders such as vehicle manufacturers and re-refiners, oil leakage as a result of improper maintenance, finance, inefficient oily waste management and lack of technology and facilities.

Lau and Wang (2009) identified several barriers hindering the effective implementation of reverse logistics. Common obstacles include misconceptions, lack of management attention, company policies, absence of standardized processes and technologies, shortage of personnel and financial resources, and concerns about competitive and legal issues. The complexity of managing reverse logistics is exacerbated by the involvement of multiple companies, necessitating a holistic approach that emphasizes close collaboration and potentially a redesign of existing forward logistics processes into a closed-loop system. Overcoming these barriers requires firms to adopt various strategies, ranging from implementing self-support systems to outsourcing to third-party logistics providers or establishing collaborative entities or strategic alliances initiated by industry associations or governments. Each approach has its merits and challenges, impacting the ability to efficiently manage reverse logistics operations.

2.3. Types of Waste in the Oil and Gas Industry

Thomas H. C. (2011) has given a simple definition to waste - “Waste is a left-over, a redundant product or material of no or marginal value for the owner and which the owner wants to discard”.

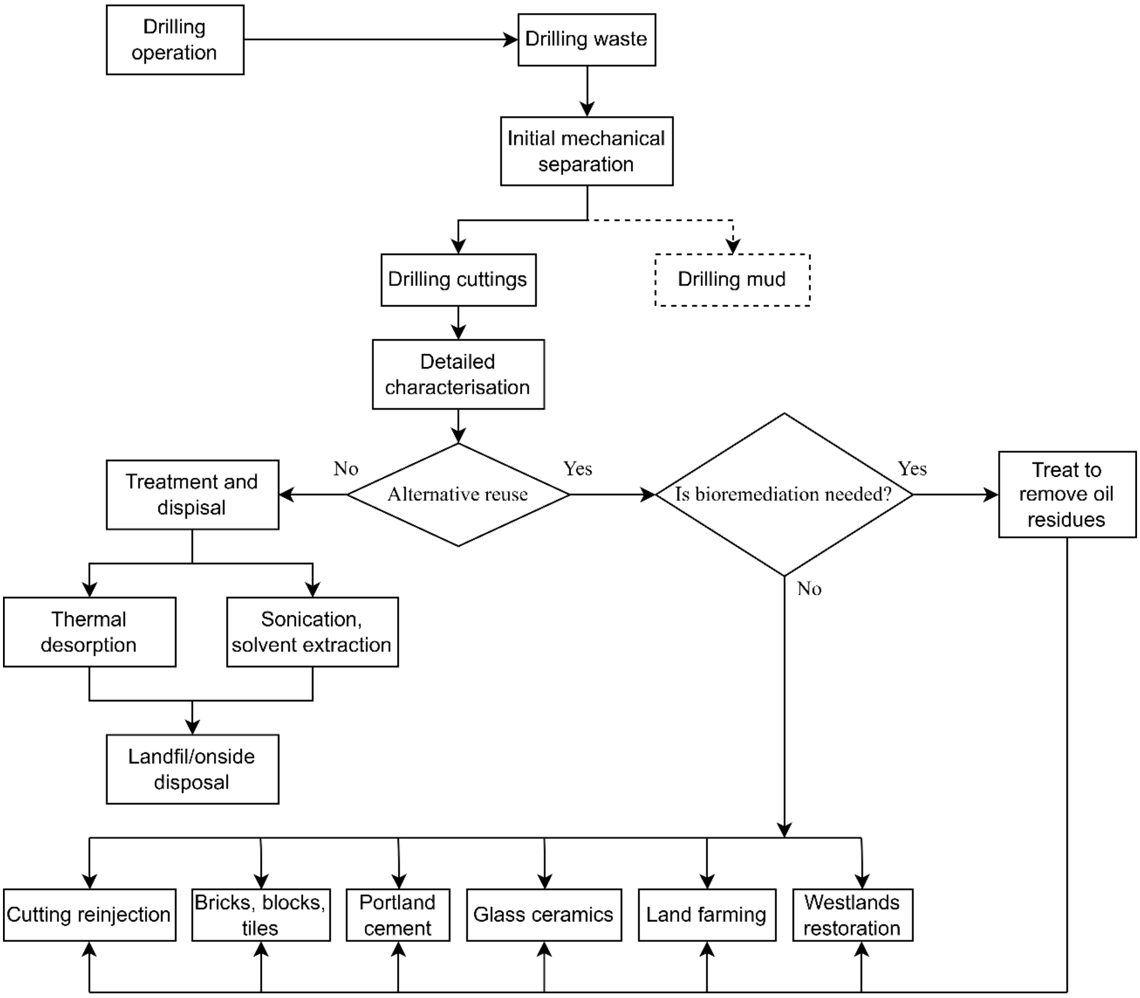
The production of crude oil and natural gas by the petroleum sector contributes significantly to the global supply of energy. During and after the exploration and production (E&P) of oil and gas different kinds of waste occur in oilfields. Generated waste is treated in several ways depending on their kind, company policy and local and international rules. The offshore oil and gas industry faces a significant environmental threat from oil pollution, both accidental spills and the discharge of oil-containing produced water. The biochemical toxicity of crude oil poses risks to the ocean environment, ecosystems, and human health through the food chain. This necessitates special attention and preventive measures in offshore petroleum and gas extraction activities (Liu et al., 2021). Odagme (2016) has mentioned that waste management options are limited to discharging, injections and transportation back to the onshore for further treatment or disposal. The author highlighted drill cuttings and drill fluid or mud as the main wastes generated in petroleum industry, briefly indicated various treatment methods in existence in the industry and made economic analysis of oilfield waste management systems in the Niger Delta. According to Randal et al. (1991), Offshore oil and gas operations generate domestic waste and marine debris such as computer write-protection rings used in micro research and drill protectors from industrial activities.

The oil industry operations encompass a series of interconnected processes. Guerrero-Martin et al., (2023) cited that the first operation in the oil industry is exploration, involving techniques like seismic data acquisition and exploratory wells to identify potential oil-rich areas. The second operation is drilling, employing fluids such as water-based mud or oil-based mud, along with downhole motors, to optimize drilling in oil-bearing zones. The third operation, production, encompasses the extraction, separation, treatment, storage, and transportation of oil and gas. This phase includes recovery systems, considering the recovery factor, with various techniques like primary and tertiary recovery. Additional activities in production involve pipeline implementation, treatment plants, and artificial lift systems. The final operation, decommissioning (teardown), involves assessing and dismantling production facilities to ensure safety, environmental compliance, and efficiency in closing the oil extraction process.

Njuguna et al. (2022) cited that throughout the process of oil exploration various waste materials are produced such as drilling fluids and drill cuttings. Drilling fluids, including water-based fluids and non-aqueous drilling fluids play a role in drilling by assisting in the removal of drill cuttings by lubricating the drill bit and regulating pressure. They may contain dissolved minerals, oil compounds, salts, metal ions and naturally occurring materials. As the drilling process penetrates Oil & Gas reservoirs, the exerted pressure leads to the dislodging of rock fragments that descend and accumulate at the well bore's base. These fragments, known as drill cuttings, pose a risk of well obstruction if they are not efficiently removed from the well and they range in size from clay particles to gravel like pieces (Costa et al., 2023; George and Antonis, 2021; Siddique et al., 2017). Properly managing and disposing of these waste materials is essential to minimize their impact and comply with waste disposal regulations, in the oil exploration industry. The authors also mentioned that as drilling cuttings and fluids contain various chemicals, disposing them on the ground surface can gradually infiltrate the soil, harm the organisms, and pose significant environmental concerns. Offshore produced water, generated during oil and gas extraction, undergoes treatment before being discharged into the ocean or reinjected into the formation (Beyer et al., 2020; Igwe et al., 2013). Efficient treatment is crucial, requiring a comprehensive understanding of the physical and chemical characteristics of produced water through systematic management and appropriate treatment processes, technologies, and equipment (Liu et al., 2021). According to Silverstone et al., (1994) local legislation within the oil and gas industry outlines specific categories of waste that require separation. These typically include organic (food) waste, hazardous waste, and industrial waste. In line with the waste management strategies employed in the oil and gas industry, the reduction of waste quantities is not only a practical approach but also an environmentally responsible one. As evidenced in the waste management practices of Kristiansund, Norway, the imposition of minimum landfill prices by local authorities motivates waste generators to discard less, thereby reducing the burden on available landfill sites. This strategy not only benefits waste generators by offering cost savings but also incentivizes private contractors to engage in proper waste separation and recycling, thereby earning a profit. Such a system ensures the effective handling of waste, including hazardous materials, and fosters environmental responsibility in industry.

Samples taken from oil wells in the Caspian Sea, as highlighted by Abbe et al. (2011), exhibit a composition comprising approximately 60-80% rock solids, 8% organic matter, and 6% mineral salts, clay, and other substances like weighting agents, drilling mud components, stabilizers, and viscosity regulators. The wide range of variations in these components makes it challenging to establish a standardized formula for the composition of these cuttings, thereby complicating the assessment of their toxicology and environmental impact. In the present-day oil industry, drilling operations have progressed to reach deeper wells, necessitating the utilization of an increased array of chemicals and additives in the drilling process. Consequently, the cuttings produced from these operations can no longer be simply disposed of through land farming or discharged into the sea. It is crucial to emphasize that the decisions regarding cuttings management are not solely determined by the depth of the well. Instead, they are influenced by a multitude of factors encompassing local and international environmental regulations, the sensitivity of the environment where waste is received, the specific type of drilling mud employed (which is directly impacted by the drilling location and depth), the available technology and infrastructure for waste management, as well as the overall volume of waste generated (Ismail et al., 2017). Each of these elements plays a role in shaping the appropriate approach to manage and manage drilling cuttings responsibly. The author proposed a decision support process for drill cuttings management as per below figure:

Figure 2. Decision support process for drill cuttings management



Source: Abbe et al., 2011

The array of produced wastes is diverse, ranging from oil-based mud cuttings to household waste from base camps, necessitating a comprehensive waste management strategy. Waste segregation and recycling remain overarching priorities, contingent on process conditions and local possibilities. When alternative options are unavailable, a range of techniques, including stabilization/solidification, landfill disposal, and treatment in authorized centres, is employed. Preferably, improved combustion using special burners is chosen, offering a more environmentally satisfactory alternative to conventional ground flaring (Geneste et al., 1998). The author categorized waste into 3 groups:

Group 1: Hazardous Waste (includes chemicals, painting residues, used oils, polluted packaging, medical waste, soil, and contaminated mud).

Group 2: General and Inert Waste (encompassing used fluids, metals, packaging, non-biodegradable waste, biodegradable waste, clean materials from civil works).

Group 3: Radioactive Waste.

The waste management strategy involves initiating waste inventory and exploring treatment routes, emphasizing source reduction, implementing pre-treatment and treatment processes, and eliminating waste through various methods. Waste reduction at the source can be achieved through the utilization of low toxicity products or by maximizing recycling and reuse efforts (Enamul Hossain et al., 2017). It was also highlighted that under specific conditions, the establishment of dedicated on-site waste management facilities becomes essential. Nevertheless, in many instances, more economically viable alternatives can be explored. This might entail partnering with local waste management facilities to adapt operational practices, making capital investments to enhance existing waste management facilities, establishing joint facilities, or constructing on-site pre-treatment facilities.

Waste categorization is the initial and most critical step, as it determines the appropriate and safe disposal methodology based on the waste's inherent physical, chemical, biological, or infectious properties. Effective management requires addressing all activities-including characterization, collection, transport, treatment, storage, and disposal-along with strategic considerations like waste minimization studies, recycle options, and alternative destruction technologies (Rao et. al., 2017). Fletcher and Hewett (2014) indicate that upstream oil and gas projects produce a diverse array of both hazardous and non-hazardous wastes. These projects are frequently situated in remote areas with limited or no waste management infrastructure. In certain instances, there might be a lack of infrastructure equipped to handle the complete spectrum of generated wastes. Alternatively, even if facilities exist, the Environmental, Health, and Safety (EHS) performance of service providers may not meet the company's minimum standards, particularly in developing countries.

2.4. Outsourcing Reverse Logistics Practices

In the context of reverse logistics, outsourcing refers to the strategic decision of a company to delegate certain reverse logistics activities to external third-party service providers rather than managing them internally. This strategic choice is made when reverse logistics activities are not considered core business functions or when the company lacks the necessary resources, expertise, or infrastructure to efficiently manage these activities in-house. The concept of core competence, widely acknowledged in both theory and practice, emphasizes the preference for outsourcing activities that do not align with the organization's identified "core business". Core business encompasses activities and processes that truly generate distinctive value, warranting their retention as in-house operations (Aas et al., 2008).

Once companies decide to outsource some RL activities, they must choose what activities should be outsourced and by which third-parties to ensure a competitive performance on the market. To choose the appropriate third-party reverse logistics provider, firm executives must accurately identify and analyse the elements that play a role in the outsourcing process, as well as rank the decision criteria that must be fulfilled by the available third-party reverse logistics providers (Tavana et al., 2016a). The capacity of an oil and gas company to shape and enhance the supply chain is crucial for achieving Health, Safety, and Environment (HSE) goals. Upholding corporate social responsibility necessitates alignment among all supply chain entities with the company's HSE policy. The ability to influence and foster an HSE culture throughout the supply chain becomes a paramount factor. Moreover, strategic decisions on outsourcing, a significant aspect of supply chain management, must align with the company's HSE policy. The integration of HSE policies aligns with the core principles of Supply Chain Management (SCM), given the substantial role of HSE activities in diverse business processes within the upstream supply chain, especially within the global oil and gas industry (Aas et al., 2008).

Outsourcing reverse logistics activities do not only cut the operation costs but only improve service quality and operational efficiency which led to competitive advantage in the sector. Nevertheless, outsourcing decisions should align with company strategies and goals which require pre-analyses. Ordoobadi (2009) has proposed outsourcing decision-making model for returned products in supply chain which has four phases: strategic, significance, economic, and decision phases. The paper also demonstrates reasons for outsourcing reverse supply chain activities categorized in strategic, operational and financial reasons. Some of the reasons to outsource the reverse logistics activities are that 3rd parties are available to offer complete reverse logistics solutions by their facilities and experience in the field, companies may have other core activities rather than reverse logistics and in outsourcing case they can focus on core competencies, economies of scale of 3rd parties can reduce the costs and last but not least instead of spending capital on assets, companies can forward it to other productive usage (Agrawal et al., 2016).

Although most of the companies outsource reverse logistics activities for economic factors, it can also improve social and environmental performance of the businesses. While economic factors focus on money and budget for managing returns, environmental components protect nature and social components address developing skills, health and safety of employees (Agrawal and Singh, 2020). Moreover, outsourcing reverse logistics operations can address various challenges faced by organizations in managing product returns, particularly in the context of online retailing and e-commerce (Nel and Badenhorst, 2020). With the electronics industry witnessing significant growth and the surge in product returns, outsourcing reverse logistics becomes imperative for sustainable business practices (Ayvaz and Görener, 2015). Litereature also highlighted that the decision to outsource reverse logistics activities is influenced by factors such as the organization's core competencies, resource optimization, and responsiveness to dynamic customer needs (Rao and Young, 1994). While outsourcing allows organizations to focus on their core functions and reduce resource investments, it also enables them to respond effectively to customer demands in a competitive business environment.

There are several models and strategies to select third party reverse logistics service providers. Before selecting third parties, companies should choose appropriate operating modes for reverse logistics. Sasikumar & Haq, (2010) suggests 3 basic operating modes for reverse logistics - self-support, joint venture and outsourcing. By using multi-criteria decision making (MCDM) model the study determines the "most appropriate" revers logistics operating modes. Furthermore, the article provides a practical case illustration involving a battery manufacturing company, demonstrating the application of Analytic Hierarchy Process (AHP) in selecting the optimal reverse logistics operating mode. By structuring the decision problem into a hierarchical framework and conducting pair-wise comparisons, the company was able to identify the most suitable operating mode-outsourcing in alignment with its organizational goals and environmental regulations. The application of AHP enables decision-makers to address potential inconsistencies in judgments and perceptions effectively. By calculating the consistency ratio (CR) and scrutinizing the pair-wise comparison matrices, decision-makers can ensure the robustness and reliability of the decision-making process.

Abdel-Basset et al., (2021) has highlighted that many of the studies have not considered the risk and safety aspect nearby economic, environmental and social aspects which are crucial while choosing the most sustainable third-party reverse logistics providers (3PRLP). Abdel-Basset et al.'s (2021) exploration of a new Multi-Criteria Decision Making (MCDM) technique, integrating Neutrosophic Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), presents a promising avenue for addressing the inherent complexity and uncertainty associated with 3PRLP selection. By incorporating qualitative and uncertain data into the decision-making process, the proposed approach offers a more comprehensive and nuanced assessment of candidate alternatives. Moreover, Abdel-Basset et al.'s (2021) emphasis on considering safety and risk alongside economic, environmental, and social dimensions underscores the importance of adopting a holistic and sustainable approach to 3PRLP selection. In today's dynamic and interconnected business landscape, organizations must prioritize the mitigation of risks and the promotion of safety within their supply chains to safeguard both their operations and stakeholders.

Sharif et al., (2011) has developed a conceptual framework of the factors which influence reverse third party logistics providers based on Information Systems and associated Resource Commitment factors. Thus, information about the status of orders or items returned should be accurate and in-time to manage third party reverse logistics. Information systems can support this by capability, compatibility and technologies. Another crucial factor to support third party reverse logistics performance is internal component-resource commitment which requires to align resources with technologies and infrastructures to support reverse logistics operations. Nearby the managerial, financial and technological resource commitments, there are two more factors which have positive relationship with third party reverse logistics performance-cost-effectiveness and operating level effectiveness.

Tavana et al., (2016) suggested that companies that are outsourcing reverse logistics activities should consider quality, cost saving and service improvement factors. Third party reverse logistics providers must also understand the importance of these factors to gain competence in the market. Chen et al., (2021) proposed a novel decision-making approach while selecting and evaluating the third-party reverse logistics providers using interval-valued intuitionistic fuzzy set based on sustainability perspectives which have economic, environmental and social aspects. According to the author economic aspects have criteria such as costs, flexibility, quality, lead time and on-time delivery, technology capabilities while social aspects have health and safety practices, social responsibility, education infrastructure and employment practices criteria and pollution control costs, resource consumption cost, green warehousing, green transportation, environmental management system, green research and development and innovation criteria for environmental aspect. The study results suggest that education infrastructure, employment practices, green warehousing, and social responsibility are the most critical criteria to evaluate third-party reverse logistics providers. Wang et al., (2021) have underscored the significance of economic, social, and environmental drivers, finding that expert evaluation identifies lead time, cost, delivery and service, and quality as the most influential criteria among economic factors, while customer voice is considered a significant social factor.

According to Öz and Özyörük, (2021), companies are increasingly turning to outsourcing to stay competitive in their core competency. Outsourcing provides benefits such as focusing on their own business and exploring new markets, reducing logistics costs, dealing with supply chain complexities, improving quality control, enhancing flexibility and efficiency in logistics operations, and gaining access to new technology and logistics knowledge.

2.5. Performance Measurement in Reverse Logistics

Neely et al. (1995) has defined performance measurement as the process of quantifying the efficiency and effectiveness of an action. The term “performance measurement” refers to a comprehensive process utilized across various business sectors and companies to evaluate the efficiency and effectiveness of decisions and strategies implemented within an organization. Additionally, the author defines a performance measurement system as a collection of metrics used to quantify both the efficiency and effectiveness of actions. Organizational performance measurement and metrics play a crucial role in the success of the company as they have potential impact on tactical, strategic and operational planning and management by setting goals, assessing performance, and choosing next steps (Gunasekaran et al., 2004).

Sri Yogi (2015) underscores the crucial role of performance measurement in reverse logistics for liquefied petroleum gas (LPG) agencies, emphasizing the need for effective metrics in guiding strategic, operational, and tactical decisions. Specific measures discussed include reverse logistics cycle time, network and transport capacity, and recovery efficiency rate. Alkahtani et al. (2021) identified 4 aspects of measuring performance of reverse logistics-economical, environmental, social and operational. In the economic realm, logistics cost optimization and profit by recovery efficiency were highlighted, emphasizing cost minimization and profit maximization through innovative strategies. The environmental aspect addressed disposal policies, emission reduction, and waste reduction, showcasing studies on e-waste remanufacturing and its environmental impacts. Social considerations included customer behavior and satisfaction, along with government interference through incentives and regulations. Operational aspects covered investment costs, retrieving, shipment, inspection, quality upgrading (remanufacturing), disposal costs, and maximizing the number of remanufactured end-of-life (EOL) products through inspection quality.

Shaik and Abdul-Kader (2012) proposes that the determinants of reverse logistics performance measurements are the drivers, which encompass various characteristics such as non-financial/financial and internal/external measures. The framework emphasizes the integration of these drivers and their outcomes in assessing performance. Specifically, the drivers can be classified into economics, legislation, and corporate citizenship, which collectively influence the effectiveness of reverse logistics. The author identifies main reverse logistics performance perspectives and measures which cover various aspects, including financial success, process efficiency, stakeholder satisfaction, innovation and growth, environmental compliance, and social responsibility. Performance measures include total RL costs, capital input, sales of returned products, revenue recovery, RL cycle time, network and transport capacity, recovery efficiency rate, customer and government satisfaction, employee and investor satisfaction, management initiatives, employee competency, IT capability, process technology innovation, product life cycle reviews, environmental compliance, materials and energy utilization, disposing capability, corporate image, relationship management, safety, and security. This comprehensive approach ensures a holistic evaluation of the reverse logistics performance and its alignment with various stakeholders and regulatory requirements.

Fernandes et al. (2017) in a systematic literature review of 24 articles, found that financial/economic indicators (e.g., profit increase, cost reduction, value addition) and customer-related indicators (e.g., customer complaints percentage, service quality, delivery effectiveness) are the most frequently used for measuring reverse logistics performance. These are followed by internal operations (e.g., production time, cycle time, inventory control, transport capacity), environmental (e.g., legislative compliance, recycled materials use, renewable energy, pollution reduction, waste disposal), innovation and growth (e.g., employee training, IT capability, strategic alliances, employee satisfaction, R&D investment), social (e.g., corporate citizenship, employee safety, partner relationships), and suppliers (e.g., environmental certifications, commitment to RL practices, product quality).

Shaik and Abdul-Kader's (2013) research on performance measurements in reverse logistics highlights key perspectives and measures for evaluating comprehensive performance measurement of reverse logistics, categorizing measures into financial (e.g., total cost of transportation, total capital input, annual sales of returned products, and revenue recovered), process (e.g., RL cycle time, network capacity, transport capacity, and recovery efficiency rate), stakeholder-related (e.g., meeting customer demands, government satisfaction, employee satisfaction, and investor satisfaction), innovation and growth (e.g., management initiatives, employee competency, information technology capability, process technology innovation capability, and product life cycle reviews), environmental (e.g., overall environmental compliance, materials utilization, energy utilization, and disposing capability), and social aspects (e.g., corporate image, relationships, security, and safety measures). Complementing this, Nunes et al. (2023) in their systematic review identify similar dimensions through qualitative and quantitative approaches, including economic/financial metrics like recycling costs and profitability from recovery, environmental indicators such as CO_2 emissions and waste volume reduction, social measures like customer satisfaction and stakeholder benefits, and operational metrics such as return transit time and volumes transported. Sangwan (2017) further addresses performance evaluation gaps in reverse logistics by proposing KPIs tailored to specific activities and decisions, including for collection location-allocation (e.g., collection cost, value added recovery, energy use, waste generation), collection methods (e.g., initial investment, operating cost, return volume, environmental impact), inspection/sorting facility location (e.g., testing cost, labour cost, volume of collection), degree of disassembly (e.g., value recovery, disassembly cost, environmental impact of processing/landfill/incineration), and product recovery (e.g., operating cost, market demand, technical feasibility, green image).

Chaves et al., (2020) identified four key dimensions for reverse logistics performance measures-costs (e.g., total reverse logistics costs, return prevention costs, transportation and inventory costs), customer service and quality (e.g., on-time delivery, consumer satisfaction, delivery reliability), productivity (e.g., process technology, network capacity, material reuse), and asset management (e.g., inventory obsolescence, turnover)-categorized across strategic, tactical, and operational levels, with additional measures for legal compliance, safety, and social aspects like employment rate.

Shaik and Abdul-Kader (2014) highlighted a variety of performance metrics within the realm of reverse logistics, including: total RL costs, total capital input, annual sales of returned products, revenue recovered, customer satisfaction, government satisfaction, employee satisfaction, investor satisfaction, RL cycle time, network capacity, transport capacity, recovery efficiency rate, management initiatives and employee competency, information technology capability, process technology innovation capability, product life cycle reviews, overall environmental compliance, materials utilization, energy utilization, disposing capability, corporate image, relationships, safety, and security. These metrics provide insights into various aspects of reverse logistics performance, ranging from financial and operational efficiency to stakeholder satisfaction and environmental impact.

The study of Butzer et al. (2017) introduces a comprehensive performance measurement system for evaluating international reverse supply chains, adopting a Balanced Scorecard (BSC) framework. The system comprises six perspectives: Citizenship and Legislation, Financial, Stakeholder, Process, Innovations and Growth, and Flexibility. Under the Citizenship and Legislation Perspective, the aim is to protect the environment and adhere to public restrictions. Performance measurements include the number of offenses of public restrictions in the field of logistics, carbon footprint of transports, reuse rate, and disposal rate. The Financial Perspective targets profit maximization and cost reduction. Key performance measurements involve costs for the reverse supply chain, taxes related to reverse supply chain activities, and the disposal value of regenerated products compared to new products. The Stakeholder Perspective focuses on maximizing stakeholder satisfaction, considering metrics such as customer satisfaction, satisfaction of supply chain collaboration, and supply chain visibility/transparency. Within the Process Perspective, the emphasis is on improving customer-relevant processes. Performance measurements include lead time of reverse logistics and the quality of products. The Innovations and Growth Perspective aims to sustain competitiveness through investments in training for reverse logistics and overall reverse logistics investments. The Flexibility Perspective, added to address uncertainties in international reverse supply chains, involves metrics like the number of flexible employees and volume flexibility, defined as the scale of variations a company can manage without profitability losses.

The following table provides a comprehensive overview of performance measurement indicators for reverse logistics (RL), synthesized from a range of authoritative studies to support a holistic evaluation of RL processes. These indicators are categorized into key dimensions, such as Financial/Costs, Customer Service, Productivity, Asset Management, Environmental, Social, Innovation, Operational, Legal/Compliance, and Flexibility to reflect the multifaceted nature of RL performance across strategic, tactical, and operational levels. Each category includes specific metrics identified in the literature, ensuring a balanced assessment that encompasses efficiency, effectiveness, and sustainability considerations relevant to organizational goals and stakeholder expectations.

Table 3. Performance Indicators for Reverse Logistics

Category	**Indicators**
Financial/Costs	Total reverse logistics costs, Return prevention costs, Transportation and inventory costs, Total capital input, Annual sales of returned products, Revenue recovered, Costs for reverse supply chain, Taxes related to reverse supply chain activities, Disposing costs, Disposal value of regenerated products compared to new products, Collection cost, Operating cost, Testing cost, Disassembly cost, Initial investment
Customer Service	On-time delivery, Consumer/customer satisfaction, Delivery reliability, Satisfaction of supply chain collaboration, Supply chain visibility/transparency, Quality of products
Productivity	Process technology innovation, Network capacity, Transport capacity, Material reuse, Recovery efficiency rate, Energy use
Asset Management	Inventory obsolescence, Turnover
Environmental	Overall environmental compliance, Materials utilization, Energy utilization, Disposing capability, CO_2 emissions, Waste volume reduction, Disposal policies, Emission reduction, Waste reduction, Carbon footprint of transports, Reuse rate, Disposal rate, Environmental impact of processing, Environmental impact of landfill, Environmental impact of incineration
Social	Corporate/green image, Relationships, Security, Safety measures, Government satisfaction, Employee satisfaction, Investor satisfaction, Meeting customer demands, Stakeholder benefits, Health and safety issues, Customer behavior, Government interference (incentives and regulations), Employment rate, Employees' competencies

Category	Indicators
Innovation	Management initiatives, Employee competency, Information technology capability, Process technology innovation capability, Product life cycle reviews, Investments in training for reverse logistics, Overall reverse logistics investments, Innovation capacity
Operational	Return transit time, Volumes transported, Investment costs, Lead time of reverse logistics, Return volume, Reverse logistics cycle time, Value added recovery, Volume of collection, Market demand, Technical feasibility, Retrieving, Amount of remanufactured end-of-life (EOL) products, Inspection quality, Remanufacturing
Legal/Compliance	Legal compliance, Number of offenses of public restrictions
Flexibility	Number of flexible employees, Volume flexibility

Source: Author's elaboration

2.6. Technological Innovations in Waste Management and Reverse Logistics

Recent efforts have been focused on enhancing the sustainability and efficiency of reverse logistics through the integration of Industry 4.0 technologies, such as real-time information sharing and the promotion of eco-friendly products. Sun et al. (2022) introduced term "Reverse Logistics 4.0" and defined it as the sustainable management of material flows and processes to recover value or responsibly dispose of end-of-life (EOL) products achieved through the utilization of data-driven and intelligent technologies, which enable personalization and the introduction of innovative services. The authors indicated that collection, sorting and process management, remanufacturing and recycling, transportation and distribution and disposal are technology relevant reverse logistics processes which can be achieved by industry 4.0 technologies such as IoT, CPS, big data, cloud technology, AR, AM, virtual technology, cybersecurity, autonomous robots, UAV, AI and blockchain (Sun et al., 2022; Yu, 2022). Krstić et al. (2022) evaluated the applicability of Industry 4.0 technologies in reverse logistics and highlighted some of them for their importance such as IoT to track and monitor waste collection data and even develop reverse supply chain management, automated guided and autonomous vehicles to handle transportation and materials remotely, Artificial Intelligence (AI) to make decisions about reverse logistics, such as designing networks, planning vehicle routes, managing product collection and transportation, establishing disposal rules, organizing warehousing, predicting returns, overseeing sorting and inspection, and selecting recycling, reassembly, and remanufacturing options, Big Data and Data mining to collect and deal with large volumes of data which would help planning, predictions, performance and decision making. Furthermore, the author highlighted the importance of blockchain, 3D printing and advanced robotics in the area. Complementing this, Dutta et al. (2022) provided a systematic review of Blockchain and IoT's individual and integrated impacts on sustainable supply chains, underscoring IoT's enhancements in real-time visibility and predictive analytics for reducing product damage and optimizing e-waste collection in reverse logistics, while Blockchain facilitates secure traceability for refurbishing and remanufacturing to minimize resource waste.

Industry 4.0 technologies, including IoT sensors and advanced analytics, are expanding into waste management. Vafeiadis et al. (2019), in his work, introduces a data analytics platform for optimizing waste procedures. This platform emphasizes monitoring, forecasting, and route optimization, offering scalable solutions in smart waste management to reduce costs. As noted by Bayramov (2023), platforms such as the Cloudera Data Platform and the Hortonworks Data Platform can be used to process, store, and analyse large volumes of waste-related data, enabling deeper insights into waste streams and supporting more informed decisions across collection, handling, and disposal activities. Drawing parallels, the application of similar principles to reverse logistics in the oil and gas industry could enhance efficiency, decision-making, and environmental benefits through advanced analytics and IoT technologies. Industry 4.0 represents a digital transformation in production and related industries, revolutionizing the management of industrial value chains and offering significant performance benefits through the implementation of advanced technology. It plays a crucial role in enhancing supply chain operations (Chatchawanchanchanakij et al., 2023). The integration of blockchain technology with reverse logistics offers potential benefits in enhancing transparency, accuracy, and efficiency in asset transactions (Khan et al., 2023). It provides organizations with a means to address ecological and social constraints while delivering profitable business results. However, widespread adoption in reverse logistics is still in its early stages, requiring tailored approaches and models for effective implementation (Bekrar et al., 2021). The author also mentioned disadvantages of blockchain such as risk of hacking, coding transparency as it may not always be obvious to users and legal contract precedence as smart contracts should not replace legal contracts entirely.

One of the key significances of IoT in reverse logistics is its ability to monitor the fulfillment level of collection boxes for waste materials in real-time (Hisham Che Soh et al., 2019). Through the integration of sensor data and IoT technology, an efficient collection signal algorithm can be devised, optimizing the collection schedule and resulting in cost savings. Moreover, the implementation of IoT-enabled waste collection systems contributes to improved waste management practices, promoting recycling activities and fostering a safer and more sustainable environment (Gomathy et al., 2022; Hassan et al., 2018; Sung et al., 2020). Xu and Yang, (2022) delves into the transformative role of technology, particularly IoT and smart sensors, in revolutionizing reverse logistics within waste management. By strategically deploying sensors on dumpsters, municipalities gain real-time insights into fill levels, enabling optimized waste collection routes and significant reductions in operational costs. This data-driven approach not only enhances the efficiency of waste management but also aligns seamlessly with the broader principles of reverse logistics, focusing on improved waste reduction, collection, and recycling strategies.

The use of Radio Frequency Identification Devices (RFID's) and other wireless signaling methods enables solid waste collection to provide real-time signals over long geographical distances (Purohit and Bothale, 2011). This capability, achieved through IoT technology, enhances the efficiency and effectiveness of waste management processes. Additionally, the integration of cloud manufacturing and real-time information systems allows for the systematic integration of IoT and logistics processes, providing intelligent resource management and meaningful utilization of resources in waste collection (Thürer et al., 2019). Investigation of Hannan et al., (2011) unveils an integrated system employing RFID, GPS, GPRS, GIS, and cameras to orchestrate the monitoring of solid waste bins and trucks. RFID facilitates wireless data capture, while a cost-effective camera supports real-time image processing and waste estimation. GPS ensures precision in location tracking, and GSM/GPRS technology enables seamless data transmission to a designated server (Arebey et al., 2010; Islam et al., 2012). The Geographic Information System (GIS) amplifies spatial data analysis capabilities. The articulated system not only enhances waste collection efficiency but also optimizes truck routes, exemplifying a paradigm shift in IoT and technological applications within the domain of reverse logistics. Namen et al. (2014) discusses the revolutionary impact of Radio Frequency Identification (RFID) technology in waste management, citing its simultaneous reading and writing capabilities that enhance operational efficiency compared to traditional barcodes. Bayramov (2023) notes that solutions such as MotionWorks Asset, Higgs RFID ICs, and Motorola's Automatic Location Tracking System may be used to improve the tracking and routing of oily waste during collection and transportation.

Parry et al. (2016) article explores the transformative impact of IoT in supply chain management, using a showering case study to demonstrate real-time data capture beyond sales. The study introduces and empirically validates four User Value Models (UVMs), enhancing Supply Chain Visibility (SCV). It emphasizes the shift from passive consumer roles to active agents, enabled by IoT insights. The article highlights environmental benefits, potential for innovative business models, and the pivotal role of IoT in shaping efficient and sustainable reverse supply chains. Overall, it positions IoT as a key driver for future supply chain innovation. Xie and Chen's (2022) research on Supply Chain and Logistics Optimization Management for International Trading Enterprises through an IoT-based economic logistics model offers valuable insights that can be extrapolated to benefit reverse logistics. The study's emphasis on optimizing transportation, enhancing efficiency, and improving overall supply chain processes aligns with the principles essential to successful reverse logistics operations. The IoT-based model's effectiveness in reducing waiting times and enhancing departmental collaboration suggests a potential application in streamlining reverse logistics processes, leading to improved efficiency and responsiveness in handling product returns and recycling(Mo et al., 2022; Rodrigues et al., 2025). Chen (2022) explored the integration of Machine Learning (ML) and the Internet of Things (IoT) in smart city waste management. It addresses inefficiencies in garbage collection, proposing the Automatic Machine Learning-Based Waste Recycling Framework to enhance waste separation accuracy using machine learning algorithms. The research suggests deploying IoT-powered devices in waste containers for real-time data on garbage generation. This includes image processing to calculate a dump's garbage index, providing insights into trends. The article emphasizes the potential of machine learning and IoT for efficient and environmentally friendly smart waste management. In the context of the oil and gas industry, adopting similar ML and IoT approaches could streamline operations, optimize resource utilization, and enhance environmental monitoring. Integrating these technologies in oil and gas processes could lead to improved efficiency, cost-effectiveness, and sustainable practices (Anaba et al., 2024; Wanasinghe et al., 2020).

Examination of Slonecker et al. (2010) underscores the pivotal role of remote sensing technologies, such as aerial photography and satellite imagery, in delineating, characterizing, and mitigating hazardous waste associated with agricultural, industrial, military, and mining operations. These technologies offer a comprehensive overview for identifying environmental contaminants arising from diverse activities (Fraternali et al., 2024). The papers underscore the transition from traditional aerial photography to sophisticated multispectral and hyperspectral remote sensing approaches. Integration of these technologies into reverse logistics within the oil and gas industry holds promise for enhancing waste management efficiency and curbing the environmental ramifications of hazardous waste disposal.

3. Systematic Literature Review (SLR)

A systematic literature review is a rigorous and transparent approach to reviewing a large body of literature on a specific topic, with the aim of synthesizing and summarizing the existing knowledge, identifying research gaps, and suggesting future research directions (Tranfield et al., 2003). According to Snyder (2019), in order to guarantee accurate, trustworthy and precise literature review certain procedures must be taken. The initial phase involves mapping and assessing prior research to motivate the study's aim, justifying research questions, and hypotheses.

The literature review was conducted in several stages, following the steps proposed by Tranfield et al. (2003) and Kitchenham et al., (2009). First, a comprehensive search strategy was developed to identify relevant academic and industry sources. The search included databases such as Scopus and Web of Science. The search terms were refined based on the research questions and the initial search results. While searching, "AND" and "OR" Boolean logical operators were used and the selection of keywords for the systematic literature review was carefully constructed to ensure that the search captured a comprehensive and relevant body of literature aligned with the core objectives of this research (Xiao and Watson, 2019). Given the study's focus on improving waste management in the oil and gas industry through reverse logistics (RL), the keywords were designed to reflect both sector-specific and concept-specific dimensions.

The primary term **"Reverse Logistics"** formed the cornerstone of the search strategy, as it relates to the central phenomenon under investigation. This term encompasses processes such as return, recovery, recycling, reuse, and proper disposal - practices integral to sustainable waste management and increasingly critical in industrial contexts (CUNHA and LIMA, 2023; Novita Sari., Achmad Hizazi, 2021). To contextualize the study within the appropriate industry, the terms **"Oil," "Gas,"** and **"Petroleum"** were incorporated. These ensure that the review captures literature specific to the oil and gas sector, thus filtering out unrelated domains while maintaining focus on sector-specific logistics practices and challenges. The inclusion of **"Waste Management"** supports the study's environmental focus and aligns with the operational and regulatory concerns addressed in the research. This keyword was necessary to target literature discussing how RL contributes to reducing environmental impact, improving compliance, and enhancing operational sustainability (Novita Sari., Achmad Hizazi., 2021). In addition, the term **"Sustainable Supply Chain Management"** was employed to encompass broader discussions surrounding environmental and social responsibility within supply chains. This enabled the identification of literature that situates reverse logistics within a larger sustainability discourse, offering insights into how RL supports the triple bottom line: economic, environmental, and social performance. The keywords **"Outsourcing"** and **"3rd Party"** were introduced to capture literature focusing on strategic decision-making and vendor relationships, which are particularly relevant in oil and gas operations where waste-related processes are frequently outsourced. Including these terms allowed for the exploration of themes such as contractor selection, risk management, and performance evaluation in outsourced reverse logistics systems.

Later, the overall selection process was guided by established systematic review protocols, particularly those outlined by (Barbara Kitchenham and Stuart M. Charters, 2007), which emphasize the importance of applying predefined inclusion and exclusion criteria. These criteria help to ensure objectivity, transparency, and replicability by focusing only on studies that are peer-reviewed, relevant to the research questions, and methodologically sound. Thus, studies that addressed topics such as the benefits of reverse logistics, reverse logistics networks, outsourcing and decision-making, inventory, routing, waste management, technological enablers, the petroleum industry, or sustainability were included. Conversely, studies unrelated to industrial reverse logistics or waste management, purely mathematical works, and non-peer-reviewed publications were excluded to ensure thematic relevance and practical applicability.

The chosen time frame, **2001 to 2022**, was selected to reflect the evolution of reverse logistics and sustainability practices over the past two decades. This period encompasses both foundational and contemporary studies, offering a robust overview of the theoretical development and practical application of RL within the sector.

To ensure consistency and relevance, a language filter was applied to include only English-language publications. The screening process began with an initial review of paper titles, abstract and keywords, and the full-text publications were assessed using the inclusion and exclusion criteria. Studies that lacked accessible full texts or provided only abstracts were also excluded consistent with the strict exclusion criteria of Xiao and Watson (2019). The data extraction procedure contained the selected studies' primary results, research techniques, theoretical frameworks, and limitations. The quality of the selected studies was evaluated using recognized criteria such as credibility, transferability, dependability, and confirmability of the study (Cope, 2014; Loh, 2013; Maria T. Northcote, 2012).

Finally, the data was synthesized and analysed using thematic analysis, which is a flexible and inductive approach to identifying patterns and themes across the selected studies (Braun and Clarke, 2006). The themes and patterns were mapped onto the research questions, and the implications and recommendations were discussed based on the synthesis and analysis of the data.

Research studies, which were added to Mendeley, were categorized based on the sub-topics covered. After conducting the pilot searches, the review protocol was adjusted and finalized as described in **Table 4.**

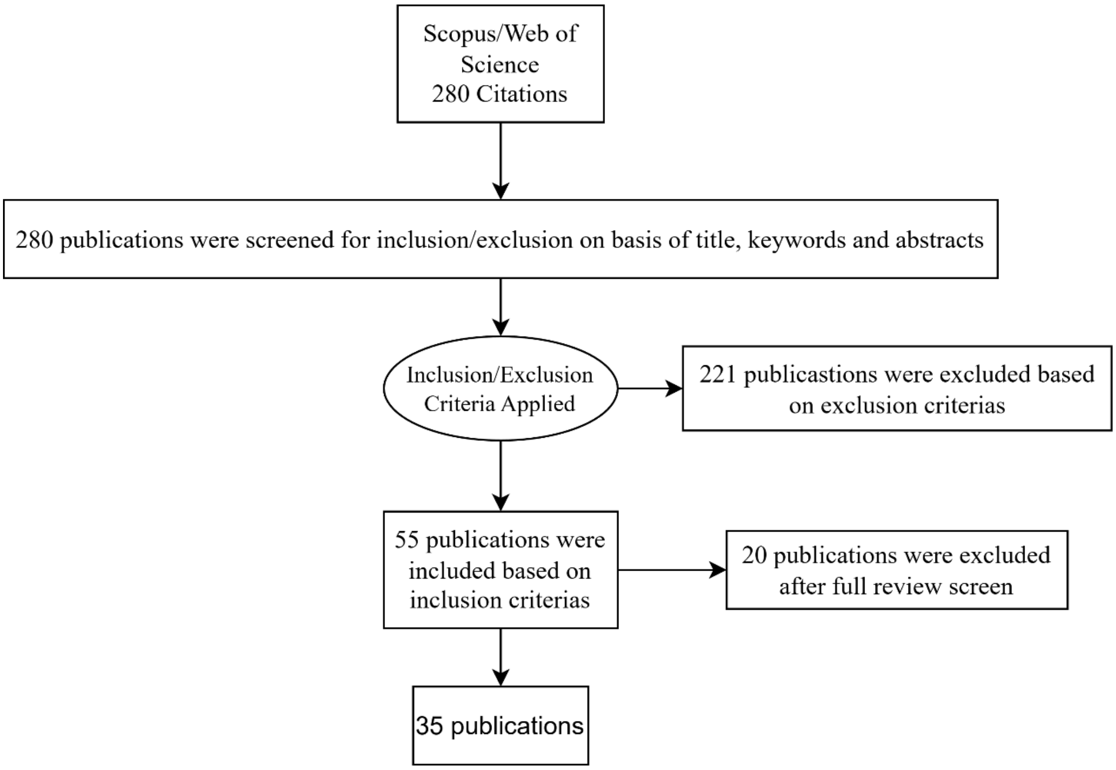
Table 4. Systematic review protocol.

Keywords	**Reverse Logistics, Oil and Gas Industry, Waste Management, Sustainable Supply Chain Management, Outsourcing**
Search items	TITLE-ABS-KEY("Reverse Logistics" AND ("OIL" OR "Petroleum" OR "Gas")) OR TITLE-ABS-KEY ("Reverse Logistics" AND "Waste Management" AND ("Oil" OR "Gas" OR "Petroleum")) OR TITLE-ABS-KEY ("Reverse Logistics" AND ("Oil" OR "Petroleum" OR "Gas") AND "Benefits" OR "Challenges" OR "Barriers") OR TITLE-ABS-KEY ("Supply Chain" AND ("Oil" OR "Gas" OR "Petroleum")) OR TITLE-ABS-KEY ("Reverse Logistics" AND "Outsourcing" OR "3rd Party") OR TITLE-ABS-KEY ("Reverse Logistics" AND ("Oil" OR "Gas" OR "Petroleum") AND "Sustainability") AND (LIMIT-TO (LANGUAGE, "English"))
Period	2001-2022
Inclusion criteria	Benefits of reverse logistics, reverse logistics network, outsourcing and decision making in reverse logistics, inventory management in reverse logistics, routing for reverse logistics, waste management in oil and gas, technological enablers, petroleum industry, sustainability in oil and gas reverse logistics, empirical studies with practical insights
Exclusion criteria	Duplications, mathematical models without practical application, papers unrelated to reverse logistics or waste management, non-peer-reviewed sources, studies without full-text access
Type of source	Articles, conference papers, book chapters
Language	English
Database	Scopus, Web of Science

Source: Author's elaboration

The following **Figure 3** illustrates the rigorous screening process conducted in the systematic literature review, an essential component of the research. This visual representation, based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram, encapsulates the systematic approach adopted to identify, evaluate, and select pertinent scholarly works from the extensive corpus of academic literature available (Moher et al., 2009). The PRISMA constitutes an evidence-based, minimum set of recommendations designed primarily to encourage transparent and complete reporting of the systematic review. This framework was developed to assist authors with accurately and transparently reporting diverse knowledge synthesis methods (Mishra and Mishra, 2023; Rethlefsen et al., 2021).

Figure 3. PRISMA screening flow chart.



Source: Author's elaboration

Initiating with an exhaustive search across prominent databases, Scopus and Web of Science, a total of 280 citations were identified. These citations were carefully reviewed, with the titles, keywords, and abstracts used as the first step to check them against the set inclusion and exclusion criteria.

This initial phase of screening led to the exclusion of 220 articles, ensuring that only studies closely aligned with the research objectives were considered. Subsequently, 55 articles were identified as promising and proceeded to the next stage of full-text screening.

In the next step, the full texts of these 55 articles were closely examined in detail. This phase revealed that 20 did not meet the exacting standards set by the study. Consequently, a refined selection of p articles emerged as the foundation of the systematic literature review.

The full text of each paper was reviewed and identified the research questions and contributions of each publication, followed by identification of common topics.

The systematic literature review conducted for this thesis encompasses a comprehensive analysis of the initial search results obtained from selected databases. This rigorous examination delves into various dimensions of research in the domain of reverse logistics and waste management within the oil and gas industry.

Within this analysis, the study examines the yearly distribution of published papers, providing valuable insights into the evolving trends and shifts in research focus over time.

Furthermore, the review identifies and highlights the journals that have prominently featured in this field. This helps to highlight the main sources of academic discussion and expertise on reverse logistics and waste management in the oil and gas sector.

Geographic coverage is also examined to capture the international scope of research in this field. This helps reveal differences in research focus and legislation, showing how reverse logistics and waste management are implemented and practiced across different countries.

The review also examines the main subject areas and recurring themes in the literature, highlighting the key topics and issues that researchers in this field focus on.

In addition to these insights, the systematic literature review uncovers limits and gaps in the existing research. These include areas where further investigation is warranted, such as theoretical, empirical, and methodological gaps that can inform future research directions. To address the identified research gaps in waste management and reverse logistics within the oil and gas sector, qualitative research provides a valuable, exploratory methodology. Qualitative methods were particularly well-suited for this study due to the noted gaps in theoretical, empirical, and methodological knowledge on reverse logistics specific to the petroleum sector. As described, theoretical gaps emerged in understanding integration of reverse logistics into the oil and gas supply chain, with limited research on topics such as supply chain partner collaboration, digital innovation for waste management efficiency, and theoretical frameworks for managing uncertainty in waste disposal operations. These gaps further highlight the necessity of primary data and case-specific insights to understand the practical integration of reverse logistics practices within oil and gas companies. Existing studies in this area relied on secondary sources, small sample sizes, and did not fully explore the sustainability dimensions of reverse logistics beyond carbon emissions. This lack of primary, company-specific data suggested that qualitative interviews with industry specialists would yield essential, contextual insights and allow for an exploration of multi-dimensional sustainability beyond emissions, including waste reduction and resource conservation.

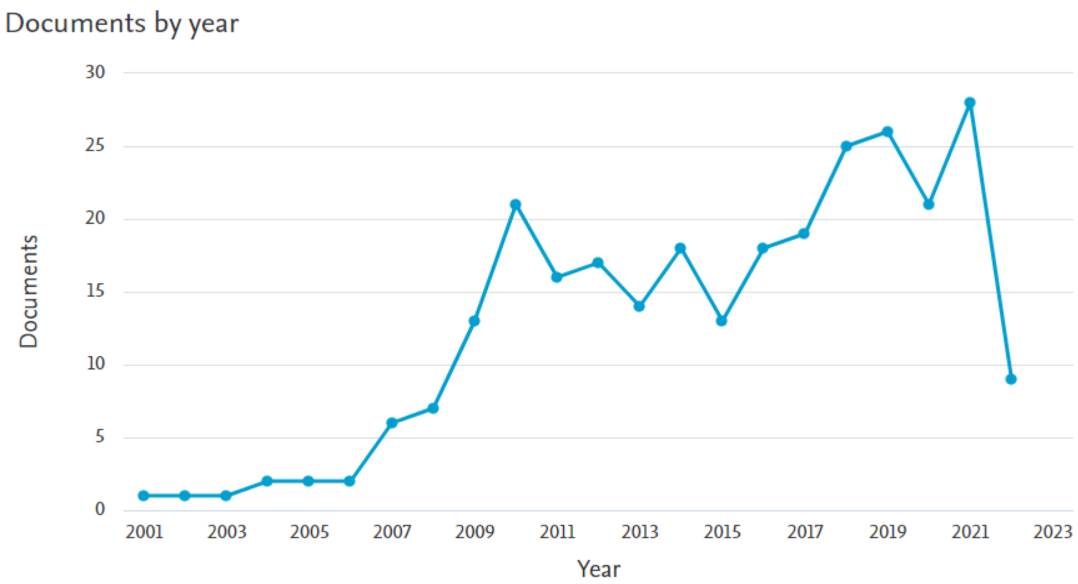
The paper-level study concentrated on each work's research purpose, methodology, contributions, limitations, and target audience. This data was coded in accordance with the "4W1H" principle (What, When, Where, Why, and How) which was inspired by "5W1H" method. According to According to Jia et al. (2016), the 5W1H framework was adapted from its journalistic roots in Kipling's "Just So Stories (1902)" and provides a clear structure for exploring research areas in unfamiliar fields, particularly through systematic mapping studies. In this study, 4W1H was streamlined by omitting the "Who" dimension (e.g., author affiliations or contributors), as the focus was on thematic and structural elements rather than individual researchers. This adaptation aligns with broader applications of the 5W1H framework in systematic literature reviews where it enhances methodological rigor and transparency by systematically addressing key interrogative dimensions (Paul et al., 2024). Based on this principle, review analyses the research motivation and purpose, research problems, object of research, methodology and geographical location and date that research was conducted.

The next step of systematic literature review is reporting and dissemination of the findings after analyzing 2nd stage. Tranfield, Denyer, and Smart (2003) claimed that reporting can be divided into 2 stages as well-descriptive analysis by a simple set of categories and thematic analysis as a result of interpretative and aggregative methods. This study reports and disseminates results in 2 sections. In the first stage, descriptive data of examined publications is summarized, while in the second section, thematic analysis of the study findings is discussed.

3.1. Descriptive Findings from the Systematic Literature Review

This research analysed articles, conference papers, book chapter and reviews. **Figure 4** illustrates the number of papers by years for **initial search results** which is in line with review protocol from 2001 till 2022 where it is visible that interest towards reverse logistics topic has increased in the last two decades. 2021 saw the largest quantity of documents being published on 28. After 2005, interest in the topic increased gradually and went up to 21 papers in 2010.

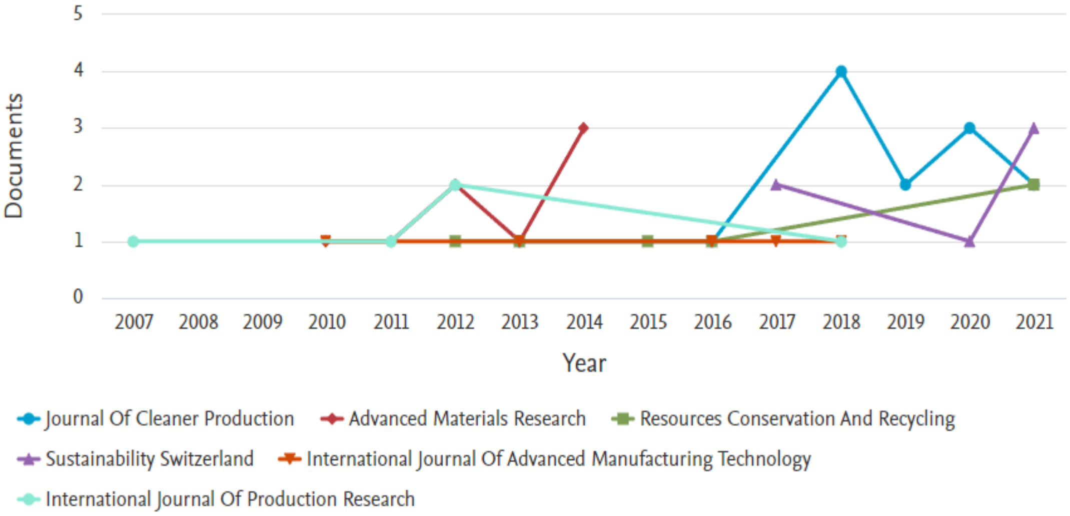
Figure 4. Number of published documents by year (n=280)



Source: Scopus.com

Figure 5 demonstrates the most active journals in this research topic. Top journals covering reverse logistics and waste management topic are *Journal of Cleaner Production, Advanced Materials Research, Resources Conservation and Recycling, Sustainability Switzerland, International Journal of Advanced Manufacturing Technology, International Journal of Production Research* which is accounted to gather 15 percent (43 papers) of the total pool.

Figure 5. Journals activity by year (n=43).

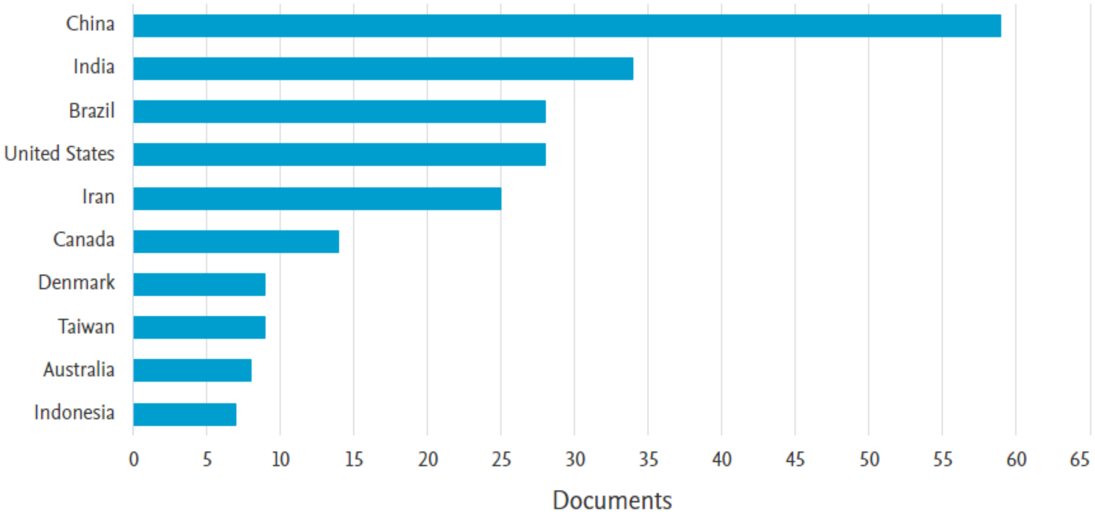


Source: Author's elaboration

Reverse logistics is not as widely recognized in developing countries as it is in developed ones. In the context of reverse logistics and oily waste management, developing nations often face more significant practical challenges. This topic has recently gained more attention and urgency. The lack of awareness often results in the inefficient management of reverse logistics activities or even the absence of a sustainable reverse logistics network. Additionally, there is a lack of relevant legislation and less motivation to implement green supply chain management.

The importance of this field for developing countries cannot be overstated. Consequently, a substantial amount of research has emerged in these regions. Developing countries are at the forefront of producing research papers on the topic, contributing 121 documents, which accounts for 43% of the total. In contrast, the United States of America has produced 28 documents on this subject, indicating a higher level of concern in this area compared to other developed countries.

Figure 6. Geographical distribution of papers.



Source: Scopus.com

3.2. Methodological and Geographical Profile of Literature

Systematic literature reviews are a crucial tool for gathering the data that is currently available on a particular research issue or subject. This study used a systematic method to make sure that every relevant paper was included to find and evaluate the available literature on a certain topic.

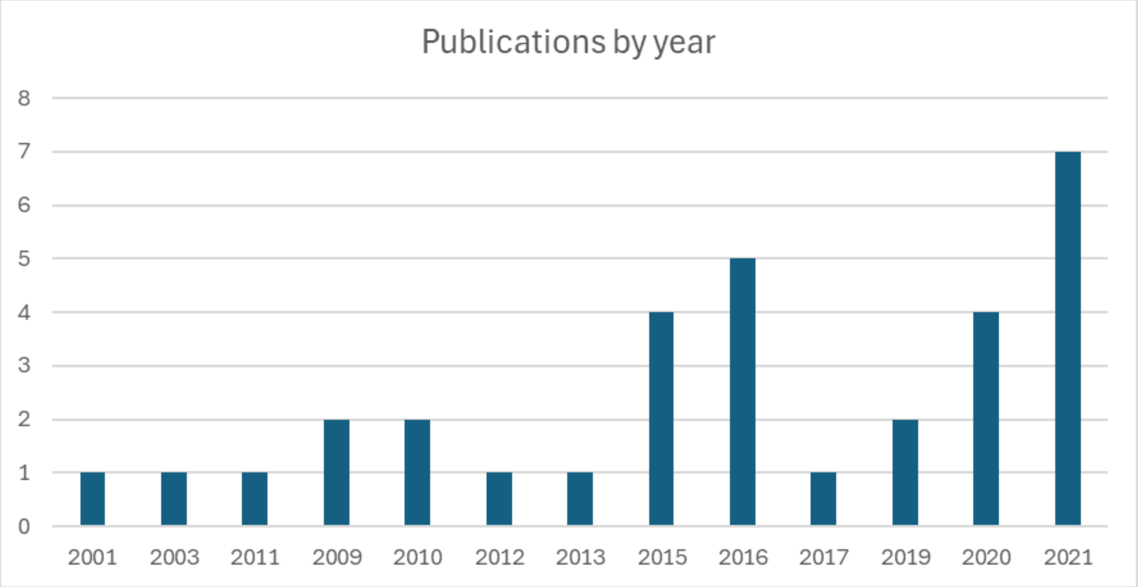
Through a thorough search of numerous databases, including Scopus and Web of Science, the study found a total of 280 studies. After the studies were reviewed using predetermined inclusion and exclusion criteria, 35 papers were chosen to be included in the review.

Numerous methodologies were implemented in the studies reviewed; among them were qualitative, quantitative, and mixed methods approaches. Asia and Europe correspondingly represented leading geographic locations for research endeavors. Lastly, there was substantial variability regarding sample sizes.

The employed systematic literature analysis methodically evaluates the extant data on the topic and highlights several significant areas requiring further investigation. Its meticulousness and transparency stemming from its systematic approach enhances its reliability, underscoring robust generalizability. Future research areas were identified in the publications based on the highlights of the author's and the result of review.

Below data shows that there has been a steady increase in the number of publications on this topic from 2001 to 2021. The highest number of publications were in 2021 with 7 publications which indicates that there has been an increasing interest in this research area in recent years.

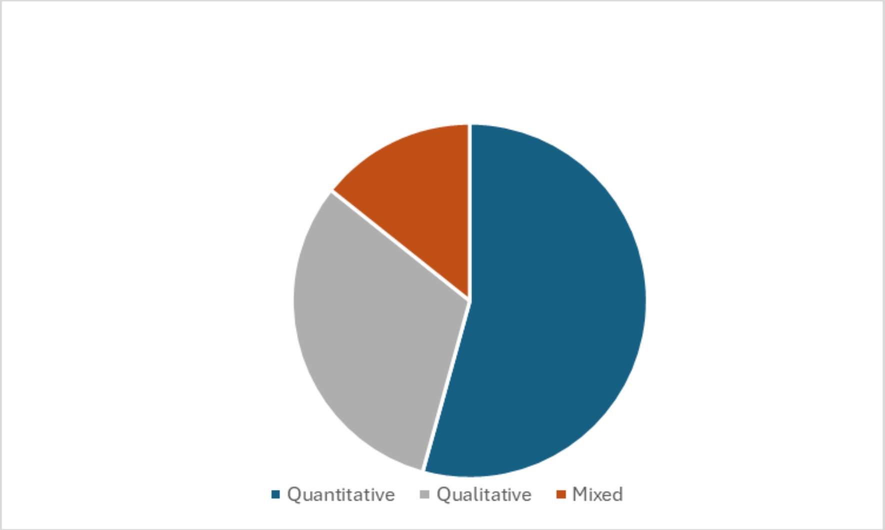
Figure 7. Annual distribution of publications on the research topic (2001-2021)



Source: Author's elaboration

The analysis of research methods used in the selected studies is presented in **Figure 8**. The results indicate that quantitative methods are the most frequently employed, representing more than half of the reviewed studies. Qualitative approaches are the second most common, followed by mixed-method studies, which make up the smallest share. This trend suggests that research in this domain is data-driven, although qualitative and mixed approaches continue to provide complementary insights.

Figure 8. Distribution of research methods in the reviewed publications



Source: Author's elaboration

Methodological Approaches Identified in the Literature

Most of the research methods used in the publications related to improving waste management operations in the oil and gas industry through reverse logistics were quantitative (19), followed by qualitative (11) and mixed (5). This indicates a trend towards using quantitative methods to study this topic, due to the need to gather and analyse numerical data related to waste management operations. The literature review findings suggest that research studies addressing decision-making processes in the context of outsourced reverse logistics operations have primarily adopted a quantitative research approach. However, it is worth noting that qualitative research methods were also used in a considerable number of publications, indicating that researchers also value the insights that can be gained from exploring the experiences and perspectives of individuals and organizations involved in waste management in the oil and gas industry.

Research Designs Identified in the Literature

After carefully reviewing and categorizing the data, it is evident that there are various research designs and methods that have been used in the literature to study reverse logistics practices. The most common research designs identified in the data include case studies, literature reviews, and mixed-method approaches. Additionally, multiple methods were utilized to gather and analyse data, such as interviews, questionnaires, mathematical modeling, and multi-criteria decision-making techniques.

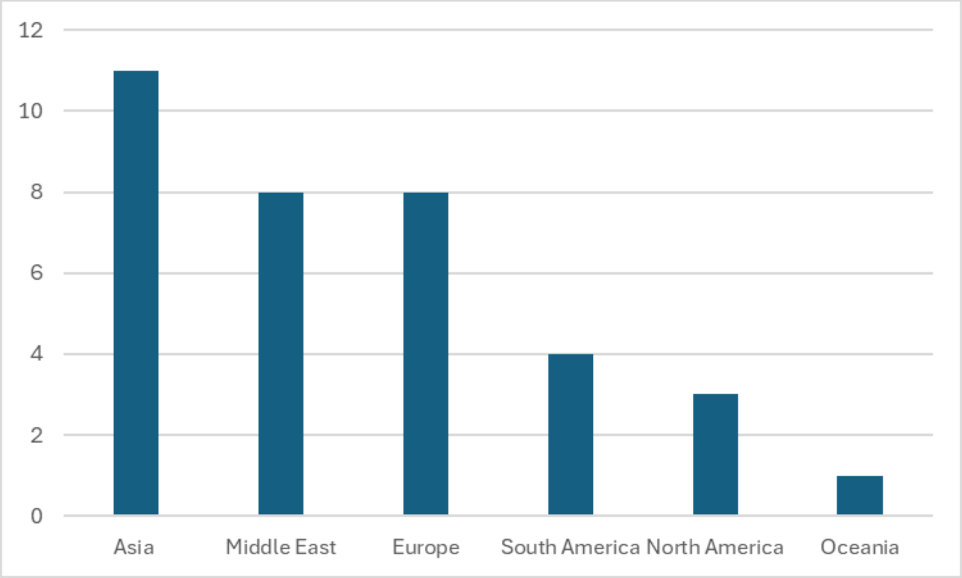
Case studies were utilized as research design in most studies identified in the data. This approach allowed researchers to gain an in-depth understanding of reverse logistics practices in specific companies and industries. In some cases, scenario generation and reduction algorithms were employed in the case study analysis to generate realistic scenarios and identify optimal solutions. Thematic analysis and content analysis were the primary methods utilized to analyse the data collected from the case studies.

Literature reviews were another common research design utilized in the data to provide a comprehensive and rigorous synthesis of the existing literature on reverse logistics practices in the oil and gas industry. The literature review was often combined with other methods, such as interviews and site visits, to gain a deeper understanding of the research topic. Surveys are another commonly used method, often combined with multi-criteria decision-making techniques such as the Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The use of fuzzy sets theory and weighted aggregated IVIF-decision matrix is another approach utilized in a few studies.

Mixed-method approaches, such as combining qualitative interviews with quantitative modeling techniques or using multiple multi-criteria decision-making techniques, were also identified in the data. These approaches provided researchers with a more complete and in-depth understanding of the complex phenomenon of reverse logistics practices in the oil and gas industry.

Mathematical models, such as mixed-integer linear programs (MILP) and fuzzy multi-objective mathematical models, are also identified in the literature. These models often involve the optimization of certain parameters, such as transportation routes or waste disposal methods, and may utilize optimization algorithms such as bee colony optimization (Hashemi, 2021) or genetic algorithms.

Figure 9. Published papers by region



Source: Author’s elaboration

In terms of geography, most of the studies included in this systematic literature review are from Asia, with a total of 11 publications. The Middle East and Europe also had a notable presence in the review with 8 and 8 publications, respectively. Allocation of papers in South America, North America and Oceania was 4, 3, and 1, respectively. The concentration of research in Asia implies that interest in reverse logistics techniques is developing there, possibly because of the region's increased attention to sustainability and environmental concerns. There is a global interest in this topic, as evidenced by the existence of research from developed regions like Europe and North America. Reverse logistics practices are not just used in developing nations.

However, there is still an imbalance in the distribution of research with a concentration in a few select regions. Further research in underrepresented regions could provide valuable insights into the unique challenges and opportunities for improving waste management operations in the oil and gas industry through reverse logistics.

Overall, reverse logistics is a global issue, and more study is needed in both established and developing nations to better understand and advance these practices, according to the geographic distribution of the studies.

3.3. Thematic Insights from the Systematic Literature Review

There is a wide range of subjects, viewpoints, theoretical frameworks, and modeling techniques in the current research on waste management and reverse logistics. This suggests that this study topic is scattered, making it difficult to construct a comprehensive overview of reverse logistics research. Therefore, "4W1H" principle has been applied in this thesis to overcome the challenge which enables to understand the research motivation and purpose, research problem, target audience, methodology and geographical location and date of the papers better (**Table 5**).

Table 5. Coding based on the 4W1H principle.

4W1H	***Configured question***	***Description***
Why	Why was the study conducted?	Motivation, aim and objectives of the study
How	How was the research conducted?	Research design, methods, models, data sources, sample details, and analytical models used
What	What was the research objective?	Research objective, questions, or hypotheses of the study
	What thematic area did research cover?	Functional area or product kind investigated in research and place of topic in supply chain management
	What was the contribution of the research?	Key contributions, including new knowledge, methods, theories, or managerial implications

4W1H	*Configured question*	*Description*
	What was the limitation?	Constraints or obstacles that restricted the study
	What future research areas were identified?	Suggested directions for further research
When	When was the research conducted?	Time frame of the study
Where	Where was the research conducted?	Geographical location(s) of the study

Source: Author's elaboration

The following 35 tables (Table 6-40) present a detailed analysis of the papers included in the Systematic Literature Review (SLR) procedure. Organized according to the 4W1H principle outlined above, each table provides a structured summary of the selected studies, capturing their research motivation, methodology, objectives, thematic coverage, key contributions, limitations, and identified areas for future research.

Table 6. 4W1H summary of Perspectives in reverse logistics: A review (Shaligram P. et al)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study's goal was to give a comprehensive overview of reverse logistics (RL) and its different components, from collection through resale and remanufacturing, as well as to highlight the significant problems and possibilities in RL.
How	How was the research conducted?	The research implemented a content analysis strategy that entailed carefully assessing and classifying the content of published research publications on RL from multiple academic databases.
What	What was the research objective?	The research objective was to identify the different holistic perspectives and components of RL and to propose directions for future research in RL.
	What thematic area did research cover?	Various stages of reverse logistics were covered such as, collection, inspection, and consolidation, integrating, manufacturing, and remanufacturing, product modularity, disassembly, coordination, supply chain, inventory, repair and after-sales service, pricing and competition, customer relation

4W1H	*Configured question*	*Description*
	What was the contribution of the research?	The research contributed to the understanding of reverse logistics (RL) by presenting a holistic perspective of the RL system, covering various aspects from inputs to outputs and then to inputs again. It also highlighted the growing recognition of RL as a driver of supply chain and logistics and proposed some important research directions in assessing the stochastic nature of supply and demand, developing generic models to tackle this type of situation, designing a good pricing policy for the acquisition of used products, incorporating product obsolescence and pricing of used and remanufactured products, and managing collection centres.
	What was the limitation?	The study depended on the availability and quality of published research in this field because it was based on a content analysis of existing research on RL. Some relevant studies may have been overlooked due to access restrictions or being unpublished. Moreover, no primary research, such as surveys or case studies, was conducted to validate or test the recommended research directions.
	What future research areas were identified?	The study proposed several future research areas, including assessing the stochastic nature of supply and demand and the yield from a remanufacturing process, developing generic models to tackle this type of situation, designing a good pricing policy for the acquisition of used products, incorporating product obsolescence and pricing of used and remanufactured products, and managing collection centres.
When	When was the research conducted?	2009
Where	Where was the research conducted?	Singapore

Source: Author’s elaboration

Table 7. 4W1H summary of An Examination of Reverse Logistics Practices (Rogers and Tibben-Lembke)

4W1H	***Configured question***	***Description***
Why	Why was the study conducted?	The study was conducted to discuss the definition of reverse logistics, present an overview of the current state and estimated size of reverse logistics activities, and identify strategies for companies to pursue their reverse logistics strategies effectively.

4W1H	***Configured question***	***Description***
How	How was the research conducted?	The research was conducted by reviewing existing literature on reverse logistics and analyzing examples of companies that have implemented effective reverse logistics strategies.150 managers with reverse logistics responsibilities were interviewed and visits were made to companies.
What	What was the research objective?	The research objective was to identify the importance of reverse logistics in business operations, highlight the benefits of effective reverse logistics management, and suggest strategies for companies to improve their reverse logistics processes.
	What thematic area did research cover?	Reverse logistics practices and barriers were defined in the paper to implement good RL practices.
	What was the contribution of the research?	The importance of RL in increasing revenue and cutting costs was highlighted and real practices were shared based on interviews conducted with managers in the RL field. General overview of RL and estimated size of activities were presented in the paper. Benefits of implementing RL were mentioned. Strategic importance of RL practices to be more competitive were discussed. Comparison of "reverse logistics" and "green logistics" terms was demonstrated in the paper. Characterization of items in reverse logistics flops was described.
	What was the limitation?	The limitation of the research is that it did not provide specific recommendations or guidelines for firms to pursue their reverse logistics strategies.
	What future research areas were identified?	There is much room for improvement in reverse logistics information systems to examine specific elements that should be included in a good RL system. Future research could be pursued in reverse logistics activities that include international elements and effective gatekeeping strategies to reduce return rates.
When	When was the research conducted?	2001
Where	Where was the research conducted?	USA

Source: Author's elaboration

Table 8. 4W1H review of Outsourcing reverse logistics and remanufacturing functions: A conceptual strategic model (Sharon M. Ordoobadi)

4W1H	***Configured question***	***Description***
Why	Why was the study conducted?	The study was conducted to develop a decision model to help manufacturers make informed decisions regarding their supply chain policies, specifically in the context of outsourcing activities in the reverse supply chain.
How	How was the research conducted?	The paper presents a multi-phased decision model for strategic analysis of outsourcing such activities. The research was conducted through a literature review and the development of a decision model based on strategic analysis and economic evaluation.
What	What was the research objective?	The research objective was to develop a decision model that can be used to determine whether it is strategically sound and economically feasible to outsource an activity in the reverse supply chain. The specific focus was on the remanufacturing process, but the model can be applied to any activity in the reverse supply chain.
	What thematic area did research cover?	The research covered the area of supply chain management, specifically the reverse supply chain and outsourcing decisions.
	What was the contribution of the research?	The research proposed a decision model to help manufacturers make informed decisions regarding their supply chain policies with respect to outsourcing of activities in the reverse supply chain. The model provided a strategic and economic analysis of the core competencies, peripherals, and significant factors to be considered while outsourcing. The model can be applied to any activity in the reverse supply chain, but the remanufacturing process was chosen to illustrate the application of the model.
	What was the limitation?	The economic evaluation phase of the model could be expanded by identifying specific individual costs associated with outsourcing a reverse logistics function as well as costs of performing the function in-house. The analysis performed in the research was based on academic research alone and could be enriched by adding the expertise of practitioners and professionals to the academic findings.
	What future research areas were identified?	Outsourcing costs should be calculated for the model. This analysis can be enriched by adding the expertise of the practitioners and professionals to the academic findings. It is recommended that the process proposed in this research be implemented into a software or internet-based tool as the analysis was performed based on the findings from academic research alone.

4W1H	*Configured question*	*Description*
When	When was the research conducted?	2009
Where	Where was the research conducted?	USA

Source: Author's elaboration

Table 9. Evaluating reverse third-party logistics operations using a semi-fuzzy approach (Amir M. Sharif et al.)

4W1H	Configured question	Description
Why	Why was the study conducted?	The study was carried out to investigate and evaluate the Information System (IS)and resource commitment-based performance factors that relate to a case organization in Thailand specializing in reverse 3PL operations. The aim was to provide insights into the "soft" aspects of such business processes through a combination of qualitative interview responses and quantitative modelling techniques.
How	How was the research conducted?	The research was conducted using a mixed-methods approach, which involved qualitative interviews and quantitative modeling techniques. Qualitative interviews provided rich contextual explanations for otherwise unexplainable phenomena, while the quantitative modeling techniques used systems dynamics-inspired cognitive causal modeling.
What	What was the research objective?	The research objective was to highlight the key performance factors that relate to a case organization in Thailand specializing in reverse 3PL operations. The study aimed to determine the relationship between IS and resource commitment-based operating performance, resource cost-effectiveness, and resource commitment (at financial, managerial, and technological levels in the firm) on the success of reverse 3PL operations.
	What thematic area did research cover?	Third party reverse logistics operations and factors influencing RL are investigated.
	What was the contribution of the research?	The research provided insights into the soft aspects of business processes through a mixed-methods approach, combining qualitative interviews and quantitative modeling techniques. It identified that IS and resource commitment-based operating performance, resource cost-effectiveness, and resource commitment have a strong positive relationship and input into reverse 3PL operations for the firm studied.

4W1H	Configured question	Description
	What was the limitation?	Paper had limitations such as the potential for bias and subjectivity in the Fuzzy Cognitive Mapping (FCM), and the limited number of scenarios investigated.
	What future research areas were identified?	Future research could focus on identifying and solidifying comprehensive resource-based views of 3PL providers to examine the true effect of logistics support within supply chain management contexts. Additionally, future research could include independent verification and validation of responses and inputs, and the extension of the number of scenarios investigated.
When	When was the research conducted?	2011
Where	Where was the research conducted?	Thailand

Source: Author's elaboration

Table 10. An integrated intuitionistic fuzzy AHP and SWOT method for outsourcing reverse logistics (Tavana et al., 2016)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study was conducted to propose a new hybrid method to rank the criteria and sub-criteria characterizing RL outsourcing decision making. The aim was to provide a more effective decision-making framework for organizations dealing with or willing to implement RL outsourcing.
How	How was the research conducted?	SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis was proposed as a method to valuate internal and external decision-making factors in reverse logistics outsourcing. After identifying criteria and sub-criteria of decision with SWOT analysis, Intuitionistic Fuzzy (IF) version of Analytic Hierarchy Process (AHP) was used to assess the relative significance weights of the criteria and their related sub-criteria. Mikhailov's fuzzy preference programming method was extended to produce local weights for all criteria and sub-criteria. Results and proposed model were applied to a real company with a case study method.
What	What was the research objective?	The research objective was to propose a more effective decision-making framework for RL outsourcing by combining SWOT analysis with an IF-AHP model, and to implement this framework in a case study to identify and evaluate the criteria for RL outsourcing decision making.

4W1H	*Configured question*	*Description*
	What thematic area did research cover?	The research covered the thematic area of decision making in RL outsourcing
	What was the contribution of the research?	The research proposed a new hybrid method to rank the criteria and sub-criteria characterizing RL outsourcing decision-making. The contribution of the research was the combination of SWOT analysis with an IF-AHP model, which allowed for the quantification of qualitative results obtained from the SWOT analysis. The use of triangular intuitionistic fuzzy numbers served the purpose of accounting for the ambiguity and uncertainty of the information input on which decision makers must perform the pair-wise comparisons among the decision criteria.
	What was the limitation?	One limitation of the research was that it only involved a single case study involving an actual company, so the results may not be generalizable to other settings.
	What future research areas were identified?	Further research should be developed in analyzing how and why outsourcing reverse logistics can increase the competitiveness of companies. The paper suggested that the preference programming model employed in the research to find the local weights might be adjusted and adapted to estimate the equivalent weights in other multi-criteria decision ranking approaches such as TOPSIS, VIKOR, and PROMETHEE in their fuzzy forms. These expansions suggest interesting paths of investigation for future research.
When	When was the research conducted?	2016
Where	Where was the research conducted?	USA

Source: Author's elaboration

Table 11. An Insight into Reverse Logistics with a Focus on Collection Systems (Alkahtani et al., 2021)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The motivation of this review article is to briefly examine recent advancements in reverse logistics so that readers may have a comprehensive understanding of this topic. The authors aimed to explore the current state of collection systems in reverse logistics and identify areas for improvement.

4W1H	*Configured question*	*Description*
How	How was the research conducted?	The research was conducted through a literature review of existing studies and publications related to reverse logistics and collection systems. The authors also conducted interviews with industry experts and analysed case studies to gather insights into best practices and potential areas for improvement.
What	What was the research objective?	The research objective was to provide insights into collection systems in reverse logistics, with a focus on identifying best practices and areas for improvement. The authors aimed to provide a comprehensive overview of the current state of collection systems in reverse logistics and offer recommendations for improving their efficiency and effectiveness.
	What thematic area did research cover?	Collection system of reverse logistics
	What was the contribution of the research?	The research gave valuable insights into literature on reverse logistics systems and helps to understand RL mechanism. Four key classification criteria for existing articles were determined. The results of the review showed that most of the research has measured the economic and environmental performance of the collection system while social aspects of performance were rarely considered. Another result is that solutions are problem-specific, which cannot be assessed objectively because no benchmark exists to determine which way is superior. As a result, it is required to create a problem collection that may be used to assess the answers.
	What was the limitation?	It is difficult to obtain research on the combination of all components since it complicates the study model.
	What future research areas were identified?	The following directions were mentioned in the paper for future research: a) digitalization, b) prediction methods for product return, c) benchmark problem development, d) outsourcing framework, e) uncertainty analysis, f) disposition decisions, g) social aspects, h) competition in collection, i) more sectors like FMCG
When	When was the research conducted?	2021
Where	Where was the research conducted?	United Arab Emirates

Source: Author’s elaboration

Table 12. Green supply chain quantitative models for sustainable inventory management: A review (Pablo B. et al)

4W1H	***Configured question***	***Description***
Why	Why was the study conducted?	The study’s goal was to give academics and practitioners with a starting point and road map for inventory management using quantitative green Supply Chain (SC) techniques. The goal of the writers was to give a summary of the available research on this subject and to point out any areas that needed more investigation.
How	How was the research conducted?	An extensive examination of the literature on quantitative green supply chain management techniques for sustainable inventory management was used to perform the research. To find pertinent publications, the researchers used two scientific databases, Scopus and Web of Science, using a methodical search procedure. The articles were then examined considering various factors, including their goals, contexts in which they were used, supply chains, levels of decision-making, shared information, inventory policies, variables in inventory models, sustainability, cost effectiveness, green modeling, solution approaches, and software tools.
What	What was the research objective?	The paper’s study goal was to comprehensively examine and organize the literature on quantitative sustainable inventory management (SIM) models in relation to green SC. The goal, application environment, SC structure, decision level, shared information, inventory policies, and sustainability-related criteria were among the key features the authors sought to discover in the examined literature. Additionally, they aimed to evaluate the current level of quantitative SIM models in green SC and pinpoint areas that needed more investigation.
	What thematic area did research cover?	The research covered the area of supply chain management and specifically focused on the topic of sustainable SIM in green supply chains.
	What was the contribution of the research?	The research has contributed to the understanding of how to incorporate green principles into supply chain management through quantitative inventory management methods. It provided a reference inventory of supply chain management work and its features and highlighted the relationship between the elements and their impact on sustainability. The research also identified areas for future research that can lead to the development of more advanced models to enhance environmental sustainability.

4W1H	*Configured question*	*Description*
	What was the limitation?	The limitations of the study include that the research was conducted by using only two scientific databases, Scopus and Web of Science, which are constantly updated, and the articles found correspond to those obtained at the time the research was conducted. Additionally, despite having followed a systematic search process, it is possible that some articles may have been overlooked for this review.
	What future research areas were identified?	Future research includes defining the concept and process of green SC, improving environmental sustainability, incorporating social aspect and circularity, considering multiple decision levels, evaluating with different inventory policies, and incorporating uncertainty.
When	When was the research conducted?	2021
Where	Where was the research conducted?	Spain, Chile

Source: Author's elaboration

Table 13. Inventory models with reverse logistics for assets acquisition in a liquefied petroleum gas company (Cristina L. et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	A Portuguese corporation in the energy industry proposed an industrial difficulty, and the research was done to address it. The business requested assistance in coming up with the optimum purchase strategy for Liquefied Petroleum Gas (LPG) cylinders. Three inventory models that considered reverse logistics and its effects on inventory management were created in response to this problem. The corporate manager then employed these models as decision-support tools to aid in the planning of acquisitions.
How	How was the research conducted?	To solve the issue raised by a Portuguese firm in the energy industry, the research was undertaken by suggesting three inventory models. Finding the ideal LPG cylinder sourcing strategy was the study's main goal. To do this, the researchers modified Wilson and Teunter's classic inventory models to consider the reverse flows of returned goods and their effects on inventory control. The models were then put into spreadsheets and provided to the management of the business to utilize as a tool for decision-making. To address the specifics of the difficulty provided by the organization, traditional inventory models were modified and implemented in spreadsheets as part of the study technique.

4W1H	*Configured question*	*Description*
What	What was the research objective?	The goal of the study was to determine the optimal acquisition strategy for LPG cylinders for a Portuguese energy firm. This was accomplished by creating three separate inventory models that account for the reverse flow of returned LPG cylinders and providing the company's manager with decision-supporting tools for their purchase strategy.
	What thematic area did research cover?	The research covered the area of inventory management and the optimization of the acquisition plan for LPG cylinders in the energy sector with reverse logistics.
	What was the contribution of the research?	The study aimed to solve an industrial challenge posed by a Portuguese energy company regarding the best acquisition plan for LPG cylinders. To achieve this objective, three inventory models with reverse flows were developed. These models were implemented in spreadsheets and provided to the company as decision-making tools. The first model considered deterministic continuous returns and discrete batches from the supplier, reflecting the current scenario of the company. The second model was designed for the future scenario in which returned cylinders cover the demand, thus eliminating the need for supplier replenishment. The third model considered the stochastic nature of both demand and return rates and was developed for a mixed scenario. Future work involves obtaining results from these models in real-world scenarios to assist the company in planning the acquisition of LPG cylinders.
	What was the limitation?	The limitations of the research are not explicitly mentioned in the article
	What future research areas were identified?	According to the conclusion section of the paper, future research was identified in the form of obtaining results for each of the proposed inventory models in real-world scenarios that reflect the company's possible situations
When	When was the research conducted?	2020
Where	Where was the research conducted?	Portugal

Source: Author's elaboration

Table 14. A multi-criteria decision-making methodology for the selection of reverse logistics operating modes (P. Sasikumar et al.)

4W1H	***Configured question***	***Description***
Why	Why was the study conducted?	Based on market globalization and environmental protection, the study was done to find the most appropriate operating mode for enterprises to perform reverse logistics activities. The study's goal was to improve company service levels and lower overall supply chain costs by selecting the appropriate operating mode using a decision-making process based on the Analytical Hierarchy Process (AHP).
How	How was the research conducted?	In the study, the Analytic Hierarchy Process (AHP) technique was applied as a decision-making tool. The decision-makers devised criteria and sub-criteria for selecting the best alternative for conducting Reverse Logistics operations. The three basic forms of RL operations available were self-support, outsourcing, and joint ventures. The purpose was to discover the best alternative mode by evaluating and comparing the priority assigned to each alternative based on the criteria and sub-criteria.
What	What was the research objective?	The objective of the research was to evaluate the three alternative modes of reverse logistics operations and determine the best option for companies. A decision-making methodology - AHP was used to compare criteria and sub-criteria based on quantitative and qualitative factors. The study aimed to help companies improve their service levels and reduce supply chain costs through effective reverse logistics operations.
	What thematic area did research cover?	The research covered the area of Reverse Logistics and its operating modes in the global market, considering factors such as globalization and environmental protection.
	What was the contribution of the research?	The study contributed to a better understanding of the causes for the emergence of Reverse Logistics and the various operating modes accessible to businesses to undertake RL activities. The study also aimed to identify the most important factors for determining the appropriate RL operating mode for businesses, employing the AHP as a decision-making tool. The case study findings revealed that outsourcing was a feasible alternative for enterprises to execute RL operations, allowing them to harness the knowledge of logistics service providers while focusing on their main business activities.
	What was the limitation?	The limitation of the research was not explicitly mentioned in the paper

4W1H	*Configured question*	*Description*
	What future research areas were identified?	The article does not mention any specific future research areas that were identified.
When	When was the research conducted?	2010
Where	Where was the research conducted?	India

Source: Author's elaboration

Table 15. Outsourcing decisions in reverse logistics: Sustainable balanced scorecard and graph theoretic approach (Saurabh A. et.al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study was conducted to develop a framework for outsourcing reverse logistics decisions for firms, whether to outsource reverse logistics activities partially or fully. The focus of the study was to develop a sustainable approach towards reverse logistics decisions in the context of a mobile manufacturing firm.
How	How was the research conducted?	The Sustainable Balanced Scorecard (SBSC) technique was used to analyse numerous qualities and sub-attributes linked to reverse logistics outsourcing, and the Graph Theory Approach (GTA) method was used as a decision-making tool. The suggested framework was shown using a case study of a mobile manufacturing firm.
What	What was the research objective?	The study's research goal was to build a framework that would assist decision-makers in making informed outsourcing decisions for reverse logistics operations while maintaining sustainable development. The framework's goal was to combine the triple bottom line features of sustainability with the balanced scorecard and to utilize the sustainable balanced scorecard as a tool for selecting characteristics and sub-attributes. The GTA was used to compute the outsourcing index for various scenario-based alternatives and to make judgments based on these indexes.
	What thematic area did research cover?	The research covered the area of reverse logistics and outsourcing decision-making for product returns management.

4W1H	***Configured question***	***Description***
	What was the contribution of the research?	The research's contribution was to assist managers in achieving operational and financial efficiency while also adding to the organization's sustainability initiatives. By integrating the sustainable balanced scorecard with the GTA decision-making tool, the research attempted to present a comprehensive and realistic picture of outsourcing reverse logistics decisions. The study's proposed framework might help decision makers visualize and analyse the influence of numerous qualities and sub-attributes on outsourcing decisions. The alternative scenarios were scenario-based, allowing managers to select the options that best fit their business needs.
	What was the limitation?	One of the limitations is that the attributes and sub-attributes, and alternative scenarios are based on one firm. Another limitation is that a group of twelve experts was formed for the study, and in the future, a larger group of experts could be utilized, and more case studies could be developed for the generalization of results and findings.
	What future research areas were identified?	The authors of the study noted that the methodology could be easily adapted to different scenarios and could consider different types of quantitative and qualitative attributes depending on the business need. They also suggested that a fuzzy-based scale could be used in future to avoid any vagueness or subjective biasness.
When	When was the research conducted?	2016
Where	Where was the research conducted?	India

Source: Author's elaboration

Table 16. A conceptual analytic network model for evaluating and selecting third-party reverse logistics providers (Madjid T. et al.)

4W1H	***Configured question***	***Description***
Why	Why was the study conducted?	The study was conducted to design a conceptual model based on the Analytical Network Process (ANP) for evaluating and selecting third-party logistics service providers (3PRLPs). The objective of the research was to develop a decision model that could capture the heterogeneous interactions existing among the different decision factors considered while maintaining a hierarchical structure in a network environment.

4W1H	***Configured question***	***Description***
How	How was the research conducted?	The research was conducted using the Analytic Network Process (ANP) method. This involved the use of three questionnaires where the first one was made online to gather information from 72 academic and company experts, on the different decision factors that were deemed to be important. The second questionnaire consisted of a matrix submitted to four company experts to determine the relationship and effect of the different factors on each other. The third questionnaire was directly based on the ANP model and was based on pair-wise comparisons among the factors that were deemed to be sufficient. The relative importance of the criteria was estimated using the numerical values obtained from the comparisons performed by eight company experts, which followed the basic principles of the AHP. The answers obtained from these experts were integrated into the third pair-wise questionnaire using their geometric means. A standard compatibility test was performed to validate the reliability of the matrix of pair-wise comparisons.
What	What was the research objective?	The research aimed to help both producers and contractors of third-party logistics services in making informed decisions by using the opinions of industry specialists. The model's case-specific nature was considered both an advantage and a limitation of the research. The results were dependent on the case being analysed and the capacity of the researchers to interact with experts before retrieving the information that would be input into the ANP structure.
	What thematic area did research cover?	The research covered the thematic area of third-party logistics provider selection and evaluation.
	What was the contribution of the research?	The results of the research were helpful to both the producer and the contractor of third-party logistics, but the results were highly dependent on the specific case being analysed and the capacity of the researchers to interact with the experts before inputting the information into the ANP structure. The contribution of the research was in offering a tool for decision-making for the 3PRLP selection process in a specific industry.
	What was the limitation?	The limitations of the study include the need for specialists to have knowledge of pair-wise comparisons, the time-consuming nature of pair-wise comparisons, and the specificity of the decision criteria to the industry being studied. Additionally, the results are highly dependent on the case being analysed and the ability of the researchers to interact with experts. The subjective linguistic evaluations from the experts may also lead to uncertainty.

4W1H	*Configured question*	*Description*
	What future research areas were identified?	The future research areas were not specifically identified in the article, however fuzzy logic or gray systems could be used to decrease uncertainty raised by subjective evaluations of experts.
When	When was the research conducted?	2013 (published in 2016)
Where	Where was the research conducted?	USA

Source: Author's elaboration

Table 17. Outsourcing and reverse supply chain performance: a triple bottom line approach (Saurabh A. et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study was conducted to investigate the relationship between outsourcing benefits and the triple bottom line (TBL) based performance of reverse supply chains (RSCs) in the Indian electronics industry.
How	How was the research conducted?	A questionnaire survey was used to obtain data from the Indian electronics sector for the study. The obtained data was examined using Partial Least Squares Path Modeling (PLSPM) to evaluate hypotheses and investigate the association between outsourcing benefits and Reverse Supply Chain Triple Bottom Line (TBL) performance (RSCs). The measurement model was examined to confirm that the data was fit for further investigation. The constructs and path coefficients were utilized in the study to examine the strength of the association between the constructs. The study's findings were provided in tables and a structural equation model.
What	What was the research objective?	The research objective was to examine the effect of outsourcing decisions on the TBL performance of RSCs and to provide insights for managers, researchers, and academicians in decision-making regarding RSC outsourcing issues.
	What thematic area did research cover?	The research covers the thematic area of outsourcing and its relationship with the triple bottom line (TBL) performance of reverse supply chains

4W1H	*Configured question*	*Description*
	What was the contribution of the research?	The research provided insights into the impact of outsourcing on the triple bottom line (TBL) performance of reverse supply chains (RSCs) in the Indian electronics industry. It found that outsourcing decisions were related to TBL performance of RSCs, and the findings can be used by managers, researchers, and academicians in decision-making and justifying the use of corporate social responsibility funds in outsourcing activities.
	What was the limitation?	The study had some limitations, including a small sample size and a focus on only TBL performance of RSC.
	What future research areas were identified?	Future research can include larger sample sizes in different sectors to compare and generalize the findings, as well as consider performance parameters related to the circular economy to analyse the impact of outsourcing benefits on other sustainability parameters.
When	When was the research conducted?	2020
Where	Where was the research conducted?	India

Source: Author's elaboration

Table 18. Sustainable third-party reverse logistics provider selection to promote circular economy using new uncertain interval-valued intuitionistic fuzzy-projection model (Lijuan C. et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study was conducted to identify, rank, analyse, evaluate, and select the optimal third-party reverse logistics provider (3PRLP) in manufacturing companies using a novel decision-making method.
How	How was the research conducted?	The study employed a survey-based approach to identify and rank criteria for evaluating and selecting optimal third-party reverse logistics providers (3PRLPs) in manufacturing contexts. Expert interviews and a literature review were used to establish the criteria. A novel fuzzy set-based decision-making method was then applied to analyse, rank, and evaluate 3PRLP options, using a weighted aggregated IVIF decision matrix and a projection measure to compute positive and negative ideal solutions. The results were validated through comparative decision-making methods, and a case study from a manufacturing organization demonstrated the method's applicability and robustness.

4W1H	***Configured question***	***Description***
What	What was the research objective?	The research objective was to develop a decision-making method to analyse, rank, evaluate, and select the optimal 3PRLP based on criteria related to economic, social, and environmental sustainability. The study aimed to provide a practical, efficient, and sustainable approach for companies and industries to implement and design 3PRLP and establish suitable connections between the provider and buyers.
	What thematic area did research cover?	The research covered the area of sustainable third-party reverse logistics providers (3PRLPs) in manufacturing companies.
	What was the contribution of the research?	The study proposed a novel decision-making procedure for identifying, rating, assessing, and selecting the most suitable third-party reverse logistics providers (3PRLPs) in manufacturing firms. Using a survey approach, it established sixteen key criteria aligned with sustainable development dimensions. The proposed methodology applies fuzzy sets theory, demonstrating flexibility in handling uncertain and qualitative inputs. Its main contribution is the development of a projection-based decision-making model within the IVIF environment, which can be extended to other multi-criteria decision-making applications
	What was the limitation?	The paper did not include empirical data from actual implementation of the proposed approach in manufacturing companies. Additionally, the proposed method was only assessed on a single case study, so its generalizability to other contexts is not clear.
	What future research areas were identified?	The paper suggested that future research could focus on applying the proposed approach in other sectors and industries, such as plantations, agriculture, fisheries, ports, shipping, and inland waterways. Additionally, the study suggested that further research could incorporate grey or stochastic data to indicate uncertainty and develop other types of decision-making methods under different categories of fuzzy sets. Finally, the paper implied that more research is necessary to identify the optimal 3PRLPs for different industries and companies.
When	When was the research conducted?	2021
Where	Where was the research conducted?	China, India, Saudi Arabia

Source: Author’s elaboration

Table 19. Outsourcing Reverse Logistics for E-Commerce Retailers: A Two-Stage Fuzzy Optimization Approach (Chia-Nan W. et al.)

4W1H	***Configured question***	***Description***
Why	Why was the study conducted?	The objective of the study was to provide significant insights to online merchants on the methods of evaluation and selection of third-party reverse logistics providers (3PRLP) in the e-commerce sector, with a focus on Vietnam.
How	How was the research conducted?	To analyse and choose third-party reverse logistics providers (3PRLP) in the Vietnamese e-commerce business, the study used a hybrid technique that integrated the Fuzzy Analytical Hierarchy Process (FAHP) and the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS). Expert assessment and linguistic phrases were used in the study to limit the influence of imprecise and uncertain judgment in weighting criteria and assure the robustness of the ranking outcomes. The suggested approach was shown using a case study, and the results informed e-commerce enterprises about the use of 3PRLP to improve their reverse logistics activities.
What	What was the research objective?	The research objective was to propose a hybrid approach combining fuzzy analytical hierarchy process (FAHP) and fuzzy technique for order preference by similarity to ideal solution (FTOPSIS) for evaluating and selecting 3PRLP in the e-commerce sector, with a case study applied in Vietnam, and to identify the most impactful criteria and the optimized partner for reverse logistics outsourcing in this context.
	What thematic area did research cover?	The research covered the thematic area of reverse logistics outsourcing in the e-commerce industry
	What was the contribution of the research?	The study proposed a hybrid MCDM strategy to evaluate and select third-party reverse logistics providers (3PRLP) in Vietnam's e-commerce sector. It fills a literature gap by offering a structured method for assessing 3PRLPs in developing countries, applicable to similar contexts like supplier selection. The approach provides insights for e-commerce firms to improve reverse logistics governance and highlights the role of economic, social, and environmental factors in sustainable outsourcing. Its findings offer valuable guidance for e-commerce companies, logistics providers, and investors in Vietnam and other emerging markets.
	What was the limitation?	The study only focused on the Vietnamese market, which may limit the external validity of the findings

4W1H	*Configured question*	*Description*
	What future research areas were identified?	The authors indicate that future study should focus on including other elements into the optimization model for outsourcing reverse logistics, such as multi-echelon and multi-objective reverse logistics network architecture, sustainability concerns, and big data analytics. They also advise that future research might look at the actual use of the suggested methodology in real-world circumstances and compare the outcomes to those of other existing approaches.
When	When was the research conducted?	2021
Where	Where was the research conducted?	Vietnam

Source: Author's elaboration

Table 20. A Conceptual Hybrid Approach from a Multicriteria Perspective for Sustainable Third-Party Reverse Logistics Provider Identification (Mohamed A. et. al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The research was carried out in order to develop and apply a new MCDM (Multiple Criteria Decision Making) technique that integrates neutrosophic AHP (Analytic Hierarchy Process) and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) for the evaluation and selection of an alternative for 3PRLPs (Third-Party Reverse Logistics Providers) in the automotive components industrial industry.
How	How was the research conducted?	The data for the study was gathered from a panel of automobile manufacturing experts and decision makers. The gathered replies were then used to construct the first neutrosophic judgment matrices, and decision makers' and specialists' opinions were transformed into T2NNs (Type-2 Neutrosophic Numbers) to obtain more accuracy and appropriate weights. After that, the final decision matrix was built to extract the ordering of 3PRLPs replacements.
What	What was the research objective?	The objective of the research was to suggest and apply a new Multi-Criteria Decision-Making (MCDM) technique that integrates Neutrosophic Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for the selection of an alternative for 3PRLP in the car components industrial industry. The research aimed to address the challenges caused by qualitative and uncertain data, and to evaluate and select an alternative that considers safety and risk, economic, environmental, and social dimensions, and in a sustainable manner.

4W1H	*Configured question*	*Description*
	What thematic area did research cover?	The research covered the thematic area of multi-criteria decision making (MCDM) in the context of evaluating and selecting alternatives for 3PRLPs in the automotive manufacturing industry.
	What was the contribution of the research?	The study proposed a new methodology for evaluating and selecting alternatives for 3PRLPs in the car components industry that combined the neutrosophic Analytical Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) in a Multiple Criteria Decision Making (MCDM) framework. The study revealed the validity and application of the suggested strategy, which effectively managed the selection factors in a sustainable manner, considering safety and risk, economic, environmental, and social dimensions. This study contributes by providing a flexible and adaptive technique to dealing with uncertain, ambiguous, and qualitative data in a complicated decision-making process.
	What was the limitation?	The paper does not explicitly mention any specific limitations of the study. However, the study only focused on the selection of 3PRLPs alternatives in the car components industry and did not address other industries or contexts.
	What future research areas were identified?	The authors suggested a few areas for future research, such as increasing the number of criteria to progress the fineness and accuracy of selection and valuation, determining the performance of the proposed technique utilized in other aspects of manufacturing, such as supplier selection and market selection, and in other manufacturing domains like appliances, glasses, paper for 3PRLPs selection, and beyond. Additionally, future research can associate and differentiate the validity and reliability of other MCDM techniques such as VIKOR, PROMETHEE, and TODIM with neutrosophic numbers in a variety of scenarios.
When	When was the research conducted?	2021
Where	Where was the research conducted?	Egypt

Source: Author's elaboration

Table 21. Strategic orientations, sustainable supply chain initiatives, and reverse logistics, empirical evidence from an emerging market (Chin-Chun H. et al.)

4W1H	***Configured question***	***Description***
Why	Why was the study conducted?	The study was conducted to investigate the relationship between sustainable supply chain initiatives and reverse logistics, and to identify the key components of sustainable supply chain initiatives that contribute to the adoption of reverse logistics by manufacturing companies in Malaysia.
How	How was the research conducted?	The research was conducted using a survey method, where data was collected from 125 completed questionnaires from ISO 14001-certified manufacturing companies in Malaysia. The collected data was analysed using structural equation modelling to evaluate the research hypotheses and validate the proposed model.
What	What was the research objective?	The research objective was to investigate the relationship between sustainable supply chain initiatives and reverse logistics and to identify the key components of sustainable supply chain initiatives that contribute to the adoption of reverse logistics.
	What thematic area did research cover?	The research covered the thematic area of sustainable supply chain management, reverse logistics, eco-innovation, eco-reputation, green manufacturing, green purchasing, and green packaging.
	What was the contribution of the research?	The contribution of the research is threefold. Firstly, it presents empirical evidence that sustainable supply chain strategies favourably promote reverse logistics adoption by Malaysian manufacturing firms. Second, it highlights three essential components of sustainable supply chain activities that positively promote reverse logistics adoption: eco-reputation strategic orientation, eco-innovation strategic orientation, and green packaging. Finally, it has significant management implications for manufacturers interested in building sustainable supply chain efforts and using reverse logistics.
	What was the limitation?	The study's limitations include the possibility of key informant common technique bias, the sample being confined to Malaysian manufacturing organizations, and the exclusion of small and medium-sized enterprises (SMEs).
	What future research areas were identified?	Future research areas identified include using multi-informant designs or direct investigator observations to minimize key informant common method bias, examining the findings' applicability to service sectors, investigating other components of sustainable supply chain initiatives, understanding the role of internal stakeholders, and testing and validating the proposed model with non-certified SMEs.

4W1H	*Configured question*	*Description*
When	When was the research conducted?	2016
Where	Where was the research conducted?	Malaysia

Source: Author's elaboration

Table 22. Performance evaluation of reverse logistics: A case of LPG agency (K. Yogi)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The objective of the study was to explore the performance of reverse logistics in the Liquefied Petroleum Gas (LPG) industry by conducting a case study of a selected agency. The study aimed to identify the challenges faced by the agency in managing reverse logistics and to suggest measures for improving the performance of the reverse logistics system.
How	How was the research conducted?	The research was conducted through a case study approach involving two LPG agencies (one rural and one urban) in India. It utilizes a quantitative analysis method, collecting real data on performance measures across three phases: inventory indicators, volume flexibility, and cylinder utilization. The data was analysed using statistical tools, specifically two tailed t-tests and Pearson's correlation, to test the developed hypotheses
What	What was the research objective?	The research aimed to evaluate the performance of reverse logistics at a selected LPG agency by identifying the key factors affecting reverse logistics performance and suggesting suitable measures for improvement.
	What thematic area did research cover?	The research covered the thematic area of reverse logistics in the context of the LPG industry. The study focused on evaluating the performance of reverse logistics
	What was the contribution of the research?	The research contributed to the understanding of reverse logistics in the LPG industry, by identifying the key factors affecting its efficiency and proposing measures for improving its effectiveness. The study provided valuable insights for LPG agencies and other organizations involved in reverse logistics.
	What was the limitation?	The limitation of the research was that it was conducted through a single case study, which may limit the generalizability of the findings. Additionally, the study focused only on one aspect of reverse logistics and did not cover other areas such as product returns and waste management.

4W1H	*Configured question*	*Description*
	What future research areas were identified?	Future research areas identified include the need for further research on the effectiveness of reverse logistics in different industries, and the development of standardized performance metrics for evaluating reverse logistics.
When	When was the research conducted?	2015
Where	Where was the research conducted?	India

Source: Author's elaboration

Table 23. Reverse Logistics as a Complex System: A Case Study of Waste Management in the Norwegian Offshore Petroleum Industry (Engelseth P.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The objective of the study is to explore and analyse the complexities involved in reverse logistics in the Norwegian offshore petroleum industry. Specifically, the study aims to identify the key actors, their roles, and interactions in the waste management system of the industry, and to understand the challenges and opportunities that arise in the system
How	How was the research conducted?	The research was conducted as a single case study of the Norwegian offshore petroleum industry. Data collection relied primarily on the author's own industry experience as an executive, supplemented by semi-structured interviews and student projects. The analysis applied Contingency Theory, specifically focusing on interdependencies (sequential, pooled, and reciprocal) to understand the drill cuttings waste flow as a complex system.
What	What was the research objective?	The research objective of this article is to present a case study of reverse logistics in the Norwegian offshore petroleum industry and to explore the complexity of waste management in this context. The study aims to contribute to the literature on reverse logistics by providing insights into the challenges and opportunities that arise in this specific industry, and by highlighting the importance of understanding reverse logistics as a complex system.
	What thematic area did research cover?	The article covers the thematic area of waste management and reverse logistics in the offshore petroleum industry

4W1H	*Configured question*	*Description*
	What was the contribution of the research?	The research contributes by empirically grounding reverse logistics as a complex system within the specific context of drill cuttings waste management in the Norwegian offshore industry. It applies Contingency Theory to demonstrate that while the process is primarily sequentially interdependent (physical distribution), the inherent uncertainties (such as weather and drilling operations) require the integration of pooled and reciprocal interdependencies for effective management. The study highlights that managing this reverse flow involves coordinating emergent production steps where waste is eventually transformed into value (e.g., recovered oil).
	What was the limitation?	The study did not address the financial and economic implications of the waste management system, which may be important for decision-making and sustainability.
	What future research areas were identified?	The primary limitation identified by the author is regarding the transferability of the findings. Since the research is based on a single case study within a specific industrial setting (Norwegian offshore petroleum), the results may not be directly applicable to other business cases or industries without careful consideration of context.
When	When was the research conducted?	2017
Where	Where was the research conducted?	Norway

Source: Author's elaboration

Table 24. Effect of Reverse Logistics on Operational Performance of Liquefied Petroleum Gas Companies in Kenya (Khadija Gamal)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study was conducted to address the increasing pressure on firms to become environmentally sustainable due to customer awareness, government regulations, and economic factors. It aimed to fill a knowledge gap regarding the specific effects of reverse logistics on operational performance within the Kenyan Liquefied Petroleum Gas (LPG) industry, a sector facing unique challenges like illegal refilling and high costs.

4W1H	*Configured question*	*Description*
How	How was the research conducted?	The research staff and descriptive cross-sectional survey design. The population included all 34 liquefied petroleum gas (LPG) companies in Kenya listed under the Cylinder Exchange Pool. Due to the small population size, a census was conducted, and 30 companies responded. Data was collected using self-administered questionnaires given to supply chain or operational managers and analysed using descriptive statistics and multiple regression analysis
What	What was the research objective?	The research had two primary objectives: (1) To determine the extent to which reverse logistics practices (specifically remanufacturing, reusing, recycling, and repackaging) have been adopted by LPG companies in Kenya, and (2) To establish the effect of adopting these practices on the companies' operational performance (measured by cost, quality, speed, flexibility, and dependability).
	What thematic area did research cover?	The research covered the thematic area of Reverse Logistics (RL) and operational performance within the energy sector. Specifically, it focused on the extent of adoption of RL practices (remanufacturing, reusing, recycling, repackaging) and their impact on performance metrics like cost, quality, and dependability in Liquefied Petroleum Gas (LPG) companies.
	What was the contribution of the research?	The study contributes to the limited body of knowledge regarding reverse logistics specifically within the Kenyan Liquefied Petroleum Gas (LPG) sector. It provides empirical evidence that LPG companies have adopted reverse logistics practices to appreciable levels (with repackaging being the most common) and establishes a significant relationship between these practices and operational performance metrics such as cost, quality, and dependability. The research also offers managerial recommendations for training employees and formalizing reverse logistics policies to enhance competitiveness.
	What was the limitation?	The author identified two primary limitations. First, the scope was limited to only four reverse logistics practices (remanufacturing, reusing, recycling, and repackaging), excluding others like landfill, product returns, and salvage. Second, the researcher faced time constraints which limited the time allocated to the study.
	What future research areas were identified?	The study identified the need for future research on the drivers and challenges of reverse logistics in liquefied petroleum gas companies in Kenya, a comparative study on the effect of reverse logistics on operational performance in other sectors or countries, and a study on the effect of culture on the adoption of reverse logistics.

4W1H	*Configured question*	*Description*
When	When was the research conducted?	2016
Where	Where was the research conducted?	Kenya

Source: Author's elaboration

Table 25. Reverse Logistics Applied to Wastes Oily Management (Marcos D. et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The purpose of this study was to analyse and identify critical points that impact the efficiency of reverse logistics in the lubricant sector, particularly regarding the management of waste oily returns in the productive chain. The study aimed to investigate the generation of oily waste in Brazil and identify best practices for environmentally friendly final destinations. The research was conducted to understand the scale of the problem and the challenges in minimizing the environmental impact of waste oily management.
How	How was the research conducted?	The research methodology employed in the paper was a literature review of the topic, utilizing secondary data sources. The authors synthesized information from various scholarly articles, government reports, and industry publications.
What	What was the research objective?	The primary research objective was to investigate the generation of waste oily in Brazil and identify the best environmentally friendly practices for its final disposal. The study aimed to identify critical points that affect the efficiency of the reverse logistics process in the lubricant sector and to understand the challenges in minimizing the environmental impact of waste oily management. The study also aimed to enhance existing studies on environmentally friendly reverse logistics processes and develop new interaction formats with all participants of the direct and reverse chain distribution, with a focus on managing waste oily returns in the production chain.
	What thematic area did research cover?	The research covered the thematic area of reverse logistics applied to oily waste management. Specifically, it examined the legal, economic, and social aspects of the reverse management of oily waste in Brazil, and how the participation of various actors in the reverse chain affects this process.

4W1H	*Configured question*	*Description*
	What was the contribution of the research?	The contribution of the research is to provide an analysis of the participation and responsibilities of the direct and reverse chain involved in the management of oily waste, with a focus on Brazil. The article discusses the legal framework and regulations in place in Brazil and other countries, as well as the economic, legal, and social interests involved in the management of oily waste. By providing a comprehensive overview of the topic, the research can help policymakers and practitioners in the field of waste management to better understand the challenges and opportunities associated with the reverse logistics of oily waste.
	What was the limitation?	The article does not explicitly mention any limitations of the research. However, one limitation could be that the study relied solely on secondary data sources and did not include primary data collection methods.
	What future research areas were identified?	The article does not mention any specific future research areas, however there is a need for surveys or interviews with stakeholders involved in the oily waste management chain.
When	When was the research conducted?	2010
Where	Where was the research conducted?	Brazil

Source: Author's elaboration

Table 26. A fuzzy multi-objective optimization model for a sustainable reverse logistics network design of municipal waste-collecting considering the reduction of emissions (Seyed Emadedin H.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The objective of the study was to propose a multi-objective mathematical model for vehicle routing in the reverse supply chain to collect municipal waste in fuzzy conditions. The aim was to minimize costs, including the cost of using vehicles and environmental costs, while maximizing satisfying demand.

4W1H	*Configured question*	*Description*
How	How was the research conducted?	The research was conducted by developing a multi-objective mathematical model for vehicle routing in the reverse supply chain to collect municipal waste in fuzzy conditions. The model was a mixed-integer linear programming model and included all potential centres, such as collection-restoration centres, recycling centres, and landfills with limited capacity assumptions and multi-productivity. Since the mathematical model presented was classified as an NP-hard problem, metaheuristic algorithms were used to solve the model. Specifically, the Bee colony optimization algorithm and the Genetic algorithm were used, and their results were compared in terms of quality, comparison, spacing, diversification, and solution time. Experimental sample problems were designed in three groups of small, medium, and large sizes according to previous research. The results of both algorithms were analysed, and the performance of the algorithms in such models was measured, and their accuracy was compared to each other.
What	What was the research objective?	The research objective was to develop a model to optimize the reverse logistics of municipal waste collection with a focus on reducing emissions in fuzzy conditions. The aim was to propose a cost-effective and environmentally friendly approach to waste management by considering all potential centres, including collection-restoration centres, recycling centres, and landfills with limited capacity assumptions and multi-productivity. The study aimed to solve the proposed model using metaheuristic algorithms and to compare the results obtained from two different algorithms, Bee colony optimization and Genetic algorithm, to evaluate their accuracy and efficiency. Additionally, suggestions for future research were provided to enhance the model and optimization methods.
	What thematic area did research cover?	The research covered the thematic area of green supply chain management, specifically focusing on the issue of reverse logistics in municipal waste collection, with a goal of reducing emissions in fuzzy conditions while minimizing costs and maximizing satisfying demand.

4W1H	***Configured question***	***Description***
	What was the contribution of the research?	The research contributed by developing a multi-objective mathematical model for reverse logistics in municipal waste collection that aims to minimize costs and emissions while maximizing demand satisfaction under fuzzy conditions. It applied and compared genetic and bee colony algorithms to solve the NP-hard model, offering insights into their efficiency for similar problems. The study's main contribution lies in integrating uncertainty and multi-objective optimization into reverse logistics modeling and evaluating algorithmic performance, while suggesting future research on probabilistic parameters, additional metaheuristics, and robust optimization methods.
	What was the limitation?	One of the limitations of this research is that the proposed model considers only the collection of municipal waste and does not address the sorting and separation of different waste streams, which could have an impact on the feasibility and efficiency of the proposed solution. Additionally, the model assumes that the capacity of the facilities is fixed, whereas in reality, the capacity of the facilities may vary over time due to various factors such as maintenance, upgrades, or changes in regulations. Finally, the proposed model does not consider the potential impacts of weather conditions, traffic congestion, or other external factors that may affect the routing and scheduling of waste collection vehicles.
	What future research areas were identified?	The study identified several future research areas that could be explored in further studies. Firstly, in terms of the structure of the issue under consideration, the study suggested considering parameters as probabilistic, exploring other goals for the issue, and using probabilistic and fuzzy parameters to express uncertainty. Secondly, in terms of optimization methods, the study suggested using the search pattern of meta-innovative methods based on the principles of advanced reaction methods, using the new method of fuzzy ideal programming to optimize goals, using a real example instead of generating random problems, exploring other meta-heuristic algorithms such as scatter search, PSO, ACO, DE, etc., and using the robust optimization method to solve the model. Lastly, in terms of the structure of the proposed algorithms, the study suggested using other innovative algorithms to generate initial solutions, reducing the computational time of the algorithm by creating a suitable improvement method, and using a guided structure to search for neighborhood answers.
When	When was the research conducted?	2021

4W1H	*Configured question*	*Description*
Where	Where was the research conducted?	The article does not specify a particular location where the research was conducted.

Source: Author's elaboration

Table 27. Selection of strategy for reverse logistics implementation (Himanshu Prajapati)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study was conducted to investigate the selection of strategies for implementing reverse logistics. Specifically, the researchers wanted to identify the most effective strategies for companies to use to improve their reverse logistics processes.
How	How was the research conducted?	The research was conducted through a survey of the Indian manufacturing industry. The study proposed three reverse logistics implementation strategies, namely in-house, joint venture, and outsourcing. The researchers developed a novel hybrid fuzzy analytical hierarchy process (F-AHP) and fuzzy measurement of alternatives and ranking according to Compromise Solution (F-MARCOS) based framework to evaluate and rank these strategies. The proposed framework was then applied to the survey responses to demonstrate its applicability in real-world scenarios.
What	What was the research objective?	The research objective was to identify and evaluate different strategies for implementing reverse logistics and determine which ones were most effective. The study aimed to provide practical guidance for companies looking to improve their reverse logistics processes by outlining the benefits and drawbacks of various strategies.
	What thematic area did research cover?	The research covered the thematic area of reverse logistics, specifically the selection of a suitable strategy for its implementation.
	What was the contribution of the research?	The research contributes by developing a novel hybrid decision-making framework utilizing Fuzzy Analytic Hierarchy Process (F-AHP) and Fuzzy MARCOS (F-MARCOS) to select the most appropriate reverse logistics implementation strategy (In-house, Joint Venture, or Outsourcing). It identifies and evaluates 13 specific criteria, revealing that government policy and regulations, reverse logistics risks, and reduced emissions are the most critical factors for decision-making. The study provides empirical evidence from the Indian manufacturing industry, concluding that Outsourcing (OSRL) is the most preferred strategy, followed by Joint Venture and In-house options

4W1H	*Configured question*	*Description*
	What was the limitation?	The authors noted that the research results are based on a small-scale survey (29 responses) from the Indian manufacturing industry, which may limit the generalizability of the findings to a broader context. Additionally, while the framework was tested across various manufacturing sectors, the authors suggest that for actual implementation, the survey should be limited to a particular industry to generate more precise and applicable results for that specific sector.
	What future research areas were identified?	The authors suggested three specific areas for future research. First, they recommended conducting a large-scale survey to obtain a clearer picture of reverse logistics strategies throughout the country. Second, they suggested extending the research to the service sector to study strategies specific to that domain, as the current study focuses on manufacturing. Finally, they proposed analyzing the interdependencies among the selected criteria in future studies.
When	When was the research conducted?	2021
Where	Where was the research conducted?	India

Source: Author's elaboration

Table 28. A two-stage stochastic programming model for multi-period reverse logistics network design with lot-sizing (Vahid A. et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study was conducted to address the challenges in designing an efficient and effective multi-echelon multi-period reverse logistics network under uncertainty. The researchers aimed to develop a two-stage stochastic programming model that incorporates both return and demand uncertainty and evaluates the optimal network structure for reverse logistics systems.
How	How was the research conducted?	The research employed a two-stage stochastic programming approach to study the problem. The first stage decision variables included facility location variables, while the second stage decision variables consisted of material flow variables, backorder variables, shortage variables, and outsourcing variables. The researchers used a scenario generation method and scenario reduction algorithm to generate a set of scenarios that approximated underlying continuous distributions for return and demand. They conducted a case study for a European consumer goods company with uncertain return and demand.

4W1H	*Configured question*	*Description*
What	What was the research objective?	The research objective was to develop a two-stage stochastic programming model to consider the return and demand uncertainty in a multi-echelon multi-period reverse logistics network. The researchers aimed to evaluate the optimal network structure for reverse logistics systems and demonstrate the importance of incorporating uncertainty in problem formulation. They also aimed to identify potential areas for future research, such as analyzing the correlation between demand and return, considering more uncertain parameters in modeling the problem, and developing efficient algorithms to solve large-scale instances of the problem.
	What thematic area did research cover?	The research covered the thematic area of reverse logistics network optimization under uncertainty.
	What was the contribution of the research?	The research contributed to the field of reverse logistics network design by developing a two-stage stochastic programming model that incorporates uncertainty in return and demand. The model includes first-stage decision variables for facility location and second-stage decision variables for material flow, backorder, shortage, and outsourcing. The results of the study demonstrate the importance of incorporating uncertainty in problem formulation and provide optimal network structures for reverse logistics systems. The research also applied scenario generation and scenario reduction algorithms to generate a set of scenarios to approximate underlying continuous distributions for return and demand. The study's contributions can inform the development of more effective and efficient reverse logistics systems that account for uncertainty in return and demand.
	What was the limitation?	The limitation of the study was that it assumed that demand and return are independent, while they may be dependent on each other. The study also considered only two sources of uncertainty, i.e., demand and return, while other uncertain parameters such as quality, travel time, and facility capacity were not considered.
	What future research areas were identified?	The study identified several potential future research directions. Firstly, future research could focus on analyzing the correlation between demand and return as they may not always be independent of each other. Secondly, future research could consider more uncertain parameters in modeling the problem as a multi-stage stochastic program to represent the system's stochasticity. Finally, developing efficient algorithms to solve large-scale instances of the problem could be another potential research direction.

4W1H	*Configured question*	*Description*
When	When was the research conducted?	2020
Where	Where was the research conducted?	Europe

Source: Author's elaboration

Table 29. Effect of carbon tax on reverse logistics network design (Reddy, K. Nageswara et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study was conducted to create a mixed integer linear programming (MILP) model to solve a multi-tier, multi-period green reverse logistics network that involves vehicle type selection. The study aims to contribute to the development and testing of the green reverse logistics model by taking carbon emissions and environmental consequences into account when solving the vehicle type selection problem.
How	How was the research conducted?	To address a multi-tier, multi-period green reverse logistics network that incorporated vehicle type selection, the researchers used a MILP model. The model was evaluated with various cost and parameter values determined by industry norms and existing literature. The model made selections on the ideal location of inspection and remanufacturing centres, the product quantity to be delivered by which vehicle mode, the number of vehicles to be employed, and the amount of quantity to purchase, dispose of, or hold in inventory.
What	What was the research objective?	The study goal was to create and evaluate a mixed integer linear programming (MILP) model to solve a multi-tier, multi-period green reverse logistics network that incorporates vehicle type selection while taking carbon emissions and environmental consequences into account. The model was aimed at making optimal judgments on the location of inspection and remanufacturing centres, the quantity of product to be delivered by which vehicle mode, the number of vehicles to be employed, and the quantity to purchase, dispose of, or hold in inventory.
	What thematic area did research cover?	The research covered the thematic area of green supply chain management and reverse logistics

4W1H	*Configured question*	*Description*
	What was the contribution of the research?	The study's contribution was in developing and testing a green reverse logistics model that considers carbon emissions and environmental implications. The suggested approach has applications in the best location of inspection and remanufacturing centres, transportation considerations, and inventory management.
	What was the limitation?	One limitation of the study is that it only considered one environmental dimension (carbon emissions) and did not consider other polluting elements such as NOx and SOx. Additionally, the model can be further improved by considering more complex network scenarios with variations in various parameters.
	What future research areas were identified?	The authors suggested that future research could extend the model to a multi-product scenario at the component level, consider other capacity decisions, consider other polluting elements, and explore more complex networks with variations in a variety of parameters. Additionally, the authors observed that developing heuristics and solutions that exploit the underlying structure of the model could potentially lead to significant algorithmic improvements.
When	When was the research conducted?	2020
Where	Where was the research conducted?	The article does not specify a particular location where the research was conducted.

Source: Author's elaboration

Table 30. Green Reverse Logistics: Case of the Vehicle Routing Problem with Delivery and Collection Demands (Naveed Wassan et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The research was conducted to obtain a better knowledge of Vehicle Routing Problem (VRP) models in the context of Green Reverse Logistics. The research aimed at examining how VRP models may be utilized to minimize CO_2 emissions and solve issues such as routing costs, fleet utilization optimization, fewer cars on the road, and environmental concerns. The study concentrated on VRP models with delivery and collecting requirements.

4W1H	*Configured question*	*Description*
How	How was the research conducted?	A complete evaluation of the literature on VRP models with delivery and collection demands was used to perform the research. The authors examined and evaluated numerous VRP models to determine their strengths and limitations in tackling green reverse logistics challenges. The study also explored the influence of battery power technology advancement on such modeling methodologies.
What	What was the research objective?	The research goal was to give insights into the applicability of VRP models with delivery and collection demands in addressing green reverse logistics problems. The study's goal was to examine existing VRP models and make suggestions for changes to create more realistic models that can be implemented and tested in practice. The research's ultimate objective was to develop efficient VRP models that not only maximize economic rewards but also contribute to a cleaner environment by reducing greenhouse gas emissions.
	What thematic area did research cover?	Green reverse logistics and vehicle routing problem.
	What was the contribution of the research?	The research helps to design more realistic and ecologically friendly vehicle routing models that optimize delivery and collection demands, cut routing costs, enhance fleet utilization, and reduce greenhouse gas emissions. It gives insight into the use of such models in solving important concerns for business, governments, and stakeholders.
	What was the limitation?	The authors noted that the research results are based on the responses from a survey of the Indian manufacturing industry, which might limit the findings' applicability to other sectors or regions without further validation. While the framework was tested across various manufacturing sectors, the study suggests that for actual implementation, the survey should be limited to a particular industry to generate results specific to that sector. Additionally, the authors recommended conducting a large-scale survey to obtain a clearer picture across the country.

4W1H	*Configured question*	*Description*
	What future research areas were identified?	Some prospective study areas in the subject of green reverse logistics were mentioned in the article. They include the creation of more complete and integrated models that consider a wide range of factors like sustainability, social responsibility, and economic performance. The authors also advise that future research should focus on the use and testing of these models in real-world scenarios, as well as the development of innovative technologies and practices that might increase reverse logistics efficiency and environmental impact. Furthermore, the essay underlines the importance of collaboration among academic, industrial, and government partners to establish a more sustainable and successful reverse logistics system.
Who	Who was the object of the research?	The study aimed to provide insights for industry, governments, and other stakeholders who are concerned with reducing greenhouse gas emissions and optimizing economic gains.
When	When was the research conducted?	2019
Where	Where was the research conducted?	The article does not specify a particular location where the research was conducted

Source: Author's elaboration

Table 31. Determinants of sustainable supply chain management: A case study from the oil and gas supply chain (Bhaskar B. Gardas et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The primary objective of the study was to identify the determinants of sustainable supply chain management (SSCM) in the Indian oil and gas sector and analyse the intensity of their relationship and influence on the overall performance rating (OPR) of the sector.
How	How was the research conducted?	The study employed an integrated approach of Interpretive Structural Modeling (ISM) and Structural Equation Modeling (SEM) methodologies. The ISM methodology was used for establishing the interrelationship between the determinants, and the influence of all the determinants on the OPR was evaluated. In the next phase, the identified relationships of all the determinants on the OPR were validated by formulating six hypotheses, and then the nature of influence and strength of each determinant on the OPR was evaluated by applying SEM methodology.

4W1H	*Configured question*	*Description*
What	What was the research objective?	The research objective was to identify the determinants of SSCM in the Indian oil and gas sector, analyse their interrelationship, and evaluate their influence on the overall performance rating (OPR) of the sector using an integrated approach of ISM and SEM methodologies.
	What thematic area did research cover?	The research covered the determinants of sustainable supply chain management (SSCM) and their influence on the operational performance of the Oil and Gas sector.
	What was the contribution of the research?	Using an integrated ISM-SEM technique, the researchers identified six SSCM drivers and examined their degree of association and effect on the operational performance of the Indian oil and gas industry. The findings of the study can be extended to the Oil and Gas industry in other emerging nations and adapted for use in other industries in rich economies.
	What was the limitation?	The research did not consider the metrics for sustainability development and problems with sustainable measurement systems. Additionally, the ISM approach has certain drawbacks such as poor interpretation of links and a lack of focus on the causality of links. The reliability of the model could be improved by employing other multi-criteria decision-making approaches. Moreover, the input of experts from academia and the case industry could have biased the results.
	What future research areas were identified?	The paper outlines numerous potential future study fields. One such area is the application of integrated multi-criteria decision-making methodologies, such as the interpretive ranking process, total interpretive structural modeling, analytic hierarchy process, ANP, DEMATEL, and others, in conjunction with the ISM tool to increase model dependability. Another focus is on metrics for sustainable development and issues with sustainable measuring systems. Lastly, the authors believe that the current study's findings might be extended to the same sector in other developing nations, as well as to other sectors in developed economies with minimal changes to the established model.
When	When was the research conducted?	2019
Where	Where was the research conducted?	India

Source: Author's elaboration

Table 32. Life Cycle Assessment of Lubricant Oil Plastic Containers in Brazil (Maria Clara Oliveira et al.)

4W1H	***Configured question***	***Description***
Why	Why was the study conducted?	The study was conducted to assess the environmental impacts associated with the life cycle of lubricant oil plastic containers in Brazil, including the production, transportation, use, and disposal phases.
How	How was the research conducted?	The research was conducted using a Life Cycle Assessment (LCA) methodology, which is a standardized method to evaluate the environmental impacts of a product or service throughout its entire life cycle. The study considered different types of lubricant oil containers, as well as different disposal scenarios, including recycling, landfilling, and incineration.
What	What was the research objective?	The research objective was to identify the main environmental impacts associated with the production, use, and disposal of lubricant oil plastic containers in Brazil, and to assess the potential benefits of different disposal scenarios, such as recycling or energy recovery, compared to landfilling or incineration. The study also aimed to provide insights for decision-makers in the lubricant oil industry and waste management sector to improve the sustainability of their operations.
	What thematic area did research cover?	The thematic area of the research is the life cycle assessment (LCA) of lubricant oil plastic containers in Brazil.
	What was the contribution of the research?	The research contributed to the field of sustainability by conducting a life cycle assessment of lubricant oil plastic containers in Brazil. The study provided important insights into the environmental impact of the containers throughout their life cycle and identified areas where improvements could be made to reduce their impact. Policymakers, manufacturers, and other stakeholders can use the results of the study to make more informed decisions about the design, production, and disposal of plastic containers, helping to reduce their environmental impact.
	What was the limitation?	The study relies on specific assumptions for its Life Cycle Assessment (LCA) scenarios, particularly regarding transportation distances and the current recycling rate (26.5%). While primary data was used for the recycling process, other lifecycle stages were modeled using the Ecoinvent database adapted for Brazilian conditions (e.g., energy mix), rather than direct primary data for every stage. Additionally, the scope is specifically focused on High-Density Polyethylene (HDPE) containers, which represent the vast majority of the market, rather than all possible container types

4W1H	*Configured question*	*Description*
	What future research areas were identified?	The authors suggest that future research could focus on improving the recyclability of plastic containers and the development of more environmentally friendly lubricants. They also recommend conducting life cycle assessments for other types of lubricant containers and different regions to gain a more comprehensive understanding of their environmental impacts. Additionally, they propose evaluating the economic feasibility of implementing closed-loop recycling systems for lubricant containers.
When	When was the research conducted?	2017
Where	Where was the research conducted?	Brazil

Source: Author's elaboration

Table 33. A multi-objective model for multi-product multi-site aggregate production planning in a green supply chain: Considering collection and recycling centres (Arezoo Entezaminia et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study's goal was to create a multi-objective model for multi-product multi-site aggregate production planning in a green supply chain, with the goal of combining both profit and environmental principles into production planning. The research intended to assess many environmental factors for products, such as recyclability, ease of disassembly, biodegradability, energy consumption, and product risk, while reducing supply chain total losses and increasing product overall environmental score.
How	How was the research conducted?	The research was conducted by developing a mathematical model for multi-period multi-product multi-site aggregate production planning in a green supply chain. The model considered different environmental criteria for products and incorporated various constraints, such as limited collection and recycling centres, GHG emission limits, and waste management considerations. The model was solved using the LP-metrics method to generate a collection of Pareto-optimal solutions, which were then analysed using sensitivity analysis.

4W1H	*Configured question*	*Description*
What	What was the research objective?	The research objective was to create a multi-objective model for aggregate production planning in a green supply chain that considers both economic and environmental principles. The approach attempted to reduce overall supply chain losses while increasing product environmental scores based on several environmental factors such as recyclability, ease of disassembly, biodegradability, energy consumption, and product risk. The study also attempted to consider several restrictions such as limited collection and recycling sites, GHG emission limits, and waste management issues. The study aimed to give policymakers insights into CO2 emission policies and to demonstrate that incorporating environmental factors into production planning may provide firms with a competitive edge.
	What thematic area did research cover?	The research covered the thematic area of green supply chain management, specifically focusing on multi-objective aggregate production planning that considers collection and recycling centres.
	What was the contribution of the research?	The study suggested a multi-objective model for aggregate production planning in a green supply chain that takes collection and recycling facilities into account, and it combines profit and green principles into the production planning process. The model considers environmental factors such as recyclability, biodegradability, energy consumption, and product risk, and it seeks to reduce overall supply chain losses while increasing product environmental scores. The research also evaluated transportation, trash management, and the restricted number of potential collection and recycling locations to collect and recycle returned items. The study adds to the literature on aggregate production planning models that consider green principles and profit, which are still in its infancy.
	What was the limitation?	One limitation of the research is that it did not consider uncertainties related to factors such as returns and demand. This means that further work may be needed to develop more realistic models that consider these uncertainties. Additionally, the study assumed a fixed number of potential collection and recycling centres, which may not accurately reflect the real-world situation where the number of centres can change over time.

4W1H	*Configured question*	*Description*
	What future research areas were identified?	The authors identified several areas for future research. Firstly, as the number of returned products, as well as transportation and opening costs, are difficult to predict exactly, they suggested considering parameters as independent possibilistic variables modeled by fuzzy numbers. Secondly, they recommended applying three possibilistic programming approaches, including chance constrained programming, expected value, and dependent-chance constrained programming, independently on the model to obtain more realistic models. Additionally, the authors suggested considering the vehicle routing principles instead of direct shipping as an important part of saving CO2 emissions and costs for future research. Finally, they recommended further work with more focus on robust, fuzzy, and stochastic optimization to obtain more realistic models, given that some factors including returns and demand are uncertain.
When	When was the research conducted?	2016
Where	Where was the research conducted?	Iran

Source: Author's elaboration

Table 34. Evaluation of New Technological Routes to Waste Treatment Generated on Oil Platform: Waste-to-Energy (I. B. Scorzelli et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The objective of the study was to explore the waste management options available to offshore oil and gas operators in Brazil. The study aimed to identify the different types of waste generated during offshore operations and the methods used to manage them. The study also aimed to evaluate the environmental and safety risks associated with each waste management option and their economic feasibility
How	How was the research conducted?	The research was conducted through a bibliographic review of national and international literature, legislation, and technical standards related to waste management in the offshore oil and gas industry. It analysed various waste treatment and disposal methods, such as co-processing, re-refining, incineration, and landfilling, to identify viable reuse and recycling alternatives.

4W1H	***Configured question***	***Description***
What	What was the research objective?	The primary objective was to identify and analyse the waste management options available for the offshore oil and gas industry in Brazil, specifically focusing on reuse and recycling alternatives for major waste streams like drill cuttings and produced water. The study aimed to compare these alternatives against traditional disposal methods (landfill, incineration) to determine their potential viability and alignment with environmental regulations.
	What thematic area did research cover?	The research covered waste management options for offshore oil and gas operators in Brazil.
	What was the contribution of the research?	The contribution of the research is providing a comprehensive overview of the current waste management scenario in the Brazilian offshore oil and gas sector. It identifies specific reuse and recycling opportunities (e.g., co-processing, re-refining) and highlights the critical barrier: the lack of a structured recycling market in Brazil. The study emphasizes that for sustainable options to be economically viable, there must be stronger government-industry cooperation to develop this market structure.
	What was the limitation?	The research had limitations in terms of the depth of analysis of some of the technologies discussed. For example, while it provided an overview of plasma gasification and gasification technologies, it did not provide a detailed analysis of their costs and benefits compared to other methods of waste disposal.
	What future research areas were identified?	The authors concluded that future efforts should focus on structuring the recycling market in Brazil to make reuse and recycling viable alternatives to landfilling and incineration. This involves creating government policies that encourage the use of recycled materials and fostering cooperation between the productive sector and recyclers to improve the economic feasibility of waste treatment options.
When	When was the research conducted?	2015
Where	Where was the research conducted?	Brazil

Source: Author’s elaboration

Table 35. A reverse logistics network design (Ahmed A. et al.)

4W1H	***Configured question***	***Description***
Why	Why was the study conducted?	The study was conducted to address the problem of reverse logistics (RL) network by developing a mixed-integer linear program (MILP) to model it. The overall objective was to provide decision-makers with a tool to optimize the RL process, which involves compilation, examination, recycling, renovating, and remanufacturing of used items, involving leased or owned tools and machines.
How	How was the research conducted?	The research was conducted by developing a mixed-integer linear program (MILP) to model the reverse logistics process. A case study was conducted concerning large household appliances in the UAE, with results bearing different scenarios. The model was solved to optimality by utilizing a commercial solver
What	What was the research objective?	The research objective was to develop a model to optimize the reverse logistics (RL) process, specifically in the context of large household appliances in the UAE. The model aimed to provide decision-makers with insights on the most suitable sites, number of services that need their capabilities, and priorities on the establishment of inspection centres and remanufacturing plants, among others. The model also had implications for companies that require large and costly transportation systems, such as delivery companies, by deciding the gradual replacement of outsourced transportation by in-house systems.
	What thematic area did research cover?	The research covered the area of reverse logistics in the context of large household appliances.
	What was the contribution of the research?	The research developed a mixed-integer linear programming model to optimize the reverse logistics network for large household appliances in the UAE. The model provides practical implications for decision-makers and can offer useful insights to companies that require large and costly transportation systems.
	What was the limitation?	The research did not consider stochastic parameters to account for uncertainty in the model
	What future research areas were identified?	The authors suggest that the model can be extended by integrating both forward and reverse logistics, considering different transportation modes, and exploring various contracts for outsourcing transportation. Additionally, the model can be customized for different problems to generate problem-specific results for practical applicability in a larger number of industries.

4W1H	*Configured question*	*Description*
When	When was the research conducted?	2015
Where	Where was the research conducted?	United Arab Emirates

Source: Author's elaboration

Table 36. A literature review and perspectives in reverse logistics (Saurabh A. et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study was conducted to provide a comprehensive literature review and analysis of reverse logistics. The objective was to explore the current trends, practices, and challenges in reverse logistics and to provide insights and perspectives on future research directions.
How	How was the research conducted?	The research was conducted using a systematic literature review approach. The authors searched and reviewed many academic articles, books, and other relevant sources on reverse logistics. They analysed the literature to identify the major themes and trends, and to synthesize the findings to develop a comprehensive perspective on the subject.
What	What was the research objective?	The research objective was to provide a literature review and perspectives on reverse logistics. Specifically, the study aimed to identify the current state of research on reverse logistics, to explore the key themes and trends, and to provide insights and perspectives on future research directions.
	What thematic area did research cover?	The research covered the thematic area of reverse logistics.
	What was the contribution of the research?	The research contributed to the existing literature on reverse logistics by providing a comprehensive overview of the field, including its history, current practices, challenges, and future research directions.
	What was the limitation?	One of the limitations of the research was that it relied primarily on secondary sources, such as academic journals and industry reports, rather than primary data collection.
	What future research areas were identified?	The authors identified several areas for future research in reverse logistics, including the integration of new technologies, the development of more sustainable practices, and the exploration of cross-functional collaboration within organizations.

4W1H	*Configured question*	*Description*
When	When was the research conducted?	2015
Where	Where was the research conducted?	India

Source: Author's elaboration

Table 37. Fuzzy Multi-Objective Optimization of a Green Supply Chain Network with Risk Management that Includes Environmental Hazards (Paksoy T. et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	Study aimed to propose a fuzzy programming model to manage uncertainty and risks in the green closed-loop supply chain network design, considering the tradeoffs between operational and environmental performance measures of shipping products.
How	How was the research conducted?	The researchers conducted a theoretical study by developing a multi-objective linear programming model to address the closed-loop supply chain network design problem. To handle the uncertainty and conflicting objectives (minimizing costs/emissions vs. maximizing profit), they employed a fuzzy programming approach that determines a preferred compromise solution by maximizing the minimum degree of satisfaction for each goal. The model was applied to a realistic numerical example to demonstrate its validity and explore the effects of parameters like emission rates and recyclable capacities.
What	What was the research objective?	The research objective was to develop a practical and tractable fuzzy programming model for designing a green closed-loop supply chain network under uncertainty. The model aimed to simultaneously optimize four conflicting objectives: minimizing total transportation costs, minimizing total purchasing costs, minimizing greenhouse gas emissions, and maximizing total gained recycle profit. The study sought to investigate trade-offs between these economic and environmental goals and to demonstrate the model's applicability through a numerical case study.
	What thematic area did research cover?	The research covered the area of green closed-loop supply chain network design, with a focus on managing uncertainty and risks while considering trade-offs between operational and environmental performance measures.

4W1H	*Configured question*	*Description*
	What was the contribution of the research?	The research proposed a fuzzy programming model to manage uncertainty and risks in the green closed-loop supply chain network design while considering greenhouse gas emissions in a multi-objective structure. The study applied various multi-criteria decision-making techniques to weigh each objective and showed that the proposed model is practical and tractable. The research contributes to the literature by suggesting a fuzzy optimization approach to solve the supply chain network design problem.
	What was the limitation?	The research only considers CO2 emissions as the primary measure in assessing a supply chain's environmental performance, and other environmental concerns, such as waste reduction or water conservation, are not considered. The time complexity of the proposed model is not addressed, and it may become computationally challenging for large-scale problems.
	What future research areas were identified?	The authors suggest that future research should investigate different kinds of uncertainties and risks in supply chain network design. Developing efficient and exact or heuristic solution methods can be appealing in this area. Additionally, the authors recommend incorporating other environmental concerns and factors in the decision-making process.
When	When was the research conducted?	2012
Where	Where was the research conducted?	Türkiye

Source: Author's elaboration

Table 38. Redesign of a recycling system for LPG-tanks (H. M. le Blanc et al.)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study's goal was to modify the recycling system for liquefied petroleum gas (LPG) tanks to improve recycling efficiency and reduce the environmental effect of wasted LPG tanks.
How	How was the research conducted?	The study included the design and testing of a new recycling mechanism for LPG tanks. Using the case study method, technology was created to be more efficient and ecologically beneficial than traditional ways of recycling. The researchers ran several tests to evaluate the new system's performance and compared the findings to those obtained using the prior approach.

4W1H	***Configured question***	***Description***
What	What was the research objective?	The goal of the study was to examine the feasibility of a revised recycling system for LPG tanks, as well as to assess its performance in terms of efficiency, sustainability, and economic viability. The researchers wanted to find the best design and operating conditions for the system and make recommendations for its practical implementation.
	What thematic area did research cover?	The research covered the redesign of a recycling system for LPG tanks, specifically focusing on reverse logistics.
	What was the contribution of the research?	The study offered a new design for an LPG tank recycling system that combines reverse logistics, which might improve the LPG industry’s sustainability and efficiency. The study highlighted the important elements influencing system design and deployment and made recommendations for further research.
	What was the limitation?	The study was limited to a conceptual design, and it did not include a detailed analysis of the economic feasibility of the proposed system. Additionally, the research did not consider the perspectives of stakeholders, such as customers and suppliers, who may be affected by the proposed changes.
	What future research areas were identified?	Based on the outcomes of this study, future research might concentrate on further strengthening the reverse logistics network for LPG tanks, such as optimizing collecting routes and improving the recycling process’s efficiency. Additional potential study subjects may include comparing the environmental and economic consequences of the revised system to the existing system, as well as researching the feasibility of establishing similar recycling systems in other sectors.
When	When was the research conducted?	2004
Where	Where was the research conducted?	The Netherlands

Source: Author’s elaboration

Table 39. Analysis of the transport efficiency of reverse logistics in Japan (JongJin Yoona & Yiping Le)

4W1H	***Configured question***	***Description***
Why	Why was the study conducted?	The study was conducted to examine the transportation costs of reverse logistics for waste goods in Japan and identify solutions for improving transportation efficiency. The authors aimed to propose effective measures that could be implemented to improve the reverse logistics system in Japan.
How	How was the research conducted?	The research was conducted by analyzing government statistics and conducting a quantitative analysis of the characteristics of reverse logistics in Japan. The authors also examined the current situation of waste transportation and identified major issues, such as regulations related to waste disposal, the lack of a disposers' network, and the small scale of reverse logistics providers. The authors recommended policy incentives to cultivate large-scale logistics providers for the integration of reverse logistics chains.
What	What was the research objective?	The research objective was to identify effective solutions for improving the transport efficiency of reverse logistics for waste goods in Japan. The authors aimed to propose measures such as cooperative transportation and modal shift to marine and railway transportation to improve the transport efficiency of reverse logistics. The study also aimed to identify issues and underlying reasons that hinder the implementation of these measures in Japan.
	What thematic area did research cover?	The research covered the transport efficiency of reverse logistics in Japan.
	What was the contribution of the research?	The research identified the issues and underlying reasons for the inefficient reverse logistics system in Japan and proposed solutions for improving the transport efficiency of waste goods through cooperative transportation and modal shift to marine and railway transportation. The authors also recommended deregulation and policy incentives to cultivate large-scale logistics providers for the integration of reverse logistics chains.
	What was the limitation?	The study is limited to the Japanese context, and further specific studies based on the category of waste items might be necessary to identify the categories that are most suitable for cooperative transportation or modal shift to railway and marine transportation.

4W1H	*Configured question*	*Description*
	What future research areas were identified?	The authors suggested that future research could focus on identifying waste items that are suitable for cooperative transportation or modal shift, as well as practical ways to solve the issues of reverse logistics for waste management, such as deregulation and policy incentives to promote cooperative transport and modal shift.
When	When was the research conducted?	2013
Where	Where was the research conducted?	Japan

Source: Author's elaboration

Table 40. Reverse Logistics Network Structures and Design (Moritz Fleischmann)

4W1H	*Configured question*	*Description*
Why	Why was the study conducted?	The study was conducted to investigate the network structures and design of reverse logistics, which involves the processes of managing and controlling the flow of goods from the point of consumption back to the point of origin. The study aimed to identify the different network configurations that can be used to optimize reverse logistics processes and reduce environmental impacts while still maintaining economic viability.
How	How was the research conducted?	The research was conducted by developing a conceptual framework and typology for reverse logistics networks based on a literature review and quantitative analysis. The author proposed generic network types (e.g., bulk recycling, remanufacturing) and used Mixed Integer Linear Programming (MILP) models to analyse facility location and transportation decisions. The study evaluated the impact of product characteristics (such as value and volume) on network design through quantitative modeling rather than a single empirical case study.
What	What was the research objective?	The research objective was to identify the various network structures and designs that can be used to optimize reverse logistics processes while still maintaining economic viability and reducing environmental impacts. The study aimed to provide insights into the key factors that affect the design and configuration of reverse logistics networks, as well as the trade-offs between economic and environmental considerations in network design. The research aimed to provide recommendations for companies seeking to design and implement effective reverse logistics networks.

4W1H	***Configured question***	***Description***
	What thematic area did research cover?	The research covered the thematic area of reverse logistics network structures and design
	What was the contribution of the research?	The research made several contributions, including proposing a comprehensive model for designing reverse logistics networks and analyzing the impact of various factors on network design. The study also provided insights into the trade-offs between cost, environmental impact, and efficiency in designing reverse logistics networks.
	What was the limitation?	The study relies on a generalized typology and quantitative models rather than extensive empirical validation across multiple industries. While it provides a strategic framework, the optimal network design is shown to be highly sensitive to specific product characteristics and context, meaning the general conclusions require careful adaptation for specific real-world cases. Furthermore, the paper focuses primarily on the structure of the network (topology) and less on the dynamic operational aspects of inventory management.
	What future research areas were identified?	The author identifies the need for further research into the integration of forward and reverse logistics networks, specifically analyzing when combined networks are more beneficial than separate ones. Additionally, the paper suggests a deeper quantitative analysis of how specific product characteristics (such as value, volume, and perishability) influence the optimal choice of reverse logistics network structures, aiming to refine the proposed typology with more empirical validation.
When	When was the research conducted?	2001
Where	Where was the research conducted?	The Netherlands

Source: Author’s elaboration

3.4. Limitations and Research Gaps Identified in the Literature

The systematic literature review revealed several recurring limitations across the 35 studies examined. These limitations translate into clear theoretical, empirical, and methodological research gaps that collectively define the boundaries of existing knowledge on reverse logistics and waste management in the oil and gas industry. The following synthesis integrates both the limitations identified in prior research and the resulting gaps.

Several theoretical shortcomings were identified across the reviewed publications. A dominant limitation was the narrow conceptual scope of many studies, which focused on a single industry segment, a single type of waste, or a single element of RL. This restricted focus often led to incomplete theoretical frameworks, with many studies overlooking the interconnected nature of RL activities within broader supply chain and sustainability systems. Additionally, the literature frequently relied on subjective linguistic evaluations or expert judgments without establishing clear theoretical grounding, increasing the risk of conceptual bias.

A further theoretical limitation is the absence of defined standards for waste management in the oil and gas sector. This lack of codified frameworks creates inconsistencies in how RL and waste management practices are theorised and implemented, and it restricts the ability of scholars to develop universally applicable models. From these limitations emerge several theoretical gaps.

Theoretical gaps refer to the need for further research on theoretical concepts and frameworks that can provide a more comprehensive understanding about implementing reverse logistics during waste management operations in the oil and gas industry. In literature there is a lack about the practical implementation of reverse logistics strategies specifically tailored for the unique waste management challenges faced by the oil and gas sector (Naveed Wassan et al., 2019; Yoon and Le, 2013). This aligns directly with **RG1 – "The existing literature lacks comprehensive coverage on implementing reverse logistics during waste management operations in the oil and gas sector**". In addition to this, the literature also provides limited insight into how reverse logistics fits within the broader supply chain structure of the oil and gas sector, which restricts the development of integrated theoretical models. This reflects **"RG2 - There is limited research about the place that reverse logistics takes part in supply chain in oil and gas industry"**. Additionally, there is a lack of literature on the function and involvement of supply chain partners in waste management and reverse logistics operations in the oil and gas industry. This gap is consistent with **"RG3 - There is a shortage in literature about the role and engagement of supply chain parties in reverse logistics and waste management activities realized in oil and gas sector"**. Another important theoretical gap relates to the analysis of outsourcing within reverse logistics. Despite the prevalence of outsourcing in petroleum waste management, there is limited understanding of when, how, and to what extent outsourcing strategies can be applied. This corresponds directly to **"RG4 - Insufficient analysis of outsourcing opportunities for reverse logistics and waste management activities in the petroleum industry"**. Understanding the mechanisms and approaches for effective cooperation amongst various supply chain participants requires theoretical investigation. Moreover, within this theoretical realm, an essential avenue for exploration lies in understanding the efficiency of reverse logistics and the transformative role of digital technologies (Alkahtani et al., 2021; Engelseth, 2017; Prajapati et al., 2021). Investigating how digital technologies can effectively contribute to reducing greenhouse gas emissions and enhancing the overall efficiency of waste management operations adds a crucial layer to the theoretical understanding of supply chain management dynamics in the oil and gas industry. This need aligns directly with **"RG5 - A gap in the existing research landscape is the need for a comprehensive exploration of how Industry 4.0 technologies can be effectively harnessed to optimize**

waste management operations and streamline reverse logistics processes within the oil and gas industry's Supply Chain Management". Addressing this gap would provide deeper insights into how digitalization, automation, IoT, and other advanced technologies can be integrated into reverse logistics strategies to improve operational efficiency, sustainability, and decision-making in the petroleum sector. There is also a need for more research on different kinds of risks and uncertainties, and the development of efficient and exact or heuristic solution methods (Paksoy et al., 2012). Furthermore, there is a gap in the assessment of the environmental implications of waste management operations and the evaluation of the feasibility and advantages of implementing circular economy ideas in reverse logistics (Agrawal and Singh, 2020; Engelseth, 2017; Scorzelli et al., 2015).

On the other hand, **empirical gaps** point to the demand for further empirical data and study validation. Literature displays notable empirical limitations. Many studies suffer from small sample sizes, absence of primary data, or reliance solely on academic publications without integrating industry reports or practitioner perspectives. This lack of real-world evidence constrains the generalisability and practical relevance of findings (Agrawal et al., 2015; Gomes, 2010; Pokharel and Mutha, 2009). This limitation aligns directly with **"RG6 - The lack of empirical primary data, validation and limited sample size hinders understanding the practical implementation of reverse logistics during waste management in the oil and gas industry, potentially leading to incomplete insights into effective practices"**. Addressing this gap would provide more robust insights into how reverse logistics strategies are applied in practice, enhancing the practical relevance and generalizability of research findings. In addition, there is a significant gap concerning the design of reverse logistics networks specific to the oil and gas sector. This corresponds directly to **"RG7 - The literature is almost silent about designing reverse logistics network tailored for oil and gas industry"**. Addressing this gap requires empirical studies that investigate waste generation rates, consolidation points, transportation patterns, and contractor involvement, which are essential for developing effective and efficient reverse logistics networks in the petroleum industry. Furthermore, several studies only paid attention to one part of sustainability, namely, carbon emissions, while ignoring other crucial facets, including waste minimization and resource conservation (Reddy et al., 2020). This could lead to a limited view of sustainability and miss opportunities for waste management operational improvement. There is a lack of empirical study on the position reverse logistics has in the oil and gas industry's supply chain (Chen et al., 2021; Naveed Wassan et al., 2019). Empirical research would help to assess the level of integration of reverse logistics techniques within the oil and gas industry's supply chain and identify any potential gaps in the integration process. The lack of a study on developing reverse logistics networks for the oil and gas industry is another empirical gap in the literature. A thorough understanding of the waste management practices used by the sector, the rates of waste creation, and the geographic distribution of waste sources are necessary for the construction of a strong reverse logistics network.

The systematic literature review also identified methodological limitations that restrict the robustness of existing studies in reverse logistics and waste management within the oil and gas sector. The term "**methodological gaps**" describes the need for more study on the methodological elements of waste management in the oil and gas sector. The literature highlights a need for more comprehensive approaches that consider a broader range of variables and are grounded in real-world contexts for reverse logistics in oil and gas waste management (Naveed Wassan et al., 2019). This need corresponds directly to **“RG8 - The need for more comprehensive approaches that consider multiple variables in reverse logistics for oil and gas waste management”**. Addressing this gap requires research designs that capture the complexity of petroleum waste operations, including stakeholder interactions, regulatory constraints, geographic dispersion, and operational uncertainties. There is a limited methodological treatment of outsourcing, despite the centrality of outsourced waste operations in the petroleum industry. The reviewed literature provides little empirical or analytical guidance on estimating outsourcing costs, assessing contractor capabilities, or evaluating the operational and environmental implications of outsourcing decisions (Ordoobadi, 2009). Reverse logistics tasks can be outsourced to help the oil and gas sector manage waste while lowering operating costs and guaranteeing regulatory compliance. This highlights **“RG9 - Lack of a structured framework to assess outsourcing decisions in reverse logistics and waste management, including criteria for partner selection, compliance assurance, and performance monitoring in the oil and gas sector”**. Addressing this gap requires the development of structured, repeatable frameworks that guide decision-making for outsourcing while ensuring operational efficiency, regulatory compliance, and sustainability outcomes. There is a lack of practical guidance for determining the viability and efficiency of outsourcing reverse logistics tasks in the petroleum industry. To provide a consistent way for decision-making about outsourcing reverse logistics tasks, a structured framework for evaluating outsourcing prospects should be developed. A further methodological limitation is the lack of integration between RL models and digital or technological tools, despite widespread recognition that digitalization-IoT, software systems, optimization platforms, and real-time tracking-is essential for improving waste management performance. Most studies describe potential technologies but do not incorporate them into methodological frameworks, decision-support systems, or model validation. These methodological limitations and gaps collectively highlight the need for more rigorous, technology-enabled, and industry-specific research designs that can generate practical, scalable decision-support tools for advancing reverse logistics and waste management in the oil and gas sector.

4. Interview Process and Qualitative Data Analysis

The interview process involved conducting semi-structured interviews, a widely used qualitative research method that combines the flexibility of open-ended questions with the structured framework necessary for focused discussions (Adeoye-Olatunde and Olenik, 2021). This approach was ideal for exploring complex topics such as reverse logistics and waste management in the oil and gas industry, as it allowed participants to elaborate on their experiences while ensuring that the key themes relevant to the research objectives were covered systematically.

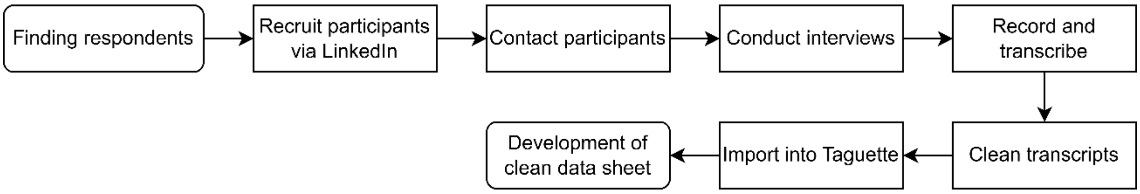
4.1. Recruiting Respondents

To ensure the empirical data captured the technical and strategic nuances of the industry, the recruitment of interview participants relied on a purposive sampling strategy. Unlike random or convenience sampling, this non-probability approach allowed for the deliberate selection of individuals possessing specific, high-value expertise relevant to the research objectives (Creswell, 2014; Palinkas et al., 2015). The study prioritized the depth and richness of information over simple statistical representativeness. Conditionally, the sample was comprised of professionals holding critical decision-making and operational roles across various levels of seniority and technical expertise. This targeted selection ensured that the data collected provided a comprehensive view of the subject matter, capturing diverse perspectives that are essential for building a robust, empirically grounded framework (Andrade, 2020; Etikan et al., 2015).

To identify and recruit participants, LinkedIn was utilized as the primary tool, leveraging its professional networking capabilities to locate individuals with relevant expertise in waste management and Reverse Logistics (RL) within the oil and gas industry. A targeted search was conducted using keywords such as “waste management”, “reverse logistics”, “health, safety and environment” and “Environment” combined with filters for company names including BP, ExxonMobil, Shell, TotalEnergies, Equinor, AA Services and SOCAR. Potential respondents were contacted via LinkedIn with a concise message outlining the study’s purpose, their potential contribution, and an invitation to participate in a 45-60-minute interview, ensuring ethical engagement and transparency. This approach resulted in twenty-two respondents for six case studies, providing a robust sample for qualitative analysis, aligning with Gentles et al. (2015), who recommend 4-10 cases for multiple case studies to avoid data saturation beyond comprehension. The interviews were conducted between February 2023 and January 2025, via virtual platforms such as Microsoft Teams or WhatsApp calls, with a minority conducted in-person at company offices, depending on participant availability and geographic location, with each session lasting 45-60 minutes to enable thorough discussions. Participants were assured of confidentiality and anonymity to foster trust and encourage candid responses, particularly on sensitive topics like regulatory compliance and operational challenges. With participants’ consent, all interviews were recorded with voice recording tools or Microsoft Teams’ auto-transcription feature, ensuring accurate capture of responses. The recordings were converted into verbatim transcriptions to preserve data integrity, resulting in raw transcripts for each of the twenty-two interviews. Transcription involved a dual process: initial drafts were generated using online tool - Riverside[1], followed by manual review to correct errors, as automated tools often misinterpret industry-specific terms like "drilling cuttings" or "hazardous waste streams". This ensured that transcripts accurately reflected participants' statements, capturing nuances in tone and context critical for qualitative analysis. Transcript cleaning was then performed to prepare the data, involving the removal of irrelevant content such as off-topic discussions (e.g., casual greetings), filler words (e.g., "um," "you know"), and repetitive phrases to enhance readability and focus on substantive content. For example, a statement like "Well, you know, we, um, we track waste… using a system" was cleaned to "We track waste using a system," preserving meaning while improving clarity. Identifiable information, such as names or proprietary systems, was anonymized (e.g., "Respondent A-1") to protect confidentiality, and timestamps and speaker labels were added to facilitate traceability during analysis. Data preparation followed, organizing transcripts for thematic analysis within a grounded theory framework. Transcripts were imported into Taguette[2], a qualitative data analysis software, to manage the textual data and facilitate systematic coding. Initial preparation involved reading transcripts to identify recurring themes that are aligning with the research questions. Coding occurred in three stages: open coding assigned initial codes (e.g., "Coordination," "Regulations"), axial coding connected codes into categories (e.g., "Stakeholder Collaboration"), and selective coding refined categories into core themes, from which key themes were identified ensuring alignment with the study's objectives. This process provided a robust foundation for analysing reverse logistics and waste management practices in the oil and gas industry.

To enhance the understanding of the methodological approach employed in this study, the flowchart presented below (**Figure 10**) provides a visual summary of the sequential steps involved in the process. It encapsulates the entire workflow, starting from the identification and recruitment of participants through LinkedIn, followed by the execution of semi-structured interviews, the transcription and subsequent cleaning of the recorded data, and concluding with the preparation and coding of transcripts in Taguette using a grounded theory framework. This visual representation illustrates the systematic and iterative process undertaken to investigate reverse logistics and waste management practices in the oil and gas industry, ensuring clarity and accessibility for readers seeking to grasp the methodology briefly.

Figure 10. Interview Data Collection



Source: Author's elaboration

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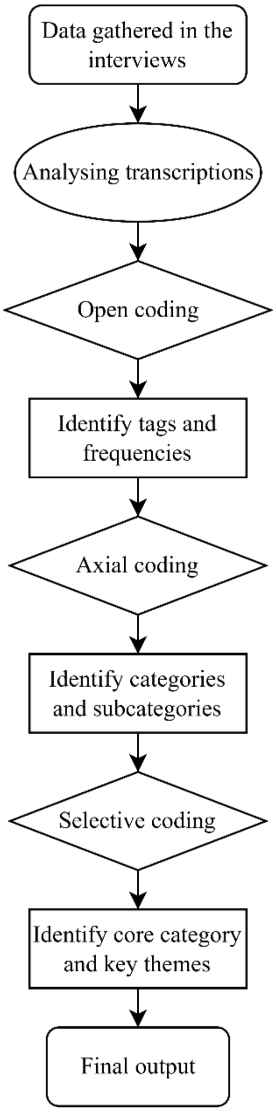
[1] Riverside.com is an AI-powered web-based tool that provides automated transcription of audio and video files, featuring speech-to-text conversion and speaker identification capabilities.

[2] Taguette (taguette.org) is a web-based qualitative data analysis tool used for organizing, coding, and managing textual data

Figure 11. Interview Data Coding Process



Source: Author's elaboration

Figure 11 illustrates the interview data coding process. The process began with analysing the transcripts in detail before conducting open coding to identify initial tags and their frequencies. These tags were then organised through axial coding, during which categories and subcategories were established based on relationships observed in the data. Selective coding followed, allowing the integration of these categories into core themes that reflect the central patterns emerging from the dataset. This structured, iterative approach ensured that the final themes were grounded in the empirical material and captured the key insights relevant to the study's research questions.

4.2. Introductory and Main Questions

Each interview began with warm-up questions aimed at establishing rapport and making the participants feel comfortable. For instance, the initial questions focused on the interviewees' roles in their respective organizations and their experience with waste management operations. This approach facilitated a natural flow of conversation and allowed the participants to ease into the more technical aspects of the discussion. Examples of warm-up questions included:

- "Could you describe your current role in waste management within your organization?"
- "How long have you been involved in reverse logistics and waste management?"
- "What motivates you to work in this field?"

These initial questions not only set the stage for a more in-depth exploration of the participants' expertise but also helped clarify their understanding of key concepts related to reverse logistics.

4.3. Main Interview Topics

The main body of the interviews focused on the key areas of reverse logistics and waste management. For instance, below topics were included:

- **Challenges in Waste Management**: Participants were asked about the operational challenges they face in implementing reverse logistics and waste management, such as handling hazardous waste, compliance with environmental regulations, and the logistical difficulties of managing waste disposal in offshore operations.
  - **Example Question**: "What are the most significant challenges your company faces in implementing reverse logistics and waste management for waste materials?"
- **Key Performance Metrics**: The interviewees were prompted to discuss the metrics they use to evaluate the effectiveness of their waste management systems. This included tracking the volume of waste recycled versus disposed, as well as performance indicators related to cost savings and environmental impact.
  - **Example Question**: "What key performance indicators do you utilize to measure the effectiveness of your waste management efforts?"

These questions provided a structured yet flexible framework that allowed participants to share their insights, challenges, and experiences in depth. At times, follow-up questions were introduced to further explore interesting points raised by the participants.

4.4. Interview Setting and Conduct

Due to geographical constraints and scheduling limitations, most of the interviews were conducted via video conferencing platforms. Each interview lasted between 45 minutes to one hour, depending on the availability of the participants. The use of video calls ensured that even participants located in different countries could be included in the research, thereby broadening the scope of perspectives gathered.

Participants were encouraged to speak candidly about the strengths and weaknesses of their companies' waste management practices. To facilitate this openness, confidentiality and anonymity were guaranteed, with all personal and organizational identifiers removed from the final analysis. This assurance of confidentiality was crucial in fostering a safe environment for discussing sensitive topics such as compliance challenges and financial constraints.

4.5. Challenges and Limitations of the Interview Process

While the interview process was successful in gathering rich qualitative data, several challenges and limitations were encountered:

- **Variability in Participant Responses**: Some participants provided highly detailed and technical responses, while others offered more generalized insights. For instance, senior managers tended to focus on strategic aspects of waste management, whereas operational staff discussed more practical, day-to-day challenges. This variability made it difficult to directly compare responses across all interviews.
- **Misunderstandings and Clarifications**: In a few instances, technical terms related to reverse logistics and waste performance metrics were not fully understood by some participants, necessitating further clarification. For example, when discussing "reverse logistics," some participants initially associated the term exclusively with the return of products rather than the broader concept of recycling and reusing waste materials within logistics systems.
- **Scheduling Difficulties**: Securing interview times with busy professionals in the oil and gas industry proved challenging. Some interviews had to be rescheduled multiple times due to the participants' limited availability, which slightly delayed the overall timeline of the data collection process.
- **Technological Issues**: While video conferencing was necessary due to geographical constraints, it presented occasional technical difficulties, such as poor internet connections, which affected the flow of a few conversations. These interruptions, while minimal, did impact the depth of discussion in some instances.
- **Limited Generalizability**: Given the small sample size and the purposive sampling method, the findings from the interviews may not be generalizable across the entire oil and gas industry. Instead, the data provides insights specific to the experiences of the selected participants, which may limit the external validity of the research. As Andrade (2020) highlights, purposive sampling often enhances internal validity but can impact the broader applicability of findings.
- **Data Privacy and Participant Engagement:** While reaching out to potential interviewees, significant hesitance and refusals were encountered, as many individuals were reluctant to engage due to concerns about sharing sensitive company data. This challenge highlighted the difficulties of accessing insights in organizational contexts where confidentiality is a primary concern.

Despite these challenges, the interview process was effective in gathering valuable qualitative insights into the complexities of waste management and reverse logistics in the oil and gas industry. By conducting semi-structured interviews, the research was able to explore both predefined topics and emergent themes, providing a rich source of data for analysis.

4.6. Data Recording and Analysis

All interviews were recorded with the participants' consent and later transcribed for thorough analysis. Thematic analysis was employed to identify recurring themes and patterns within the data. Keywords such as **"waste disposal"**, **"hazardous waste"**, and **"performance metrics"** were coded, and these codes were then categorized into broader themes such as **operational challenges**, **regulatory compliance**, and **technological innovations**. This coding process enabled the systematic identification of key insights across the interviews.

4.7. Ethical Considerations

The ethical dimensions of the interview process were carefully managed. Prior to each interview, participants were informed about the study's objectives, the use of their data, and their right to withdraw at any time. Written and verbal consent was obtained from all participants, and confidentiality was ensured through anonymization of the data. The interviews were conducted in accordance with the ethical guidelines set by the university, ensuring that all data was handled with respect and integrity.

The interview process played a crucial role in collecting in-depth qualitative data for this research. The semi-structured interview format allowed for flexibility while ensuring that key themes related to waste management and reverse logistics were thoroughly explored. Despite challenges such as variability in participant responses and scheduling difficulties, the interview data provided valuable insights that significantly contributed to understanding the complexities of waste management practices in the oil and gas industry. These insights will serve as a foundation for developing practical strategies to improve waste management efficiency and sustainability in the sector.

Table 41. Interview Portfolio Profile

Company	Interviewee code	Role Category	Interview Date	Experience	Age
Company A	A-1	Drilling Operations Management	11-12-24	15 years 11 months	44
	A-2	Environmental and social Advisory	28-11-24	11 months	34
	A-3	Commercial Project Management	10-01-24	4 years	38
Company B	B-1	Marine Engineering	03-03-24	1 year 5 months	34
	B-2	Drilling Supervision	18-03-24	2 years 10 months	40
	B-3	Marine HSE Supervision	18-11-24	1 year 2 months	32
	B-4	HSE Engineering	13-07-24	1 year 11 months	31
	B-5	Logistics Data Analysis	01-05-24	9 months	30
Company C	C-1	Environmental Science	29-09-24	1 year 6 months	35
	C-2	Waste Management Coordination	17-10-24	1 year	33
Company D	D-1	HSE Engineering	22-09-24	2 years 2 months	24
	D-2	HSE Operations	12-03-24	1 year 1 month	25
	D-3	Environmental Administration	08-03-24	11 months	27

Company	Interviewee code	Role Category	Interview Date	Experience	Age
	D-4	Environmental Engineering	28-04-24	3 years	27
Company E	E-1	QHSE Coordination	16-05-24	4 years 10 months	34
Company F	F-1	Environmental Engineering	15-11-24	1 year 9 months	38
	F-2	Petroleum Engineering	18-11-24	9 years 8 months	37
Company G	G-1	Financial Control	26-11-24	1 year 6 months	26
	G-2	HSE Engineering	25-12-24	1 year 7 months	36
	G-3	Waste Management Leadership	28-12-24	2 years 6 months	32
	G-4	Environmental Specialist	28-01-25	2 years	34
	G-5	Senior Directorate	14-02-23	6 years	36

Source: Author’s elaboration

The data presented provides a comprehensive overview of the age distribution and average work experience of the interviewees across various companies. This analysis is integral to the grounded theory and case study methodologies employed in this research, which aims to explore and develop theoretical insights into the topic. The age groups are categorized into three distinct ranges: 20-29 years (5 respondents), 30-39 (15 respondents) years, and 40-49 (2 respondents) years. The average age of the interviewees is calculated to be 33 years, indicating that the majority of the respondents are relatively young professionals, with a significant portion being in their early to mid-career stages. The average work experience of the respondents is noted to be 3 years, suggesting that the sample predominantly consists of individuals who are in the early stages of their professional careers, with a few having more experience.

The diverse range of positions held by the interviewees provides a comprehensive view of the organizational structure and the various roles that contribute to industry. Each position offers unique insights that are relevant to the research topic, allowing for a multifaceted analysis of the factors influencing reverse logistics and waste management in oil and gas companies. By integrating perspectives from these different roles through grounded theory-inspired coding, the research identifies recurring patterns and core categories to construct an empirically grounded framework that explains the phenomena related to the topic and provides practical recommendations for industry practices.

The geographic diversity of the participants further strengthens the representativeness and applicability of the study’s findings. Respondents were drawn from multiple countries, reflecting both developed and developing contexts. The countries represented include Albania, Algeria, Azerbaijan, Egypt, India, Indonesia, Kenya, Nigeria, Papua New Guinea, Uganda, United States.

The insights gained from these positions will contribute to the theoretical framework and practical recommendations that emerge from the study, ensuring that the research is grounded in real-world experiences and practices. This comprehensive approach will enhance the validity and applicability of the research findings, making them valuable for both academic and industry stakeholders.

4.8. Thematic Analysis of Interview Data

This chapter presents the thematic analysis of interview data gathered from twenty-two respondents across six oil and gas companies and one waste management solutions company, with the aim of identifying recurring patterns, challenges, and strategies in reverse logistics and waste management. The analysis followed the principles of grounded theory (Strauss and Corbin, 1998), employing a three-stage coding process: open coding, axial coding, and selective coding. This approach ensured that themes emerged inductively from the data while remaining connected to the research objectives and questions.

Open coding was first used to break down interview transcripts into discrete concepts (Strauss and Corbin, 1998), which were then grouped during the axial coding stage into broader categories that reflect systemic relationships between waste management practices (Glaser and Strauss, 1999). Finally, selective coding was applied to integrate the key categories into a core framework and identifying main themes, providing a holistic understanding of reverse logistics processes in the oil and gas sector.

The use of this method allowed for both descriptive and interpretive insights, capturing the complexity of industrial waste management in diverse contexts. It also ensured that findings were grounded in empirical evidence, while remaining aligned with existing theoretical perspectives. The following sections outline the results of each coding stage, beginning with open coding.

4.8.1. Open Coding and Tag Identification

Open coding is the first step in grounded theory analysis, where qualitative data is broken down into discrete concepts and assigned labels (Strauss & Corbin, 1998). This phase is fundamental in identifying patterns, themes, and recurring concepts within the data. For this study, open coding was applied to the interview transcripts to extract key themes related to waste management practices in the oil and gas industry. Tags were assigned based on the conceptual meaning of the data, allowing insights to emerge directly from the dataset rather than being influenced by pre-established categories.

Each interview transcript was carefully reviewed line by line, and distinct labels were assigned to segments of text that reflected various aspects of waste management. These tags included operational aspects such as **waste disposal**, **waste transportation**, **logistics**, and **procurement**, as well as more strategic considerations such as **regulatory adherence**, **performance metrics**, and **top management engagement**. Furthermore, challenges like **infrastructure limitations** and **communication barriers** were also coded to capture the constraints organizations face in optimizing their waste management processes.

In this process, 27 distinct tags emerged, capturing both the practical elements and challenges associated with waste management in the oil and gas sector. Each tag represented a unique concept identified within the data. Some of the most identified tags, such as **waste types** (78 mentions) and **challenge** (44 mentions) underscored key areas of focus in the industry. Other frequent tags like **awareness** (18 mentions), **recycling** (17 mentions), and **reduce the waste** (17 mentions) highlighted the industry's emphasis on sustainability and waste reduction.

Table 42. Open coding

Tags	Count of tag
Audit	7
Awareness	18
Challenge	44
Communication	10
Coordination	10
Forecasting	18
HSE (Health, Safety&Environment)	13
Incentivized Recycling	12
Infrastructure	9
KPI	22
Monitoring	11
Outsourcing	23
Planinning	28
Procurement	4
Recycle	17
Reduce the waste	17
Regulations	9
Reuse	10
Software and tools	11
Suggestions for improvement	28
Supplier Sustainable Enforcement	3
Top management engagement	3
Waste disposal	24
Waste transportation	27
Waste types	78

Source: Author's elaboration

4.8.2. Axial Coding and Categorization of Themes

The axial coding phase refines and reorganizes the initial codes from the open coding process to develop thematic categories that reflect systemic interconnections in reverse logistics and waste management within the oil and gas industry. This phase follows Strauss and Corbin's (1998) grounded theory approach, which emphasizes the identification of relationships among concepts to form a structured analytical framework. The categories were developed to reflect research objectives and focus on identifying challenges, inefficiencies, and opportunities for improvement in reverse logistics and waste management operations in oil and gas companies.

Axial coding is a critical phase in qualitative research as it moves beyond the fragmented nature of open coding by establishing connections between concepts and defining their relationships (Glaser and Strauss, 1999).Through this process, higher-order themes emerge, allowing for a structured and meaningful interpretation of data. In this study, axial coding was applied to categorize and connect 25 key tags derived from the interview data, forming a conceptual framework that captures the dynamics of waste management in the oil and gas industry.

The coding structure is designed to balance conceptual clarity with practical relevance by incorporating industry-specific waste management themes. Each category was selected based on three core principles:

1. Relevance to the oil and gas sector-the categories reflect specific challenges and strategies used by oil and gas companies to manage waste, ensuring practical applicability.
2. Conceptual interconnectivity-categories were developed to ensure logical relationships among themes, avoiding isolated classifications and instead focusing on systemic linkages.
3. Theoretical grounding-the structure aligns with existing waste management frameworks, sustainability models, and regulatory considerations, ensuring academic rigor and empirical validity.

The four main categories-Waste Diversity and Handling, Operational Waste Management Strategies, Compliance and Performance, and Influencing Factors were selected based on their frequency, conceptual importance, and systemic relationships. These categories represent distinct yet interconnected components of industrial waste management, ensuring a comprehensive understanding of waste handling processes while also identifying gaps, challenges, and opportunities for improvement.

4.8.2.1. Waste Diversity and Handling

The first category, Waste Diversity and Handling, captures the identification, classification, and disposal of waste. This category is crucial because different waste types require distinct handling processes, dictated by regulatory, environmental, and operational constraints(Yuzvovich et al., 2024). The inclusion of waste types and disposal reflects the industry's need to adhere to strict classification standards to avoid environmental contamination and ensure compliance with government regulations.

The proper identification of waste types is fundamental to determining the appropriate handling methods, disposal techniques, and potential for reuse or recycling. Misclassification of waste can result in regulatory violations, financial penalties, and environmental hazards, making this category a foundational element of waste management. Additionally, collection and disposal processes must be efficient and compliant with environmental and safety standards, ensuring minimal ecological impact (Lebedev and Cherepovitsyn, 2024).

4.8.2.2. Operational Waste Management Strategies

This category focuses on strategic and logistical aspects of waste management, including waste reduction strategies, reverse logistics operations, and forecasting and strategic planning. These elements were grouped together because they share a common objective: enhancing operational efficiency while minimizing waste generation and disposal costs (Daher et al., 2006; Sheriff et al., 2012).

- Waste Reduction Strategies: Recycling, reusing, and reducing waste are critical for sustainability and cost-efficiency in the oil and gas sector. Companies focus on minimizing waste generation at the source while implementing innovative approaches for reusing and repurposing materials.

- Reverse Logistics Operations: Involves the return, repurposing, and disposal of materials in a way that minimizes waste. The inclusion of outsourcing and coordination under this subcategory highlights the role of external vendors and supply chain management in waste handling.
- Forecasting and Strategic Planning: Accurate forecasting and proactive planning are essential for waste management, ensuring that companies anticipate waste production patterns and optimize resource allocation accordingly. By integrating software and tools, organizations can enhance efficiency, streamline waste tracking, and improve reporting mechanisms.

Procurement was included in this category because sustainable procurement practices directly influence waste reduction efforts, particularly in industries with high material consumption like oil and gas. The selection of eco-friendly, reusable, or recyclable materials during procurement plays a pivotal role in waste minimization efforts.

4.8.2.3. Compliance and Performance

The Compliance and Performance category addresses regulatory adherence, safety measures, and performance monitoring. Given the stringent environmental regulations governing the oil and gas sector (EPA, 2023), this category highlights key performance indicators (KPIs), audits, and monitoring mechanisms that companies implement to ensure compliance.

- Regulatory Adherence: Ensuring alignment with local, national, and international regulations is a fundamental component of waste management. The inclusion of regulations and health, safety, and environmental (HSE) considerations in this category reflects the industry’s reliance on compliance-driven operational frameworks.
- Performance Metrics: KPI monitoring and audits provide quantifiable measures to evaluate waste management effectiveness. Continuous monitoring allows organizations to assess performance trends, detect inefficiencies, and implement corrective measures.

This category reflects the industry’s focus on continuous improvement and risk mitigation, as seen in safety and health regulations (HSE) that influence waste management policies (Williams et al., 2019).

4.8.2.4. Influencing Factors

The Influencing Factors category was developed to capture both enablers and constraints affecting waste management outcomes.

- Enablers: Factors such as awareness, communication, top management engagement, incentivized recycling, and supplier sustainability enforcement play a pivotal role in promoting effective waste management. Awareness campaigns and training programs can significantly impact employees’ ability to handle waste responsibly, while management engagement ensures resource allocation and policy enforcement.

- Constraints: Challenges and infrastructure limitations were categorized as constraints, as they impede effective waste management implementation. Companies often struggle with insufficient infrastructure, logistical bottlenecks, and financial constraints, which hinder their ability to adopt sustainable waste management practices.
- Opportunities: The inclusion of suggestions for improvement under opportunities ensures that the coding framework remains solution-oriented, identifying potential pathways for enhancing waste handling processes. Recommendations for improving recycling infrastructure, investment in technology, regulatory incentives, and the adoption of software and tools are among the key opportunities for strengthening waste management strategies.

The selected categories do not function in isolation but rather form an integrated system. For example:

- Waste reduction strategies (Operational Waste Management Strategies) are heavily influenced by regulatory adherence (Compliance and Performance), which in turn is shaped by awareness and communication (Influencing Factors).
- Waste transportation and outsourcing (Operational Waste Management Strategies) are constrained by infrastructure limitations (Influencing Factors).

By structuring the data through axial coding, this study establishes a clear linkage between waste handling practices, strategic decision-making, regulatory compliance, and influencing factors.

This structured framework provides the foundation for selective coding, where a core category will emerge, integrating the findings into a cohesive theoretical model for industrial waste management.

Table 43. Axial coding

Category	**Subcategory**	**Tags (frequency)**
Waste Diversity and Handling	Waste Identification	Waste Types
	Waste Management	Waste Disposal
Operational Waste Management Strategies	Waste Reduction Strategies	Recycle, Reuse, Reduce the waste, Procurement
	Reverse Logistics Operations	Waste Transportation, Outsourcing, Coordination
	Forecasting & Strategic Planning	Forecasting, Planning
Compliance and Performance	Regulatory Adherence	Regulations, HSE
	Performance Metrics	KPI, Monitoring, Audit

Category	Subcategory	Tags (frequency)
Influencing Factors	Enablers	Awareness, Communcation, Top management engagement, Incentivized Recycling, Supplier Sustainability Enforcement
	Constraints	Challenge, Infrastructure
	Opportunities	Suggestions for improvement, Software and tools

Source: Author's elaboration

4.8.3. Selective Coding and Development of Core Category

Following the axial coding phase, which organized the 25 tags into four main categories-Waste Diversity and Handling, Operational Waste Management Strategies, Compliance and Performance, and Influencing Factors, key themes were identified from the axial subcategories to provide a deeper understanding of the central phenomenon under study. These themes were derived by examining the interconnections among subcategories, focusing on the most prominent and recurring patterns that explain how RL operates within this context. The identified key themes are as follows:

- The Importance and Role of Reverse Logistics in Supply Chain Operation
- Structuring Reverse Logistics Processes for Maximum Efficiency
- Stakeholder Collaboration and Interdepartmental Coordination
- Outsourcing as a Strategic Decision in Reverse Logistics
- Addressing Barriers to Reverse Logistics Implementation
- The Role of Technology in Advancing Reverse Logistics and Waste Management

These key themes will be comprehensively explored and analysed in the "Results and Discussion" section.

As a result of selective coding, the core category, **"Optimizing Reverse Logistics (RL) for Sustainable and Efficient Waste Management in the Oil and Gas Industry"** was identified and it encapsulates the central narrative of this study, reflecting the strategic and multifaceted process through which oil and gas companies manage waste streams to achieve both sustainability and operational efficiency. This core category emerged through the grounded theory methodology, as outlined by Glaser and Strauss (1999), integrating insights from the twenty-two semi-structured interviews conducted with industry specialists. These interviews were specifically designed to align with the research questions and objectives, which sought to investigate the significance of RL, the challenges encountered in its implementation, and the opportunities for enhancing waste management practices within the oil and gas sector. As a result, the core category directly corresponds to the thesis topics, emphasizing the dual focus on sustainability and efficiency as critical pillars of RL optimization in this industry.

At its essence, the core category highlights how reverse logistics serves as a pivotal mechanism for transforming waste management from a linear, disposal-focused process into a circular, value-creating system. In the oil and gas industry, where operations generate diverse and often hazardous waste streams-such as drilling cuttings, radioactive mud, and medical waste, RL provides a structured framework for managing these materials through reuse, recycling, or proper disposal. This process not only mitigates environmental impact but also aligns with global sustainability goals, such as reducing landfill use and promoting circular economy principles. The emphasis on sustainability within the core category is evident in the dataset, with tags like *Reuse* (10) and *Recycle* (17) reflecting the industry's commitment to minimizing waste through resource recovery. For instance, practices like repurposing drilling cuttings as gravel for road construction or returning chemical containers to suppliers demonstrate how RL enables companies to close the loop in their supply chains, reducing the need for virgin materials and lowering their environmental footprint.

Simultaneously, the core category underscores the importance of operational efficiency in RL, recognizing that the oil and gas sector operates in a high-stakes, capital-intensive environment where cost management and logistical precision are paramount. The high frequency of the tag - *Waste* Transportation (27) in the dataset highlights the critical role of efficient transportation and coordination in managing waste across geographically dispersed locations, often under challenging conditions like unstable weather in the Caspian Sea. RL optimization, as captured by the core category, involves streamlining these logistical processes to ensure that waste is moved, treated, and disposed of in a timely and cost-effective manner. This focus on efficiency not only reduces operational costs-such as disposal fees and transportation expenses-but also minimizes disruptions to core activities like drilling and production, allowing companies to maintain operational continuity while adhering to environmental standards.

A key aspect of the core category is its emphasis on balancing sustainability and efficiency with regulatory compliance, a non-negotiable requirement in the heavily regulated oil and gas industry. The tag *Regulations* (9) reflects the stringent environmental mandates companies must navigate, such as ISO 14001 standards and local government requirements for hazardous waste disposal. RL optimization, as defined by the core category, involves integrating compliance into waste management processes, ensuring that all activities, from transportation to disposal, meet legal and safety standards. This alignment with regulations not only helps companies avoid fines and reputational damage but also reinforces their commitment to environmental stewardship, a critical factor in maintaining their social license to operate. The core category thus positions RL as a strategic tool for achieving compliance while simultaneously advancing sustainability and efficiency goals, creating a holistic approach to waste management.

The core category also acknowledges the dynamic interplay of challenges and opportunities inherent in RL optimization. The high frequency of Challenge (44) in the dataset indicates that RL implementation is not without obstacles, including regulatory complexities, infrastructural limitations, and logistical constraints. However, the core category frames these challenges as opportunities for innovation and improvement, encouraging companies to adopt proactive strategies such as technology adoption, stakeholder collaboration, and strategic outsourcing. For example, the use of software tools to track waste movement or the collaboration with local communities to repurpose compost reflects how RL optimization can turn barriers into avenues for creating value, both environmentally and socially. This forward-looking perspective embedded in the core category highlights its relevance to the oil and gas industry, where innovation and adaptability are essential for addressing the evolving demands of sustainability and operational performance.

Furthermore, the core category reflects the systemic nature of RL optimization, recognizing that sustainable and efficient waste management requires an integrated approach that spans multiple dimensions of the supply chain. It connects the logistical, regulatory, and sustainability aspects of RL into a cohesive framework, emphasizing that success in waste management depends on the alignment of these elements. For instance, efficient transportation systems must be paired with sustainable practices like recycling, and both must comply with regulatory requirements to achieve the desired outcomes. The core category thus serves as a unifying concept that ties together the various facets of RL, providing a comprehensive lens through which to understand and improve waste management practices in the oil and gas industry.

In conclusion, the core category of "Optimizing Reverse Logistics (RL) for Sustainable and Efficient Waste Management in the Oil and Gas Industry" offers a robust framework for understanding the strategic role of RL in this sector. It captures the dual imperative of sustainability and efficiency, highlighting how RL enables companies to manage waste responsibly while optimizing operational performance and ensuring regulatory compliance. By framing RL as a systemic and innovative process, the core category aligns with the research objectives and provides a foundation for both theoretical contributions and practical recommendations. It underscores the transformative potential of RL in redefining waste management, positioning it as a critical driver of environmental, economic, and social value in the oil and gas industry.

5. Case Studies

This chapter presents the empirical findings derived from a multiple-case study analysis of six organizations within the oil and gas sector. Building upon the theoretical framework and qualitative coding process established in previous chapters, this section provides a detailed examination of reverse logistics and waste management practices across five leading international oil and gas companies-BP, Equinor, ExxonMobil, Shell, and TotalEnergies, and the State Oil Company of Azerbaijan Republic (SOCAR), representing the developing country context. The chapter begins by establishing the methodological foundation for the case study development, detailing the protocols for selecting organizations and interview participants, as well as the data triangulation techniques used to ensure validity. Subsequently, individual case narratives explore each company's operational context, reverse logistics and waste handling strategies, and sustainability initiatives, offering the detailed evidence necessary to address the study's research questions and inform the comparative analysis.

5.1. Methodology for Multiple Case Study Development

The adoption of a multiple-case study design was driven by the need to capture the operational realities of reverse logistics and waste management in the oil and gas industry. As noted by Yin (2003) and Mills et al. (2010), this methodological choice facilitates a comprehensive inquiry into complex industrial phenomena, moving beyond surface-level observation to understand the underlying mechanisms of reverse logistics. Furthermore, it also makes it possible to identify both shared patterns and distinct differences across cases, leading to a clearer and more comprehensive understanding of the research topic. By integrating perspectives from various organizational and geographical settings, the study identifies opportunities for improvement and highlights best practices in reverse logistics and waste management.

To ensure the findings are robust and analytically rich, the study employs a multi-method qualitative strategy. This approach provides the necessary flexibility to navigate the intricate logistics and regulatory landscapes of the sector (Köhler, 2024; Patton, 2002). The construction of each case study relied on two complementary streams of evidence:

1. **Primary Data:** The core empirical data was obtained from twenty-two semi-structured interviews with managers, coordinators, and industry specialists (the methodology of interviews was explained in Chapter 4). This method was chosen for its ability to elicit both structured and naturally emerging insights into operational realities (Adeoye-Olatunde and Olenik, 2021).
2. **Secondary Data:** Primary data was supplemented and verified by an extensive review of secondary sources. This included the analysis of company sustainability reports, operational documents, and publicly available information. This combination of sources allowed for the cross-verification of interview responses against official corporate data, strengthening the credibility of the findings and enabling the study to capture both shared practices and context-specific variations.

The integration of these sources enabled a protocol of data triangulation, minimizing researcher bias and strengthening the validity of the case narratives by ensuring that reported practices were verified against operational insights.

5.2. Selection of Case Studies

This selection provides a comparative lens. The first five companies are recognized as leading oil and gas companies operating in developed and global contexts. In contrast, SOCAR represents a prominent oil and gas company operating within the developing country context of Azerbaijan. This distinction allows the research to capture both globally standardized practices and the specific challenges related to emerging markets, facilitating the identification of best practices applicable across diverse operational settings.

The organizations included in this multiple-case study were selected based on their strategic relevance to the research objectives and their diverse operational contexts. The primary criterion was to identify leading international corporations with established waste management systems to serve as industry benchmarks, alongside a significant national entity operating within a developing economy. This deliberate selection was intended to facilitate a comparative analysis and to identify which advanced strategies employed by global leaders could be effectively adapted and applied within developing operational environments.

Consistent with methodological recommendations for multiple case study designs, this study selected six cases. This falls within the recommended range of 4 to 15 cases suggested by Gentles et al. (2015) and Sarfo et al. (2021) to ensure manageable engagement for the researcher while maintaining a manageable scope for analysis. The study presents case studies of the following companies:

1. BP
2. Equinor
3. ExxonMobil
4. Shell
5. TotalEnergies
6. SOCAR

This composition provides the necessary comparative lens: the first five organizations represent major international oil companies operating in developed and global contexts, while SOCAR represents a prominent national oil company operating within the specific developing country context of Azerbaijan.

5.3. Data Analysis and Research Rigor

The analysis of the empirical material followed a structured qualitative approach designed to ensure analytical depth and methodological transparency. Consistent with established case study procedures (Yin, 2003; Eisenhardt, 1989), the interview transcripts and secondary data sources were examined systematically to construct coherent and comparable case narratives. Grounded-theory-inspired coding techniques were applied to organise and interpret the material, allowing themes to be developed inductively while maintaining alignment with the predefined structure of the case studies.

Following the protocols outlined by Strauss and Corbin (1998), the coding process unfolded in three stages. First, open coding was used to identify relevant concepts and recurring ideas within the interview accounts. Second, axial coding allowed these initial codes to be linked and clustered into broader thematic categories connected to reverse logistics and waste management practices, such as waste identification, transportation and consolidation processes, contractor management, and regulatory compliance. Finally, selective coding helped refine thematic interpretations and ensured internal coherence across the case study descriptions and the cross-context comparative analysis.

To enhance research rigor, several procedures associated with qualitative validity were incorporated. Methodological triangulation was applied through the integration of primary interview data with sustainability reports, operational documents, and other publicly available company materials (Patton, 2002). This triangulation reduced the risk of bias associated with single-source data and strengthened the credibility of the resulting case narratives. As recommended for capturing both structured and naturally emerging insights (Adeoye-Olatunde and Olenik, 2021), the use of semi-structured interviews further contributed to the richness and reliability of the empirical base.

The analytical process also incorporated elements of reflexivity. Interpretations were revisited iteratively to ensure alignment with the data, and care was taken to limit the influence of researcher assumptions during coding and theme development. In addition, the systematic documentation of coding decisions, analytical steps, and case construction procedures contributed to transparency, following recommendations for rigorous qualitative analysis (Miles and Huberman, 1994).

By combining structured coding procedures, triangulation, reflexive analytical practices, and consistent cross-context comparison, the study ensured that the case studies presented in this chapter are empirically grounded, credible, and analytically robust. With this analytical foundation established, the following subsections provide the case studies for each of the six companies.

5.4. BP's Waste Management Practices

BP, a global leader in the oil and gas industry operating in over seventy countries, plays a critical role in energy exploration, production, and distribution, while increasingly addressing environmental sustainability challenges (BP, n.d.). Its extensive operations generate significant waste, including hazardous materials, prompting the adoption of comprehensive waste management practices that align with reverse logistics principles, focusing on reduction, reuse, and recycling across its supply chain (BP, n.d.).

In BP's operational strategy, the Life Cycle Approach (LCA) plays a pivotal role by addressing waste generation at each stage of the production process (BP, 2019, p. 29). Life Cycle Assessment is a methodology used to evaluate the environmental impacts of a product, service, or process throughout its entire life cycle, from production to disposal. Standards like ISO 14040 and 14044 provide frameworks for conducting these studies. LCA has been widely applied to areas like plastics and waste management to assess environmental performance and end-of-life options (Oliveira and Magrini, 2017). LCA allows for evaluating the environmental impacts during a product's entire lifecycle, aiding in the development of more sustainable products. The life cycle inventory involves gathering data and conducting calculations to assess the inputs and outputs of the system being studied. The life cycle impact assessment then analyses key environmental impact indicators and categories. In the interpretation stage, the results are carefully reviewed for completeness, consistency, and sensitivity, while their accuracy and potential uncertainties are also evaluated (Lee et al., 2024). This approach allows BP to implement targeted strategies that mitigate waste before it becomes an environmental burden. This approach not only helps BP reduce its environmental footprint but also aligns with the core principles of reverse logistics, which focus on recovering materials and feeding them back into the supply chain.

BP's 2023 Sustainability Report underscores the company's commitment to integrating circular economy principles into its operations, especially through the creation of new focus areas designed to enhance waste management practices (BP Sustainability Report, 2023). The circular economy, which prioritizes the prolonged utilization of resources, intersects closely with reverse logistics. Both paradigms advocate for the continual recirculation of materials within the production cycle, thereby curbing the need for virgin raw materials and minimizing waste.

BP's dedication to sustainability is further evidenced by its deployment of advanced technologies aimed at optimizing waste management processes. For instance, the company's adoption of flare efficiency software and predictive emissions monitoring systems has been instrumental in maintaining a methane intensity of just 0.05% (BP Sustainability Report, 2023). Such technologies are crucial to an effective reverse logistics framework, enabling the capture and repurposing of emissions that might otherwise exacerbate environmental degradation.

The following tables and chart present BP's reported data on hazardous and non-hazardous waste generation, recovery, recycling, and disposal. The data is categorized by operational segments and waste types to provide a structured overview of BP's waste management performance.

Table 44. Waste management report of BP (2019-2023)

Waste	**Unit**	**2019**	**2020**	**2021**	**2022**	**2023**
Hazardous waste generated (excluding deepwell)	kt		133.7	156.5	153.6	177
Hazardous waste recovered – recycled offsite (excluding deepwell)	kt		53.1	59.1	76.4	87.7
Exploration, production and LNG	kt			20.3	18.8	26.8
Refining and chemicals	kt			33.8	47.8	49
Other	kt				9.7	11.8
Hazardous waste disposed (excluding deepwell)	kt	142.6	80.6	97.4	77.2	89.3
Exploration, production and LNG	kt			19.6	18.1	30.6
Refining and chemicals	kt			65.5	49.7	49.3
Other	kt				9.4	9.4
Non-hazardous waste generated	kt	491.1	406.3	370.1	393.2	317.6

Waste	**Unit**	**2019**	**2020**	**2021**	**2022**	**2023**
Non-hazardous waste recovered – recycled offsite	kt	262.8	203.2	194.5	165.7	164.9
Exploration, production and LNG	kt			14.6	15.7	12.7
Refining and chemicals	kt			157.3	125.1	129.8
Other	kt				24.9	22.4
Non-hazardous waste disposed offsite	kt	228.3	203.1	175.6	227.6	152.7
Exploration, production and LNG	kt			63.2	108.6	31.8
Refining	kt			83.5	102.9	105.4
Other	kt				16.1	15.5
Rate of waste recycled or recovered	%					51

Source: BP, 2023. ESG datasheet 2023, p. 9. Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/sustainability/group-reports/bp-esg-datasheet-2023.pdf

Figure 12. Report on Disposed Waste by BP (2019-2023)

Source: BP, 2023. Sustainability Report 2023, p. 50. Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/sustainability/group-reports/bp-sustainability-report-2023.pdf

Figure 13. Recycled or recovered waste by BP (2020-2023)

Source: BP, 2023. Sustainability Report 2023, p. 50. Available at:

https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/sustainability/group-reports/bp-sustainability-report-2023.pdf

BP's data reveals key trends in hazardous and non-hazardous waste management over the last few years:

- Hazardous Waste: The amount of hazardous waste generated by BP increased from 153.6 kt in 2022 to 177.0 kt in 2023. However, there was also a significant increase in the amount of hazardous waste that was recovered and recycled offsite, from 76.4 kt in 2022 to 87.7 kt in 2023. This suggests that BP is not only focused on reducing the generation of hazardous waste but is also increasingly committed to recovering and recycling more of it, thereby minimizing environmental impacts.
- Non-Hazardous Waste: Non-hazardous waste generated by BP decreased significantly from 393.2 kt in 2022 to 317.6 kt in 2023. Despite the reduction in waste generation, the rate of recycling non-hazardous waste remained steady, which indicates a strong emphasis on waste recovery and recycling practices within BP's operations.

BP's approach to managing both hazardous and non-hazardous waste aligns closely with the principles of reverse logistics. By focusing on recovering and recycling waste, BP effectively reintegrates materials back into the supply chain, reducing the need for raw material extraction and minimizing waste disposal. This process is a clear example of reverse logistics in action, where waste products are systematically managed to reduce their environmental footprint.

The steady increase in hazardous waste recovery and recycling rates illustrates BP's commitment to integrating circular economy principles within its operations. By recovering more waste and repurposing it, BP is moving towards a more circular model of resource use, where materials are kept in use for as long as possible. This not only reduces waste but also contributes to the company's overall sustainability goals. Other companies in the oil and gas industry can adopt similar practices by developing robust reverse logistics systems that focus on maximizing the recovery and reuse of waste materials. Implementing advanced technologies and improving waste sorting and recycling processes can further enhance these efforts, leading to better environmental performance and compliance with increasingly stringent environmental regulations.

BP's data on waste management provides valuable insights into how reverse logistics can be effectively applied in the oil and gas industry. The trends observed in hazardous and non-hazardous waste management at BP underscore the importance of recovering and recycling materials as part of a broader sustainability strategy. By adopting and expanding these practices, BP and other companies in the industry can reduce their environmental impact, align with circular economy principles, and achieve significant cost savings.

5.4.1. Findings from Interviews (BP)

After conducting interviews specialists from BP working in Oil and Gas field, valuable insights were obtained regarding BP's waste management strategies, operational challenges, and opportunities for improvement. This section presents insights from interviews with BP specialists, structured by key topics to highlight common themes.

5.4.1.1. Awareness Levels Within the Company and Among Stakeholders at BP

The awareness level regarding waste management within BP appears to be notably high among internal stakeholders but varies significantly among external parties. The company has made significant strides in embedding waste management principles within its operational culture, ensuring compliance with stringent environmental standards. However, challenges persist in extending this awareness to external stakeholders, particularly contractors and regulatory bodies, necessitating continuous engagement and advocacy efforts.

Internally, BP has cultivated a strong culture of waste management awareness, emphasizing compliance, sustainability, and operational efficiency. Respondent A-3 emphasized that BP demonstrates one of the highest levels of awareness regarding waste management among companies they have worked with. This commitment is evident in the company's strict enforcement of waste management policies-if a project lacks a proper waste management plan, operations can be halted until all necessary infrastructure, including waste bins, segregation systems, and disposal mechanisms, are properly established (Respondent A-3). This proactive approach ensures that waste management is not treated as an afterthought but is integrated into BP's core operational framework from the outset.

To reinforce awareness, BP implements mandatory training sessions for employees at all levels, focusing on best practices in waste handling, regulatory compliance, and sustainability initiatives (Respondent A-1). These training programs are regularly updated to reflect emerging environmental policies and industry's best practices. Additionally, BP encourages employee participation in sustainability initiatives, such as waste reduction campaigns and recycling programs, to foster a culture of personal responsibility toward environmental stewardship (Respondent A-2). By embedding these practices into daily operations, BP ensures that awareness is not only theoretical but also actively practiced across its workforce.

Externally, however, awareness among contractors, subcontractors, and local governmental authorities remains inconsistent. Respondent A-3 pointed out that while contractors generally comply with baseline regulatory requirements, they often resist exceeding compliance standards due to financial constraints. Many contractors view additional sustainability measures as costly burdens rather than value-adding initiatives, which can lead to minimal engagement beyond the bare minimum required by law (Respondent A-3). This reluctance presents a significant challenge, as waste management in oil and gas operations requires a collective effort across the supply chain to be truly effective.

Similarly, local government agencies demonstrate only a fundamental level of awareness, focusing primarily on regulatory enforcement rather than proactive sustainability efforts (Respondent A-2). While BP remains compliant with national and international environmental laws, the lack of progressive regulatory enforcement from local authorities means that opportunities to implement higher waste management standards are sometimes overlooked. Respondent A-1 noted that BP actively engages with governmental bodies to promote stronger regulatory frameworks and encourages policies that incentivize best practices in waste management.

To address these external awareness gaps, BP has taken proactive steps by engaging with contractors through training sessions, awareness programs, and compliance workshops (Respondent A-1). These efforts are designed to bridge the gap between regulatory compliance and best-in-class waste management practices, ensuring that all parties involved in BP's operations align with its sustainability objectives. Additionally, BP has begun implementing contractual obligations that require contractors and suppliers to demonstrate waste management capabilities before being awarded projects (Respondent A-2). This strategic approach ensures that sustainability is not an optional consideration but rather a fundamental prerequisite for collaboration.

Furthermore, BP is investing in digital waste tracking systems to enhance transparency and accountability in its waste management operations (Respondent A-3). These digital tools allow the company to monitor waste generation, transportation, and disposal in real-time, ensuring that both internal and external stakeholders comply with waste management protocols. By leveraging data-driven insights, BP can identify inefficiencies, track non-compliance, and implement corrective measures promptly.

Looking ahead, BP aims to further strengthen its engagement with external stakeholders by introducing more structured sustainability workshops, collaborative waste management projects, and performance-based incentives for contractors who demonstrate excellence in waste management (Respondent A-3). The company is also advocating for stronger regulatory policies that encourage higher environmental standards across the oil and gas industry. Through these initiatives, BP seeks to ensure that awareness of waste management extends beyond its internal operations, fostering an industry-wide commitment to sustainability and responsible resource management.

In conclusion, while BP has successfully established a high level of waste management awareness internally, significant work remains in elevating external awareness among contractors and governmental bodies. By continuing to engage, educate, and enforce compliance, BP is positioning itself as a leader in sustainable waste management within the energy sector, driving both operational efficiency and environmental responsibility across its global operations.

5.4.1.2. Waste Disposal and Handling Strategies at BP

BP has established cuttings reinjection as its preferred method for waste disposal, prioritizing environmentally responsible waste management whenever reinjection wells are available. This practice effectively reduces shoreline disposal needs, ensuring a lower environmental footprint (Respondent A-1). However, in cases where reinjection is not feasible, BP utilizes alternative waste disposal methods, such as cuttings boxes (skips), which allow for the offshore collection of waste before transporting it onshore for proper treatment and disposal. To enhance operational efficiency, BP deploys larger skips capable of holding up to 100 barrels during exploration activities, streamlining the waste collection and handling process (Respondent A-1).

In addition to its waste transportation strategies, BP enforces strict waste segregation policies, particularly for drilling sludge, drilling mud, and cardboard waste. These materials are carefully sorted to ensure compliance with environmental regulations and are subsequently transported to specialized treatment facilities. At these facilities, waste undergoes compaction and advanced processing, significantly minimizing environmental impact and enhancing sustainability (Respondent A-1).

For drill cuttings disposal, BP differentiates between upper deck and lower deck waste, implementing distinct handling procedures for each category. According to Respondent A-2, upper deck waste can sometimes be discharged into the sea under strict regulatory guidelines, while lower deck drill cuttings require controlled handling, including onshore transportation for cleaning, filtration, and reinjection. This method ensures that hazardous materials are effectively processed before final disposal, aligning with BP's commitment to responsible waste management practices.

To further enhance waste management efficiency, BP has integrated advanced digital tools and technologies into its waste tracking, monitoring, and disposal systems. These innovations not only improve operational accuracy and compliance but also contribute to sustainability objectives by ensuring efficient waste handling processes. Respondent A-3 emphasized the role of the PIMS (Process Information Management System), which serves as a core digital platform for waste tracking and compliance verification. The PIMS system utilizes barcodes and GPS tracking to monitor waste movements in real time, ensuring full traceability from generation to final disposal. This system enables BP to remain compliant with government-monitored inventory systems while offering detailed insights into waste streams, improving accountability, and allowing for data-driven decision-making (Respondent A-3).

Beyond PIMS, BP is exploring the potential of RFID (Radio Frequency Identification) technology to further enhance its waste tracking capabilities. Respondent A-3 noted that RFID-based waste monitoring would improve categorization accuracy and transportation tracking, allowing each waste unit to be tagged with a unique identifier for remote scanning. This system would provide granular data on waste composition, movement, and disposal, reducing human errors in classification and improving regulatory reporting. Moreover, RFID technology could streamline auditing processes, ensuring that all waste is accounted for in compliance with environmental and legal obligations.

BP has also integrated data-driven forecasting and predictive analytics into its waste management framework. Respondent A-2 highlighted that AI-powered analytics enable BP to anticipate waste generation trends, allowing for efficient resource allocation, scheduling optimization, and waste reduction planning. By continuously monitoring task completion times and operational benchmarks, BP can identify workflow inefficiencies and make proactive adjustments, improving both logistical efficiency and sustainability efforts. The ability to forecast waste output ensures that BP prevents unnecessary accumulation and enhances its overall waste reduction strategies.

The adoption of real-time waste tracking systems, RFID monitoring, and predictive analytics reflects BP's commitment to optimizing waste disposal while maintaining high environmental standards. By leveraging these advanced digital tools, BP streamlines its waste management operations, reduces costs, and ensures compliance with global sustainability regulations. These technological innovations position BP as a leader in responsible waste management, demonstrating the company's ongoing efforts to integrate smart solutions into traditional waste handling practices.

By continuously refining its waste disposal strategies and adopting cutting-edge technology, BP ensures that its waste management framework remains adaptable, efficient, and aligned with industry best practices. These initiatives reduce the ecological footprint of drilling activities while enhancing operational transparency and accountability. As BP advances its digital capabilities, the company is expected to integrate even more innovative solutions-such as artificial intelligence (AI) and machine learning-into its waste management systems, further improving sustainability outcomes and regulatory compliance.

5.4.1.3. Waste Classification and Types at BP

Drilling-related waste types constitute a significant portion of the waste generated in BP's operations, particularly in offshore drilling activities. Respondent A-1 describes "drilling mud and drilling sludge" as the "primary constituents" on platforms, noting their prevalence due to the additives they contain, which necessitate specialized handling (A-1). These materials arise from the drilling process and are managed through methods like reinjection or offshore-to-onshore transportation, depending on logistical and infrastructural availability. Respondent A-2 reinforces this focus, explaining that "drill cuttings are utilized" in deeper drilling phases after initial upper deck discharges into the sea are permitted, with subsequent transportation to shore for cleaning and reinjection (A-2). Respondent A-3 adds that, although organic waste surpasses drilling cuttings in volume during project phases, cuttings with oil content remain a notable waste stream requiring specific management (A-3). Together, these accounts position drilling mud, sludge, and cuttings as dominant waste types in production-oriented operations, demanding rigorous disposal strategies to meet environmental standards.

Organic waste emerges as a critical category, especially in project-based settings with significant human activity. Respondent A-3 identifies "organic waste, including food waste and green waste from construction activities like tree cutting," as the most substantial waste type in his domain, estimating "about 2 kilograms of food waste per person daily" based on a workforce of approximately 6,500 people (A-3). This volume highlights the scale of food waste in remote project sites, directly tied to personnel numbers. Additionally, green waste, such as tree stumps and branches from land clearing, is processed using woodchippers and combined with compost for reforestation efforts (A-3). While Respondents A-1 and A-2 concentrate on drilling-related wastes, the emphasis on organic waste by A-3 underscores its prominence in project phases, reflecting the varied waste profiles across BP's operational spectrum.

Beyond drilling and organic categories, other operational wastes, including cardboard, oily residues, and miscellaneous daily items, are also significant. Respondent A-1 notes "a notable presence of cardboard waste" on platforms, which is separated into cardboard and paper categories to enhance recycling efficiency, with shipments sent to Sumgait for advanced processing (A-1). This segregation illustrates BP's approach to managing recyclable materials systematically. Oily wastes, encompassing items like clothing, helmets, and casings from routine maintenance, are similarly highlighted by A-1 as requiring dedicated containers for disposal or potential treatment (A-1). Respondent A-3 mentions "used cooking oil" as another waste type, lacking internal recycling facilities and thus reliant on third-party recyclers (A-3). These examples broaden the scope of waste types, capturing residues from ancillary operations that complement the primary drilling and organic streams.

The waste types identified-drilling mud, sludge, cuttings, food waste, green waste, cardboard, oily wastes, and used cooking oil-illustrate the complexity of BP's waste management challenges across offshore platforms and remote project sites. Drilling-related wastes predominate in production contexts, as evidenced by Respondents A-1 and A-2, driven by the technical nature of extraction processes. In contrast, organic wastes take precedence in project phases with large workforces, as detailed by Respondent A-3. Cardboard and oily wastes, though secondary in volume, reflect the operational diversity and the need for tailored segregation and disposal approaches. Citations to Respondents A-1, A-2, and A-3 ground this analysis in their firsthand accounts, ensuring empirical rigor appropriate for academic research.

This categorization of waste types lays a foundation for deeper analysis of BP's waste management practices, highlighting the interplay between waste generation, operational context, and environmental responsibility. The variation across respondents' experiences suggests the necessity of adaptive strategies, a theme warranting further exploration in subsequent research phases.

5.4.1.4. Recycling, Reuse, and Waste Reduction Initiatives in BP

BP integrates comprehensive recycling, reuse, and waste reduction initiatives into its waste management strategy, ensuring that valuable materials are recovered and repurposed to support sustainability and resource efficiency. The company actively seeks innovative solutions to minimize waste generation, optimize resource use, and reduce environmental impact across its operations. By embedding circular economy principles into its waste management framework, BP not only meets regulatory requirements but also strengthens its position as an industry leader in sustainability and responsible resource utilization.

A key area where BP has successfully implemented recycling efforts is drilling cuttings management. Respondent A-1 explained that oil separated from drilling cuttings is reused as a lubricant for drilling equipment, reducing the need for virgin materials and ensuring a closed-loop system that maximizes resource efficiency. This approach not only minimizes waste but also lowers operational costs and reduces environmental impact by extending the lifecycle of valuable materials. Additionally, BP continuously explores advanced thermal desorption technologies, which help recover higher volumes of reusable oil from cuttings, further enhancing resource recovery rates and reducing waste disposal volumes (Respondent A-1).

BP also reprocesses drilling sludge to enable the reuse of materials. As noted by Respondent A-1, the company employs specialized treatment techniques to extract usable resources from drilling sludge, reducing the need for additional raw material extraction. This process supports BP's broader commitment to a circular economy, ensuring that materials are reintegrated into operations rather than discarded.

Beyond operational waste, BP has adopted low-waste procurement strategies to mitigate waste generation from the outset. Respondent A-1 emphasized that BP's supply chain policies focus on sourcing materials and equipment designed for durability, reusability, and recyclability. By engaging with suppliers to minimize packaging waste and select materials with lower environmental impact, BP ensures that sustainability is incorporated at multiple stages of its supply chain, reducing waste before it is even generated.

In managing general waste, BP relies on third-party contractors for collection, segregation, and processing, ensuring that waste is handled in compliance with local and international environmental regulations (Respondent A-1). However, BP does not merely delegate waste management responsibilities; it enforces strict compliance measures through contractual agreements, active monitoring, and regular audits to ensure that waste processing aligns with its sustainability goals. Contractors engage in innovative recycling practices, such as repurposing plastic waste into pipe protectors and industrial-grade materials, reinforcing BP's commitment to resource recovery and sustainable material utilization (Respondent A-1).

BP also prioritizes specialized waste treatment for organic waste, implementing composting facilities to process biodegradable materials. Respondent A-3 described how compost generated from organic waste is repurposed for reforestation programs and land rehabilitation projects, contributing to ecological restoration efforts and carbon sequestration. This initiative is particularly impactful in BP's operations located in ecologically sensitive areas, where restoring natural habitats is a key sustainability priority (Respondent A-3). By reducing landfill dependency and transforming organic waste into a valuable resource, BP demonstrates its proactive approach to waste reduction and biodiversity enhancement.

BP's waste reduction strategies also extend to collaborating with local communities to enhance the sustainability of its waste management practices. Respondent A-3 highlighted BP's initiative to repurpose excess compost for agricultural and reforestation projects, benefiting both local ecosystems and communities. These initiatives not only reduce landfill dependency but also strengthen BP's role as a responsible corporate citizen, fostering positive relationships with stakeholders while advancing its environmental goals.

Additionally, BP collaborates with third-party recyclers to ensure the responsible disposal and reuse of materials such as used cooking oil and industrial lubricants. Respondent A-3 highlighted that used cooking oil collected from offshore facilities is repurposed into biofuels, supporting waste-to-energy conversions that align with BP's broader decarbonization strategy. The company has also explored innovative solvent recovery programs, where used chemical solvents from industrial processes are purified and reused, further reducing hazardous waste output and minimizing environmental risks (Respondent A-2).

BP's commitment to waste reduction, recycling, and material repurposing is reinforced through industry collaboration and policy advocacy. The company actively supports research and development projects focused on plastic waste management, advanced recycling technologies, and circular economy integration (Respondent A-2). Furthermore, BP works with government agencies and environmental organizations to advocate for stronger waste management policies and incentives for companies adopting sustainable waste reduction strategies (Respondent A-3).

Looking ahead, BP aims to further enhance its recycling and repurposing efforts by investing in advanced waste processing technologies, expanding waste-to-energy programs, and strengthening partnerships with sustainability-driven organizations. The company is also exploring digital tracking systems to monitor waste flow and recycling efficiency in real-time, allowing for data-driven decision-making and continuous improvements in waste management strategies (Respondent A-1).

By embedding recycling and waste reduction initiatives into its waste management framework, BP continues to advance its sustainability goals, ensuring compliance with global environmental standards while driving innovation in waste management within the energy sector. These strategies highlight BP's commitment to minimizing its environmental footprint, enhancing resource efficiency, and leading the industry toward a more sustainable and circular economy-focused future.

5.4.1.5. Waste Transportation and Logistics at BP

BP's logistics department plays a crucial role in overseeing the planning, execution, and monitoring of waste transportation, ensuring full compliance with government regulations, environmental policies, and internal operational standards (Respondent A-2). Given the complexity of managing hazardous and non-hazardous waste across various operational sites, BP employs a structured, technology-driven approach to optimize waste movement, minimize risks, and improve overall efficiency. The company enforces stringent regulatory measures for hazardous waste shipments, requiring specialized permits that ensure compliance with safety standards and environmental protection laws. This reduces the likelihood of contamination and legal non-compliance (Respondent A-3). To enhance transparency and accountability, BP utilizes digital tracking systems, where every waste transfer is electronically recorded. This system enables real-time monitoring of shipments, facilitates compliance verification, and supports audit and reporting requirements (Respondent A-3). Additionally, BP collaborates with regulatory authorities to ensure adherence to international waste transportation agreements, such as the Basel Convention on Hazardous Waste Movement (Respondent A-1).

BP optimizes its vessel routing strategies to improve transportation efficiency and minimize environmental impact. Vessels are strategically scheduled to avoid empty voyages, reducing fuel consumption, operational costs, and emissions (Respondent A-1). Route optimization software is employed to assess weather conditions, fuel efficiency, and regulatory constraints, ensuring sustainable and cost-effective transportation. The company also integrates pipeline injection systems for the disposal of liquid waste, eliminating the need for excessive handling and reducing the risk of spills, leaks, and contamination (Respondent A-2). By streamlining liquid waste transportation, BP minimizes its reliance on road tankers and offshore vessels, thereby reducing logistics costs and operational risks.

The container management system follows strict operational protocols to ensure that no waste is left unaccounted for during shipment. BP employs specially designed skip boxes and sealed containers to handle hazardous and dense materials, preventing spills, leakage, and cross-contamination during transit (Respondent A-2). These containers are engineered to withstand extreme environmental conditions, ensuring that waste remains securely contained throughout transportation. Before each shipment, waste containers are pre-registered in BP's digital tracking system, allowing for seamless inventory management, real-time tracking, and compliance verification (Respondent A-3). This ensures that every waste container is accounted for at every stage of transportation, eliminating the risk of lost or improperly handled waste. BP also implements pre-shipment inspections, verifying that all waste packaging meets safety and labelling requirements before transit (Respondent A-3). The company continues to invest in advanced waste containment technologies, such as vacuum-sealed tanks for liquid waste and automated container locking systems, to enhance safety and efficiency.

BP collaborates with third-party waste management contractors to facilitate efficient waste transportation, treatment, and disposal. The company maintains strict oversight over these partnerships, requiring contractors to adhere to BP's internal environmental policies and sustainability commitments (Respondent A-1). Regular compliance audits and performance evaluations ensure that waste is handled, transported, and processed in accordance with global environmental standards (Respondent A-1). Beyond compliance, BP prioritizes partnerships with waste management firms that implement circular economy initiatives, such as repurposing industrial waste into reusable materials (Respondent A-3). For example, BP works with third-party vendors to recycle metal waste from offshore rigs into construction materials, ensuring that valuable resources are reintegrated into the economy rather than sent to landfills (Respondent A-3).

Looking ahead, BP aims to further enhance its waste transportation efficiency through investments in automation, predictive analytics, and AI-driven logistics solutions. The company is exploring AI-powered forecasting tools that predict waste generation patterns, allowing for more precise scheduling of waste shipments and reducing unnecessary transport movements (Respondent A-3). BP is also considering the integration of electric and hybrid-powered waste transport vehicles, further reducing carbon emissions associated with waste logistics (Respondent A-1). Additionally, BP is evaluating blockchain-based tracking systems to enhance supply chain transparency, ensuring that every stage of waste movement is securely recorded and verifiable

(Respondent A-2). These advancements will enable BP to strengthen regulatory compliance, reduce environmental risks, and improve operational efficiency.

Through its comprehensive waste transportation strategies, BP ensures that waste disposal operations remain safe, efficient, and environmentally responsible. By leveraging digital tracking technologies, strategic vessel routing, specialized waste containment, and strict regulatory adherence, BP continues to enhance its sustainability initiatives while maintaining cost-effective waste management practices. As the company moves forward, continuous investments in digitalization, automation, and eco-friendly transportation solutions will further strengthen BP's ability to manage waste responsibly and sustainably across its global operations.

5.4.1.6. Performance Monitoring and Key Performance Indicators (KPIs) at BP

BP has developed a comprehensive system of Key Performance Indicators (KPIs) to evaluate and enhance its waste management operations. These KPIs provide valuable insights into operational efficiency, compliance adherence, and sustainability performance. By continuously monitoring and analysing data, BP ensures that its waste management strategies remain effective and adaptable to regulatory and environmental changes. The systematic tracking of these indicators enables BP to proactively address inefficiencies, identify areas for improvement, and optimize waste reduction efforts across its global operations.

BP meticulously tracks the **volume of waste disposed** of monthly, allowing for trend analysis and process optimization (Respondent A-1). This KPI helps BP understand seasonal variations in waste generation and evaluate the effectiveness of waste minimization initiatives. By analysing long-term disposal trends, BP can adjust procurement strategies, implement waste reduction measures at the source, and optimize recycling and treatment processes. Additionally, the company monitors waste disposal costs in relation to waste volume, ensuring that waste management remains both environmentally responsible and financially efficient (Respondent A-2).

Non-Conformance Rate serves as a critical KPI for identifying instances where waste handling deviates from established protocols. BP conducts routine compliance audits to measure adherence to internal policies, industry best practices, and regulatory requirements (Respondent A-2). Any deviations are logged, investigated, and addressed through corrective actions, reinforcing a culture of accountability and continuous improvement. The company also classifies non-conformance cases based on severity, prioritizing immediate resolutions for high-risk infractions while implementing long-term preventive measures for recurring issues (Respondent A-3).

Incident Metrics play a crucial role in BP's risk management strategy, as the company records and assesses safety or compliance incidents related to waste disposal. These include spills, contamination cases, and non-compliance with waste handling procedures. By categorizing incidents based on root causes-such as equipment failure, human error, or regulatory gaps-BP develops targeted intervention strategies to mitigate future risks (Respondent A-3). Lessons learned from these incidents are shared across BP's operational teams, ensuring that best practices are continuously refined and reinforced.

BP evaluates transportation and supplier waste management performance through its **Logistics Efficiency** KPI. This metric assesses the environmental and economic impact of waste transportation, measuring factors such as fuel consumption, emission levels, and route optimization effectiveness (Respondent A-2). BP leverages digital logistics tracking tools to enhance efficiency, ensuring that waste shipments are consolidated, properly scheduled, and aligned with sustainability goals. Supplier performance is also evaluated based on waste segregation accuracy, recycling rates, and adherence to contractual waste handling commitments (Respondent A-1). Underperforming vendors are provided with corrective guidance, and partnerships with high-performing suppliers are strengthened to drive industry-wide sustainability improvements.

Online Waste Assessment Tools further enhance BP's ability to monitor and improve waste management practices. These digital platforms collect and analyse data from multiple operational sites, offering real-time visibility into waste handling performance (Respondent A-3). By integrating artificial intelligence and machine learning, BP's digital assessment tools identify inefficiencies, predict waste generation patterns, and recommend corrective actions. The company also uses these tools to benchmark waste management performance against industry standards and internal sustainability targets, ensuring continuous progress toward zero-waste and circular economy initiatives (Respondent A-3).

Beyond these primary KPIs, BP also measures additional indicators such as landfill diversion rates, carbon footprint reduction from waste recycling, and employee training effectiveness in waste management protocols. BP's commitment to sustainability is reflected in its drive to enhance waste tracking systems, promote transparency, and reduce environmental impact. The company continuously refines its KPI framework by incorporating stakeholder feedback, industry advancements, and evolving regulatory requirements, ensuring that its waste management strategy remains at the forefront of environmental responsibility and operational excellence.

Through its data-driven approach to waste management, BP not only maintains regulatory compliance but also drives continuous sustainability improvements. By leveraging advanced analytics, real-time monitoring systems, and digital assessment tools, BP strengthens its ability to mitigate waste-related risks, enhance efficiency, and uphold its environmental stewardship commitments across its global operations. As the company progresses, it aims to further integrate predictive analytics, automation, and blockchain technology into its waste management framework, ensuring greater transparency, efficiency, and sustainability in the long term.

5.4.1.7. Challenges in Waste Management and Reverse Logistics at BP

Despite BP's structured approach to waste management, the company encounters a range of challenges that complicate its efforts, particularly in the transportation of hazardous waste and logistical coordination. Respondent A-1 highlighted that one of the most significant hurdles is the obtaining of government approvals for hazardous waste shipments. The process of securing these approvals is often time-consuming and cumbersome, which adds substantial complexity to logistical planning. The bureaucratic nature of waste disposal regulations requires BP to navigate a maze of procedures and compliance requirements, necessitating close and ongoing collaboration with regulatory authorities. This collaboration is essential to ensure that operations run smoothly and that the company can secure timely approvals for waste shipments, avoiding delays that could result in operational inefficiencies or violations of regulatory requirements.

Another challenge mentioned by Respondent A-3 is managing waste from remote operational locations, which presents both transportation costs and logistical difficulties. In some cases, the company must move hazardous materials over long distances, which significantly increases transportation costs and complicates logistics planning. These remote locations often lack the infrastructure to support efficient waste collection and disposal, requiring BP's logistics, marine, and environmental departments to work in close coordination. Together, these departments collaborate to optimize the transportation of hazardous materials while ensuring the highest standards of safety and compliance are met. The complexity of transporting waste from isolated sites also necessitates specialized equipment and vehicles, further escalating costs and logistical considerations.

Beyond the technical and logistical challenges, BP also faces resistance from external contractors regarding its sustainability initiatives. Respondent A-3 pointed out that many contractors and suppliers prioritize cost reduction over environmental responsibility, which can create a significant barrier to advancing sustainability efforts. For these contractors, environmental initiatives may be viewed as an additional expense or an obstacle to reducing operational costs, leading them to adhere only to the minimum compliance requirements set by regulations. This mindset presents a challenge for BP as it seeks to integrate sustainability into every facet of its operations, not just within its own departments but across the entire supply chain.

To address this resistance, BP is focusing on enhancing stakeholder awareness through targeted programs designed to educate external contractors on the long-term benefits of sustainability. These programs aim to foster a deeper understanding of the environmental and economic value that can be derived from investing in more sustainable practices. In addition, BP is working to improve its regulatory coordination efforts to streamline compliance processes and reduce the bureaucratic barriers that can delay progress. The company is also investing in logistics optimization, utilizing advanced technologies and data analytics to improve the efficiency of its waste management operations, reduce costs, and minimize environmental impact (Respondent A-1, A-2, and A-3)

Ultimately, BP's goal is to ensure that sustainability remains a core focus in all aspects of waste management, both internally and across its external partnerships. By continuing to educate and engage with contractors, improving regulatory coordination, and optimizing logistics, BP is committed to overcoming these challenges and advancing its waste management practices to align with its broader sustainability objectives.

5.4.1.8. Opportunities for Improvement and Future Strategies at BP

BP continues to explore numerous opportunities for improvement and future strategies to enhance its waste management framework, ensuring alignment with sustainability goals and regulatory compliance. Interviewees highlighted key areas where BP can refine its approach, integrate advanced solutions, and strengthen collaboration with stakeholders to optimize waste handling processes.

Respondent A-1 emphasized the importance of strengthening partnerships with specialized waste treatment and recycling firms. While BP currently works with external contractors for waste collection and processing, deeper collaboration with these partners could improve waste segregation, recycling rates, and resource recovery. By integrating more advanced waste treatment technologies, BP could reduce landfill dependency and enhance circular economy principles. Additionally, forming long-term partnerships with innovative waste solution providers could enable BP to adopt best practices from other industries and implement more efficient disposal methods.

Another key improvement area identified by Respondent A-2 is the greater use of digital tracking and AI-driven waste management systems. While BP already monitors waste movement through tracking mechanisms, further investments in artificial intelligence and automated monitoring could enhance efficiency, reduce errors, and improve reporting accuracy. AI-based systems could optimize waste collection schedules, predict generation trends, and identify inefficiencies in real time. These improvements would not only increase transparency and compliance but also support cost reduction efforts by streamlining operations and minimizing unnecessary waste transportation expenses.

Employee awareness and training remain critical components of BP's sustainability strategy. Respondent A-3 pointed out that expanding training programs and awareness initiatives could significantly enhance compliance with waste management policies. While BP currently conducts periodic training, a more structured and continuous education framework could reinforce waste handling protocols, realize best practices, and ensure that employees and contractors consistently adhere to environmental standards. BP could also introduce certification programs or incentivized learning modules to encourage proactive engagement with sustainability initiatives.

Another strategic improvement discussed by Respondent A-3 involves investing in waste-to-energy solutions. BP has already begun exploring the feasibility of converting certain waste streams into alternative fuel sources, but further research and investment in this area could yield substantial benefits. Waste-to-energy initiatives could reduce overall waste volume, generate renewable energy, and contribute to BP's broader decarbonization goals. By leveraging advancements in pyrolysis, anaerobic digestion, or gasification technologies, BP could transform organic and plastic waste into valuable energy resources, minimizing environmental impact.

Furthermore, Respondent A-2 highlighted the need for refining supplier and contractor engagement strategies. BP currently enforces waste management requirements among external stakeholders, but strengthening these measures could ensure better alignment with the company's sustainability objectives. Implementing stricter contractual obligations, requiring suppliers to adopt circular economy practices, and developing incentive-based programs for environmentally responsible vendors could encourage greater compliance and innovation. For instance, suppliers who demonstrate significant improvements in waste reduction and material repurposing could receive preferential contract terms, fostering a culture of continuous improvement.

Beyond operational enhancements, Respondent A-1 suggested that BP should also focus on policy advocacy and industry collaboration. By working closely with regulatory bodies, industry associations, and environmental organizations, BP can contribute to the development of progressive waste management policies. Engaging in multi-stakeholder initiatives and knowledge-sharing platforms could position BP as a leader in sustainable waste practices, influencing industry standards and promoting responsible waste management across the sector.

Finally, BP could enhance its corporate sustainability reporting and transparency efforts. While the company tracks key performance indicators related to waste management, expanding public disclosures and sustainability reports could strengthen accountability and stakeholder trust. By providing more detailed insights into waste reduction achievements, recycling improvements, and future goals, BP can reinforce its commitment to environmental stewardship and attract sustainability-focused investors.

Through these targeted improvements, BP aims to refine its waste management strategies, integrating advanced technologies, enhancing workforce engagement, and fostering stronger collaborations with partners and regulatory bodies. These initiatives will help BP maintain its leadership in environmental sustainability while optimizing waste management efficiency, reducing costs, and contributing to global circular economy objectives.

5.5. Equinor’s Waste Management Practices

Equinor is a leading international energy company with a significant focus on sustainability, operating across oil and gas, renewables, and low-carbon solutions. As part of its commitment to the energy transition, Equinor emphasizes reducing its environmental impact, including managing waste more effectively. The company’s sustainability strategy includes addressing hazardous waste generated by its operations, improving water management, and adopting circular economy principles to enhance the reuse and recycling of materials across its facilities.

Equinor’s waste management focuses primarily on mitigating hazardous waste from its offshore and onshore operations. In 2023, the company reported increased volumes of hazardous waste due to water disposed of after cleaning offshore wells. These challenges highlight the importance of continuous improvement in waste management processes to reduce environmental impacts.

1. **Hazardous Waste Management:**
    - Hazardous waste generation increased due to the rise in offshore drilling activities, specifically well cleaning. Equinor has acknowledged this issue and plans to improve its management by focusing on better treatment processes in 2024 and beyond. By minimizing the volume of water that requires external treatment, Equinor aims to reduce the risks associated with hazardous waste disposal.
2. **Circular Economy Initiatives:**
    - Equinor’s circular economy strategy is aimed at improving the lifespan of its assets, increasing recycling rates, and reusing materials. In 2024, the company will focus on enhancing awareness and practices related to the

circular economy by extending the useful life of facilities and increasing material recycling and equipment reuse. These initiatives are in line with the global transition toward more sustainable waste management practices.

Table 45. Sustainability report of Equinor between 2018 and 2023

Indicators	**Units**	**2023**	**2022**	**2021**	**2020**	**2019**
SO_2 emissions	ktonnes	1.1	1.1	0.9	1.3	2.2
NO_x emissions	ktonnes	30	32	34	36	41
Non-methane volatile organic compounds	ktonnes	33	23	26	35	40
Accidental oil spills (net volume >0) - Number	Number	132	111	120	136	219
Accidental oil spills (net volume >0) - Volume	m^3	18	33	40	154	8913
Other accidental spills (net volume >0) - Number	Number	132	122	98	117	204
Other accidental spills (net volume >0) - Volume	m^3	370	302	3335	3,997	57
Serious accidental spills	Number	0	0	2	2	3
Regular discharges of oil in water to sea	ktonnes	10	11	11	13	1.2
Hazardous waste generated	ktonnes	339	304	280	318	313
Non-hazardous waste generated	ktonnes	34	37	33	29	40
Exempt waste - drill cuttings and solids (US onshore operations)	ktonnes	16	1.2	0.09	17	84
Exempt waste - produced water and flowback (US onshore operations)	million m^3	0.02	0.05	2	5	7
Total freshwater withdrawal and consumption	million m^3	6	6	6	8	8
New projects with net positive impact plans	Number	0	n/r	n/r	n/r	n/r
Sites with site-specific inventory of key biodiversity features	Number	35	n/r	n/r	n/r	n/r

Source: Equinor, 2023. 2023 Integrated Annual Report, p. 70. Available at: https://cdn.equinor.com/files/h61q9gi9/global/76629806e2cc50eefdd89d5b8daabda39247db63.pdf?2023-annual-report-equinor.pdf

Table 46. Waste Management report of Equinor between 2018 and 2023

Waste Indicators	**Units**	**2023**	**2022**	**2021**	**2020**	**2019**	**2018**
Hazardous waste generated [1]	thousand tonnes	339	304	280	318	313	244
Non-hazardous waste generated	thousand tonnes	34	37	33	29	40	31
Exempt waste generated: cuttings and solids [1]	thousand tonnes	16	1.2	0.09	17	84	55
Exempt waste generated: produced water and flowback [1]	million m^3	0.02	0.05	2	5	7	6
Hazardous waste diverted from disposal by recovery operation	thousand tonnes	258	232	202	221	n/r	n/r
.. by preparation for reuse	thousand tonnes	5	4	4	6	n/r	n/r
.. by recycling	thousand tonnes	2	9	2	8	n/r	n/r
.. by other recovery operations (remediated water)	thousand tonnes	250	219	195	207	n/r	n/r
.. hazardous waste recovery rate [2]	%	76	76	72	70	n/r	n/r
Non-hazardous waste diverted from disposal by recovery operation	thousand tonnes	16	15	16	14	n/r	n/r
.. by preparation for reuse	thousand tonnes	2.8	0.6	0.01	1.3	n/r	n/r
.. by recycling	thousand tonnes	13	15	15	13	n/r	n/r

Waste Indicators	Units	2023	2022	2021	2020	2019	2018
.. by other recovery operations (remediated water)	thousand tonnes	0.7	0.00001	0.3	0.3	n/r	n/r
.. non-hazardous waste recovery rate [2]	%	48	40	47	49	n/r	n/r
Exempt waste diverted from disposal	thousand tonnes	0	0	0	0	n/r	n/r
Hazardous waste directed to disposal-by-disposal operation	thousand tonnes	81	72	78	97	n/r	n/r
.. by incineration with energy recovery	thousand tonnes	29	28	27	23	n/r	n/r
.. by incineration without energy recovery	thousand tonnes	0.003	0.002	0.06	0.04	n/r	n/r
.. by landfill	thousand tonnes	55	45	51	74	n/r	n/r
.. by other disposal operation	thousand tonnes	0	0	0	0	n/r	n/r
Non-hazardous waste directed to disposal-by-disposal operation	thousand tonnes	18	22	17	15	n/r	n/r
.. by incineration with energy recovery	thousand tonnes	12	13	10	9	n/r	n/r
.. by incineration without energy recovery	thousand tonnes	0.00006	0.00004	0.00001	0.003	n/r	n/r
.. by landfill	thousand tonnes	5	9	7	5	n/r	n/r

Waste Indicators	Units	2023	2022	2021	2020	2019	2018
.. by other disposal operation	thousand tonnes	0	0	0	0	n/r	n/r
Exempt waste directed to disposal-by-disposal operation	thousand tonnes	n/r	n/r	n/r	n/r	n/r	n/r
.. exempt cuttings and solids waste to landfill	thousand tonnes	16	1.2	0.09	17	n/r	n/r
.. exempt produced and flowback water to deep well injection	million m^3	0.02	0.05	2	5	n/r	n/r

Source: Equinor, n.d. Environment tables. Available at: https://sustainability.equinor.com/environment-tables

1. Hazardous Waste Generation

- Trend: Hazardous waste increased from 304 ktonnes in 2022 to 339 ktonnes in 2023.
- Analysis: This continues an upward trend and highlights Equinor's operational impact, especially from activities like well interventions and cleanouts. While the recovery rate remained high at 76%, ongoing efforts are needed to minimize waste generation at the source and increase reuse where feasible.

2. Non-Hazardous Waste

- Trend: Slight reduction in non-hazardous waste from 37 ktonnes in 2022 to 34 ktonnes in 2023.
- Analysis: This decline reflects improved segregation, recycling, and possibly operational efficiency. A 48% recovery rate in 2023 (up from 40% in 2022) also supports the progress toward circular practices.

3. Exempt Waste (Drill Cuttings and Water)

- Trend: Drill cuttings jumped sharply from 1.2 ktonnes in 2022 to 16 ktonnes in 2023, while water waste dropped to 0.02 million m^3.
- Analysis: The spike in drill cuttings may be tied to increased US onshore activity. Meanwhile, the decline in produced/flowback water reflects tighter water reuse and treatment practices. These changes may point to differing operational intensity across assets.

4. Recovery vs Disposal of Hazardous Waste

- Trend: 258 ktonnes of hazardous waste were recovered in 2023, while 81 ktonnes went to disposal.
- Analysis: The continued preference for recovery (especially water remediation) over disposal signals environmental responsibility. Recovery rate improvements from 70% in 2020 to 76% in 2023 show progress, though achieving even higher recovery efficiency remains an important goal.

5. Non-Hazardous Waste Disposal

- Trend: Disposal volumes fell to 18 ktonnes in 2023 from 22 ktonnes in 2022.
- Analysis: The consistent downward trend in disposal volumes aligns with waste hierarchy principles, favouring reuse and recycling. The share sent to landfill (5 ktonnes) was markedly lower than previous years (9 ktonnes in 2022), indicating positive steps in landfill diversion.

5.5.1. Findings from Interviews (Equinor)

This section presents an in-depth analysis of Equinor's waste management practices based on interviews with company specialists. The responses have been categorized into key topics to provide a comprehensive understanding of Equinor's approach to waste disposal, recycling, logistics, and operational challenges. The findings highlight the company's strategies, performance indicators, and areas requiring improvement.

5.5.1.1. Awareness Levels Within the Company and Among Stakeholders at Equinor

Equinor demonstrates a strong internal culture of environmental awareness and regulatory compliance. Employees and contractors follow the company's HSE policy and adhere to well-defined waste segregation procedures (Respondent F-2). Regular training and awareness campaigns ensure that personnel understand their responsibilities in waste management, reducing the risk of contamination and non-compliance. These training programs are conducted through workshops, digital learning platforms, and on-site briefings, reinforcing key environmental protection measures.

Equinor integrates sustainability principles into its corporate policies, ensuring that environmental compliance is not only a legal requirement but also a fundamental part of its operational philosophy. Internal audits and compliance checks are conducted regularly to assess adherence to waste management regulations, and any deviations result in corrective actions and retraining initiatives (Respondent F-2). Furthermore, employees are encouraged to participate in sustainability programs, fostering a proactive approach to environmental stewardship.

Despite this strong internal commitment, challenges persist with external contractors, who often prioritize cost efficiency over sustainability (Respondent F-1). Many subcontractors operate under different environmental policies, creating inconsistencies in waste handling practices. Encouraging subcontractors to go beyond compliance remains difficult, particularly in regions where environmental enforcement is weaker. This results in variations in adherence to waste segregation, disposal methods, and reporting standards.

To address these challenges, Equinor has implemented a structured contractor engagement framework that includes mandatory training sessions, compliance monitoring, and performance evaluations. Contractors are required to report their waste management practices, ensuring transparency and alignment with Equinor's sustainability objectives. Regular audits and site inspections help identify areas where improvements can be made, ensuring that all waste handling processes align with the company's environmental standards (Respondent F-1).

Additionally, Equinor continues to invest in stakeholder engagement programs, aiming to align all partners with its sustainability goals. This includes collaborative initiatives with governmental agencies, industry organizations, and local communities to enhance environmental awareness and create a unified approach to waste management. By promoting knowledge-sharing and adopting best practices from other sectors, Equinor aims to continuously improve its environmental performance and reduce its overall ecological footprint.

Through these efforts, Equinor is working to bridge the gap between internal and external stakeholders, ensuring that waste management remains a top priority across all levels of operation.

5.5.1.2. Waste Disposal and Handling Strategies at Equinor

Equinor takes a comprehensive, highly structured approach to waste segregation, management, and disposal to meet its sustainability and regulatory requirements. By enforcing strict waste segregation policies and procedures, the company ensures that waste is managed in a responsible and environmentally conscious manner, reducing the environmental impact of its operations. These policies are enforced at the source, with personnel required to sort waste into designated bins and skips, ensuring that each type of waste is properly categorized for its specific disposal method (Respondent F-2). The area authority plays a critical role in overseeing the proper storage, transport, and maintenance of collection centres, further reinforcing Equinor's commitment to proper waste management (Respondent F-2).

Equinor's protocols for hazardous waste are especially rigorous, as these materials require careful handling and disposal to mitigate risks to both human health and the environment. For highly reactive materials such as spent catalysts and absorbents, Equinor utilizes sealed 200-liter drums to prevent auto-ignition and ensure that these substances remain secure during storage and transportation (Respondent F-1). Temporary storage facilities are used until contracts with certified disposal vendors are in place, providing an additional layer of safety and compliance while waste is waiting for final processing (Respondent F-1).

For unknown or unidentified waste, Equinor adopts a cautious approach by treating the materials as hazardous until laboratory tests can confirm safe disposal options (Respondent F-2). This precautionary principle ensures that potentially dangerous substances are not overlooked, and proper testing is conducted to determine the safest and most effective disposal methods. In the case of radioactive waste, Equinor follows stringent procedures, keeping the materials isolated and coordinating with regulatory authorities to ensure compliance with all local and international safety standards (Respondent F-1).

Equinor also has structured processes for managing non-hazardous waste, applying efficient techniques to reduce waste volume and maximize recycling efforts. Plastic bottles and aluminium cans are compacted using baling machines before being transported to designated recycling centres, facilitating easier handling and more efficient recycling processes (Respondent F-1). Cardboard and wood waste, two common types of non-hazardous waste in the industry, are processed through external recycling contractors, ensuring that these materials are properly sorted and recycled (Respondent F-1). This approach aligns with Equinor's broader strategy to reduce the environmental footprint of its operations and enhance sustainability through recycling and resource recovery.

For food waste, Equinor uses a specialized incineration process, where the waste is first incinerated, and the resulting ash is sent to lined landfills to prevent contamination (Respondent F-2). This waste-to-energy approach not only reduces the volume of food waste but also contributes to energy recovery, minimizing landfill use and supporting Equinor's goals to reduce its overall waste output. Battery waste, a more complex category due to its chemical content, is either recycled or stabilized with cement before being disposed of (Respondent F-2). This process ensures that potentially hazardous materials are managed in a way that minimizes environmental risks and enhances waste management efficiency.

Equinor is committed to the continuous improvement of its waste management practices, and the company regularly updates its waste management plan to incorporate the latest technologies and industry best practices. By staying ahead of emerging waste management technologies and integrating new solutions into its operational framework, Equinor can enhance the efficiency of its waste management efforts while minimizing its environmental impact. These ongoing updates reflect Equinor's dedication to sustainability and its proactive approach to reducing waste, improving recycling rates, and ensuring that all waste is managed in a way that supports the company's corporate and environmental goals.

While landfilling remains the cheapest disposal method, Equinor prioritizes long-term sustainability over short-term cost savings, ensuring that its waste management practices align with environmental responsibility and regulatory compliance (Respondent F-1). Rather than focusing solely on cost reduction, Equinor integrates strategic sustainability initiatives to balance economic efficiency with environmental stewardship.

To offset waste management costs, Equinor has adopted innovative cost-reduction measures, including donating recyclable materials to contractors while covering the associated transportation expenses (Respondent F-1). This approach not only helps reduce landfill dependency but also strengthens corporate partnerships by enabling contractors to repurpose waste materials more effectively.

Equinor further improves cost efficiency by implementing a range of optimization strategies within its waste management framework:

- Enhancing waste segregation to increase recycling rates and reduce disposal costs (Respondent F-2). By ensuring that recyclable materials are properly sorted at the source, Equinor minimizes the volume of non-recyclable waste sent to landfills, thereby lowering waste handling expenses.

- Investing in waste-to-energy technologies to maximize resource utilization (Respondent F-1). Equinor has explored alternative energy recovery methods, converting waste materials into usable energy, which further offsets disposal costs while promoting sustainability initiatives.

- Exploring vendor partnerships to reduce hazardous waste processing expenses (Respondent F-1). By collaborating with specialized waste management firms, Equinor can negotiate cost-effective disposal solutions, ensuring that hazardous waste is treated efficiently while maintaining compliance with environmental regulations.

By integrating these cost-effective waste management strategies, Equinor continues to strengthen its commitment to sustainable business operations, ensuring that financial efficiency and environmental responsibility remain complementary objectives. Through optimized waste segregation, advanced energy recovery solutions, and strategic vendor collaborations, Equinor effectively reduces its overall waste management costs while maintaining its leadership in sustainability-focused industrial practices.

In summary, Equinor's waste management system is a highly coordinated effort that encompasses detailed segregation, specialized handling procedures, and continuous improvements. By addressing both hazardous and non-hazardous waste with tailored protocols, Equinor ensures regulatory compliance, enhances operational efficiency, and minimizes environmental impact. Through these measures, the company demonstrates its commitment to responsible waste management and sustainable business practices, ensuring that it meets its environmental and sustainability targets while contributing to a circular economy.

5.5.1.3. Waste Classification and Types at Equinor

Equinor effectively manages a broad range of hazardous and non-hazardous waste types while adhering to strict regulatory standards and promoting sustainability across its operations. The company's waste management approach is underpinned by advanced tracking and reporting mechanisms, which allow for precise monitoring of waste generation, optimizing disposal methods, and enhancing resource efficiency.

Hazardous Waste Management: Equinor manages various hazardous waste materials that require careful management due to their potential toxicity and reactivity. According to Respondent F-1, the hazardous waste stream includes pyrophoric substances, such as H2S and mercury absorbents, spent catalysts, activated carbon, and expired chemicals. These materials necessitate specific storage and handling procedures to mitigate risk and prevent contamination. The company employs specialized containers designed for the safe storage and transportation of hazardous materials, adhering to industry standards to ensure that all regulatory requirements are met. The handling of these substances is carefully monitored to ensure that they do not pose environmental or safety hazards during transit or disposal.

Equinor also manages insulation materials, such as glass wool and rock wool, which fall under hazardous waste due to their chemical composition and potential environmental impact. These materials are disposed of through partnerships with licensed disposal facilities, where they are safely treated and managed in accordance with environmental regulations (Respondent F-1). This collaboration with certified waste disposal providers helps minimize risk and ensures that all hazardous materials are disposed of responsibly.

Non-Hazardous Waste Management: In addition to hazardous waste, Equinor generates a variety of non-hazardous waste materials, including used oil, plastic bottles, aluminium cans, and household waste. These materials are sorted through source segregation practices to maximize recycling potential and reduce landfill dependency (Respondent F-1). Used oil, for example, is carefully collected and either reprocessed for reuse or disposed of in an environmentally responsible manner. Equinor's waste segregation efforts contribute significantly to enhancing recycling efficiency, aligning with its sustainability goals to reduce the environmental impact of waste and increase resource recovery.

5.5.1.4. Recycling, Reuse, and Waste Reduction Initiatives at Equinor

Equinor is actively implementing comprehensive waste reduction strategies that focus on minimizing waste at the source, enhancing material reuse, and adopting innovative technologies to improve sustainability across its operations. These initiatives are designed to align with circular economy principles, reduce environmental impact, and optimize resource efficiency.

One of Equinor's primary waste reduction approaches, as highlighted by Respondent F-1, is its commitment to circular economy principles, emphasizing recycling and material reuse as a fundamental aspect of waste management. By integrating waste recovery strategies into its operational framework, Equinor aims to reduce its dependence on virgin raw materials, thereby lowering its overall environmental footprint. These initiatives help foster a closed-loop system, ensuring that waste materials are repurposed or reintegrated into industrial processes rather than being discarded.

Another critical element in Equinor's waste reduction efforts is its collaboration with vendors to improve catalyst recycling solutions (Respondent F-1). Catalysts play a crucial role in industrial processes, and their disposal presents significant challenges due to their chemical composition and potential environmental impact. Equinor has been actively working with specialized waste management contractors to explore alternative recycling technologies that allow for the safe and efficient recovery of valuable materials from spent catalysts. These collaborations not only enhance waste management efficiency but also reduce operational costs by repurposing materials that would otherwise be discarded.

To further reduce waste, Equinor has invested in new food waste processing techniques, particularly through the implementation of drying machines, which help minimize emissions from incineration (Respondent F-1). Traditional food waste disposal methods, such as incineration or landfilling, contribute to greenhouse gas emissions and environmental degradation. By utilizing drying technology, Equinor significantly reduces the volume of food waste, making it easier to repurpose organic materials for alternative uses, such as composting or bioenergy production. This initiative not only improves waste handling efficiency but also aligns with Equinor's broader sustainability goals by reducing its overall carbon footprint.

In addition to operational waste reduction measures, Equinor incorporates waste minimization strategies at the design stage of its facilities. As noted by Respondent F-2, facility planning and process engineering are key components in ensuring sustainable waste management. The company has been actively designing facilities with improved chemical reuse strategies, aiming to minimize material wastage and maximize resource efficiency. By integrating waste reduction principles into facility design, Equinor ensures that its industrial processes operate with lower waste output, promoting a more sustainable and efficient production cycle.

Beyond technological and operational strategies, Equinor also places strong emphasis on behavioural change and corporate culture to drive sustainability efforts. The company actively promotes awareness campaigns and employee engagement programs to encourage sustainable waste management practices at all levels of operation. Employees receive training on waste reduction techniques, and internal sustainability initiatives provide incentives for personnel to actively participate in waste minimization efforts (Respondent F-1). These programs help to develop a culture of environmental responsibility, ensuring that waste reduction remains a key focus across all departments and operational teams.

By implementing these multifaceted waste reduction strategies, Equinor continues to advance its commitment to sustainability, environmental stewardship, and circular economy principles. Through technological advancements, collaborative partnerships, facility design improvements, and employee engagement initiatives, the company is making significant progress toward reducing its overall waste output and optimizing its resource utilization.

5.5.1.5. Waste Transportation and Logistics at Equinor

Equinor has developed a comprehensive waste transportation system that prioritizes safety, regulatory compliance, and environmental sustainability. The company's approach to transporting waste, particularly hazardous waste, is designed to ensure that all materials are moved securely and in compliance with both local and international regulations. Waste transportation is carried out by licensed waste carriers that operate vehicles compliant with International Safety Guidelines (ISG), ensuring that waste is managed with the utmost care, reducing the risk of accidents or environmental contamination (Respondent F-2).

Equinor places a significant emphasis on regulatory compliance during the waste transportation process. For hazardous waste shipments, the company requires all transportation activities to be accompanied by government permits and transfer documentation. This ensures full traceability of the materials from their origin to their final disposal point, a critical step in maintaining accountability and transparency throughout the waste management process (Respondent F-2). The required permits and documentation provide regulatory oversight and help guarantee that all actions comply with national and international waste disposal standards.

In addition to permit requirements, Equinor utilizes a waste transfer note system to meticulously record every transfer of waste. This system tracks the movement of waste materials, enabling real-time audits and ensuring that the transportation and disposal processes align with both local and international environmental regulations (Respondent

F-2). The use of this system helps maintain a comprehensive audit trail, which is invaluable for regulatory inspections and internal compliance checks. It also enhances the company's ability to respond to any issues promptly, ensuring swift corrective actions when necessary.

Equinor's waste transportation operations further incorporate safety measures aimed at preventing spills, leaks, and exposure risks. The company uses fit-for-purpose containers designed to securely hold hazardous materials, ensuring that the contents are safely transported without any risk of contamination. These containers are built with specialized features to withstand the demands of transporting hazardous waste, providing additional security and peace of mind that the materials will not cause harm to the environment or surrounding communities during transit (Respondent F-1).

Equinor has embraced digital technology to enhance waste transportation efficiency and safety. Advanced tracking systems and digital monitoring tools have been integrated into the company's logistics network to ensure that waste movement is closely monitored at all stages. These systems provide operational transparency, allowing Equinor to track and monitor waste from its production site to the disposal or treatment facility. The digital tools not only help improve logistical planning and coordination but also support rapid responses to any potential safety concerns, such as route diversions or delays, which could lead to regulatory non-compliance (Respondent F-2).

By adopting these cutting-edge technologies, Equinor can ensure that waste transportation is not only efficient but also compliant with the highest safety standards. The use of digital monitoring further reduces the risk of human error, enabling faster, more accurate reporting and decision-making. Additionally, the ability to monitor waste movement in real-time provides the company with critical data that can be used to improve future waste transportation strategies, reducing operational costs while enhancing environmental safety.

However, Equinor faces some logistical challenges during transportation of waste management. One of the primary challenges Equinor faces is the limited availability of local hazardous waste treatment facilities, particularly for specialized materials such as PiraSpec absorbents, which require highly specific disposal methods (Respondent F-1). In regions where such treatment facilities are scarce, Equinor is often forced to rely on international contractors who possess the expertise and infrastructure necessary to properly manage and dispose of these specialized waste streams. While this ensures proper waste treatment, it also leads to increased costs due to the need for long-distance transportation and higher fees for international disposal services.

The reliance on international contractors also introduces logistical complexity, as coordinating waste transportation and treatment across borders involves navigating additional regulatory hurdles, securing permits, and dealing with longer transit times. These challenges can create delays in the waste disposal process and result in higher transportation-related emissions and environmental impact. Moreover, the added complexity of international shipping can create unforeseen risks, such as potential incidents during transit or delays in receiving necessary documentation.

Given these challenges, Equinor recognizes the importance of expanding regional waste treatment infrastructure to reduce its reliance on international contractors. Investing in local facilities capable of processing specialized hazardous waste materials would not only improve operational efficiency but also reduce the carbon footprint associated with long-distance waste transportation. By strengthening the local infrastructure for hazardous waste treatment, Equinor could enhance its sustainability efforts, lower costs, and improve the overall environmental performance of its waste management strategies.

Equinor's reliance on international waste contractors underscores the need for a strategic push toward enhancing regional waste management capabilities. The company is actively exploring opportunities to collaborate with local authorities, industry partners, and waste management providers to help develop the infrastructure necessary for handling more specialized hazardous waste within regional contexts. By fostering partnerships and investing in localized solutions, Equinor aims to alleviate some of the logistical complexities associated with international waste transportation, improve sustainability outcomes, and reduce transportation-related emissions.

This approach aligns with Equinor's broader sustainability goals, as local waste management infrastructure reduces the carbon footprint of waste handling operations and minimizes environmental impact. Furthermore, by relying on local facilities, the company can improve response times for waste management, decrease costs, and better integrate its operations with community and regulatory requirements.

Through its commitment to sustainable waste transportation, Equinor aims to enhance the environmental performance of its operations while meeting the complex demands of global waste management. By refining its waste transportation processes and supporting regional infrastructure development, the company can continue to lead the way in responsible waste management practices, contributing to a more sustainable and circular economy.

5.5.1.6. Performance Monitoring and Key Performance Indicators (KPIs) at Equinor

Equinor has developed a robust and comprehensive set of Key Performance Indicators (KPIs) to monitor, evaluate, and improve its waste management practices. These KPIs are integral to ensuring the company's waste handling processes not only comply with regulatory standards but also contribute effectively to its broader sustainability objectives. The metrics derived from these KPIs help the company assess its environmental impact, operational efficiency, and overall effectiveness in managing waste across its operations, providing a foundation for continuous improvement and strategic alignment with global sustainability goals.

The primary KPIs that Equinor employs to evaluate its waste management performance include the following:

1. **Reduction of Hazardous Waste Quantities:** One of the foremost KPIs focuses on reducing the quantity of hazardous waste generated through improved processing technologies and optimized waste minimization strategies (Respondent F-1). Equinor aims to minimize the generation of hazardous waste by refining its operational processes, introducing cleaner technologies, and adopting more efficient waste treatment methods. By enhancing these treatment

techniques, the company seeks to significantly reduce its reliance on landfill disposal. This reduction in hazardous waste not only lowers the environmental impact of disposal practices but also aligns with global efforts to minimize hazardous material accumulation. Equinor's commitment to reducing hazardous waste underscores its dedication to mitigating the risks associated with harmful waste streams and promoting long-term sustainability.

2. **Increase in Recycling Rates for Non-Hazardous Materials:** Another critical KPI for Equinor is the increase in recycling rates for non-hazardous materials, including plastic, paper, metal, and organic waste (Respondent F-1). This KPI is directly linked to the company's support for circular economy initiatives, where the focus is on reducing resource consumption, extending the life cycle of materials, and reducing waste sent to landfills. By prioritizing the recycling of materials such as plastics, metals, and organic matter, Equinor seeks to close the loop on resource use, ensuring that valuable materials are repurposed and reused in a sustainable manner. The company continuously explores innovative recycling solutions, such as advanced sorting technologies and waste-to-energy processes, to improve its recycling efficiency and minimize its environmental footprint. These efforts are part of Equinor's broader strategy to foster a circular economy within its operations and contribute to a more sustainable future.

3. **Environmental Compliance Inspections and Audits:** Equinor conducts regular environmental compliance inspections to verify that its waste management activities adhere to both internal policies and external regulatory requirements, including local, national, and international standards (Respondent F-2). These inspections play a critical role in identifying any potential non-conformances and ensuring that corrective actions are promptly implemented. The thoroughness of these audits enables the company to maintain a high level of environmental integrity in its operations, ensuring that its waste management practices do not contribute to pollution or ecological degradation. Moreover, these inspections help Equinor stay ahead of emerging regulations and anticipate changes in environmental policy, positioning the company as a responsible corporate entity that actively contributes to the preservation of ecosystems and human health.

4. **Tracking Waste Inventory and Disposal Efficiency via Digital Tools:** To improve the transparency and accuracy of its waste management processes, Equinor tracks waste inventory and disposal efficiency using advanced digital monitoring tools (Respondent F-2). These automated systems allow for real-time data collection, reporting, and analysis of waste generation trends, treatment processes, and disposal routes. By employing these digital tools, Equinor gains deeper insights into its waste production and handling, enabling better decision-making and more efficient resource allocation. This real-time tracking ensures that waste streams are closely monitored throughout their lifecycle, from generation to final disposal, and that data is available for continuous analysis. It also facilitates prompt corrective actions if inefficiencies or regulatory violations

are detected. Furthermore, by automating waste tracking, Equinor enhances overall operational transparency and ensures that waste management decisions are based on accurate, up-to-date information.

These KPIs collectively form the foundation of Equinor's waste management strategy, ensuring that the company maintains a data-driven approach to its sustainability goals. By focusing on both the reduction of waste and the optimization of waste handling processes, Equinor can make informed, evidence-based decisions that drive continuous improvements. Regular performance reviews and KPI assessments allow the company to identify gaps in its waste management practices, evaluate the effectiveness of its current strategies, and fine-tune its waste reduction initiatives in response to emerging environmental challenges and technological advancements.

Equinor's commitment to improving its waste management framework is also reflected in its ongoing efforts to adapt to evolving industry standards and regulatory requirements. As global environmental challenges continue to grow, such as increased pressure to reduce carbon emissions, minimize plastic pollution, and tackle the environmental impact of waste, the company's KPIs provide a dynamic and adaptable framework for addressing these issues. Equinor's proactive stance in refining its waste management practices not only strengthens its compliance with existing regulations but also positions it as a leader in the transition toward a more sustainable and circular economy.

Moreover, these KPIs help Equinor measure the broader environmental benefits of its waste management efforts, such as reduced carbon emissions, minimized environmental degradation, and enhanced resource conservation. By continuing to refine these performance metrics, Equinor ensures that its waste management strategies evolve in line with best practices, technological innovations, and global sustainability trends. This adaptive approach fosters a culture of continuous improvement, where each step in the waste management process is optimized to contribute to a more sustainable, responsible, and economically viable future.

In conclusion, Equinor's comprehensive set of KPIs not only ensures the effectiveness and efficiency of its waste management practices but also reinforces the company's broader commitment to environmental stewardship. By focusing on reducing hazardous waste, enhancing recycling rates, maintaining regulatory compliance, and leveraging digital tools for waste tracking, Equinor can drive meaningful progress toward its sustainability goals. Through ongoing evaluation and refinement of these KPIs, Equinor will continue to strengthen its waste management framework, helping to mitigate environmental risks, reduce operational costs, and contribute to a more sustainable global economy.

5.5.1.7. Challenges in Waste Management and Reverse Logistics at Equinor

Equinor faces a series of complex challenges in its waste management operations, with particular emphasis on the disposal of hazardous waste, cost-efficiency, and stakeholder engagement. These challenges require an ongoing commitment to innovation, close collaboration with regulatory authorities, and substantial investments to achieve long-term environmental sustainability while maintaining operational effectiveness. The company is actively working to address these issues by enhancing its strategies and forging stronger partnerships within the industry.

One of the most significant obstacles highlighted by Respondent F-1 is the limited availability of specialized local disposal options for hazardous waste, specifically in relation to materials such as PiraSpec absorbents. Due to the lack of regional treatment facilities capable of processing these specialized materials, Equinor often finds itself reliant on outsourcing to international waste processing plants. This situation presents a considerable logistical burden, as hazardous waste must be transported over long distances to facilities equipped to handle such materials. Furthermore, this reliance on external treatment plants significantly escalates the financial costs associated with hazardous waste disposal, as transportation and processing fees add up. Given these challenges, Equinor is exploring opportunities to invest in localized treatment facilities, as well as more efficient waste disposal methods that could reduce both transportation costs and environmental impact.

In addition to the logistical and financial challenges posed by hazardous waste disposal, Equinor also faces an issue of awareness and compliance among external contractors. While the company enforces strict environmental and sustainability policies, some of its third-party contractors may not be fully aligned with these standards, which can lead to inconsistent practices and potential non-compliance with waste management protocols. As waste disposal is often outsourced to external vendors, this inconsistency can create significant risks, particularly in relation to hazardous waste handling. To address this gap, Equinor has implemented a series of enhanced contractor training programs, aiming to improve awareness of the company's sustainability commitments and operational standards. The company has also strengthened its compliance monitoring frameworks to ensure that third-party contractors adhere to the same high environmental standards required by Equinor. These efforts are designed to foster better collaboration between internal teams and external vendors, ensuring that all waste management practices meet Equinor's stringent environmental objectives.

Furthermore, the high financial costs associated with outsourcing waste disposal are a substantial concern for Equinor, particularly when dealing with specialized materials such as spent catalysts and chemically contaminated industrial waste. As the company relies on third-party vendors to process these materials, the associated costs can be significant, creating strain on the budget and affecting the company's overall financial performance. Respondent F-1 noted that this reliance on external vendors also brings challenges in terms of scalability, as demand for waste disposal services can fluctuate based on project timelines, making it difficult to secure cost-effective solutions. To mitigate these financial pressures, Equinor is exploring alternative strategies to reduce waste generation in the first place, such as optimizing operational processes, and increasing its investment in waste recycling partnerships. By focusing on waste minimization, Equinor aims to lower both the generation and disposal costs of hazardous waste, thereby ensuring a more cost-effective and sustainable waste management approach.

In addition to financial challenges, Equinor faces the complex task of managing large volumes of waste, particularly spent catalysts, which require specialized treatment processes. Spent catalysts are difficult to treat and require extensive logistical coordination, as they often necessitate specific handling and storage protocols to avoid contamination and ensure safe disposal. Given the technical difficulties involved in processing these materials, Equinor is actively investigating the development and implementation of advanced waste treatment technologies. The goal is to enhance waste recovery efforts, reduce the environmental impact of spent catalysts, and support the company's broader commitment to the circular economy. By focusing on developing innovative treatment solutions, Equinor aims to close the loop on waste materials, promoting recycling and reuse, and ultimately reducing the need for landfill disposal.

To address these challenges, Equinor continues to prioritize research and development initiatives, seeking to identify new technologies and practices that can enhance its waste management processes. In addition to investing in advanced treatment methods, the company actively collaborates with regulatory bodies, industry leaders, and environmental organizations to stay ahead of evolving waste management standards. By working together with these stakeholders, Equinor can ensure that its waste management practices remain effective, efficient, and aligned with emerging regulations and global sustainability trends.

Moreover, Equinor is committed to refining its waste reduction and sustainability strategies to promote continuous improvement. This includes strengthening its efforts to engage stakeholders, whether they be contractors, regulatory agencies, or local communities, ensuring that environmental sustainability remains at the forefront of its operations. Through these ongoing initiatives, Equinor aims to not only address current challenges but also position itself as a leader in the sustainable management of hazardous and non-hazardous waste, furthering its commitment to reducing its environmental impact while maintaining operational excellence.

In conclusion, while Equinor faces several significant challenges in waste management, including limited disposal options for hazardous materials, financial pressures, and the need for enhanced contractor compliance, the company is taking a proactive approach to addressing these issues. Through continued innovation, investment in advanced waste treatment technologies, and stronger stakeholder engagement, Equinor is working to overcome these challenges and further solidify its position as a responsible corporate entity committed to environmental sustainability. By refining its waste management strategies, Equinor is not only ensuring compliance with regulatory requirements but also making meaningful progress toward its long-term sustainability goals.

5.5.1.8. Opportunities for Improvement and Future Strategies

Equinor's waste management practices demonstrate a robust framework aimed at ensuring regulatory compliance and advancing sustainability. However, the interviews reveal several opportunities for improvement and potential future strategies that could enhance efficiency, reduce environmental impact, and align with emerging industry trends.

One prominent opportunity for improvement lies in addressing the infrastructural limitations for hazardous waste treatment, particularly for challenging materials like PiraSpec. Respondent F-1 notes that Equinor lacks "the necessary equipment, technology, and expertise required for safe disposal" onsite, relying instead on international contractors due to limited facilities in Algeria (F-1). This dependency presents a strategic opportunity to invest in localized treatment infrastructure. Developing onsite or regionally accessible processing capabilities for hazardous wastes, such as spent catalysts and pyrophoric materials, could reduce transportation costs, mitigate delays associated with international vendor coordination, and enhance control over disposal processes. Such an initiative would require capital investment but could yield long-term benefits by improving operational autonomy and reducing reliance on external entities, aligning with Equinor's sustainability goals.

Another area for enhancement is the optimization of waste reduction at the source, an approach both respondents emphasize as critical yet underexplored. Respondent F-2 advocates for "designing the waste generation out" during the facility design phase, suggesting that proactive strategies-such as selecting durable materials, modular designs, and integrated recycling infrastructure-could significantly limit waste creation (F-2). This preventive approach could be expanded by incorporating advanced lifecycle assessment tools during planning stages to identify potential waste streams and design them out before operations commence. Additionally, Respondent F-1 highlights operational efforts like "waste reduction at the source" to avoid landfilling, exemplified by the introduction of a drying machine for food waste to produce fertilizer (F-1). Scaling this technology across sites and exploring similar innovations for other waste types, such as chemical absorbents or expired chemicals, could further minimize waste volumes and enhance resource recovery, reinforcing Equinor's circular economy principles.

The management of recyclable materials presents a further opportunity for strategic improvement through enhanced vendor collaboration and community engagement. Respondent F-1 describes Equinor's practice of donating recyclables like plastic bottles and aluminium cans to contractors, covering transportation costs to reduce financial burdens (F-1). While this reduces landfill use, it could be evolved into a more structured circular economy model by establishing formal partnerships with local recyclers or communities to repurpose these materials into value-added products, such as construction materials or consumer goods. Respondent F-1 also suggests "exploring vendor partnerships for catalysts to develop recycling solutions," indicating a nascent strategy that could be expanded to other recyclables (F-1). This approach would not only enhance recycling rates but also create economic opportunities locally, strengthening Equinor's social license to operate.

Technological innovation offers a significant avenue for future strategies, particularly in waste treatment and monitoring. Respondent F-1 mentions the adoption of a drying machine for food waste to reduce greenhouse gas emissions, transforming it into fertilizer (F-1), while Respondent F-2 references operational practices like glycol reuse and partial change-outs to minimize chemical waste (F-2). Building on these, Equinor could invest in advanced technologies such as pyrolysis or anaerobic digestion for organic and hazardous wastes, enabling energy recovery or biogas production. Additionally, integrating digital tools like IoT-based waste tracking or real-time emission monitoring could enhance the precision of waste inventory management, as suggested by the need for updated waste plans and verified data (F-2). These technologies would improve efficiency, reduce costs, and support Equinor's KPIs for reducing hazardous waste quantities and increasing recycling rates (F-1).

Stakeholder awareness and training represent another critical opportunity for improvement. Respondent F-1 identifies a challenge in “raising awareness among contractors about proper waste segregation and disposal practices” (F-1), while Respondent F-2 notes awareness campaigns like “only take the food you will eat” to reduce food wastage (F-2). Expanding these initiatives into comprehensive training programs for all personnel and contractors could standardize waste handling practices across operations. Incorporating incentivized recycling, as mentioned by Respondent F-2 with alternatives to aerosols (F-2), into a broader behavioural change strategy could further enhance compliance and innovation in waste minimization, fostering a culture of environmental responsibility.

Finally, Equinor could explore waste-to-resource strategies to transform disposal liabilities into economic assets. Respondent F-1’s mention of fertilizer production from food waste hints at this potential (F-1), which could be extended to other waste streams. For instance, ash from incineration (0.9 tons reported in July 2024, per F-2) could be researched for use in construction materials, while treated non-aqueous mud and cuttings (F-2) could be repurposed for land reclamation. Such strategies would require R&D investment but could reduce landfill dependency, generate revenue, and align with Respondent F-2’s vision of a circular economy where waste is “a resource to be reused or transformed” (F-2).

In summary, Equinor’s waste management could be enhanced through localized treatment infrastructure, source reduction via design optimization, expanded recycling partnerships, technological innovation, enhanced training, and waste-to-resource strategies. These opportunities, rooted in the respondents’ insights (F-1, F-2), offer a roadmap for Equinor to elevate its practices, balancing operational efficiency with environmental stewardship and setting a benchmark for sustainable waste management in the energy sector.

5.6. ExxonMobil’s Waste Management

ExxonMobil is one of the world’s leading energy companies, committed to addressing environmental challenges and contributing to a more sustainable future. With a focus on operational waste reduction, advanced recycling technologies, and responsible water management, the company aims to integrate circular economy principles into its operations. ExxonMobil’s waste management strategy is guided by its **Operations Integrity Management System (OIMS)** framework and **Environmental Aspects Guide**, which prioritize waste avoidance and the reduction, recovery, and reuse of unavoidable waste. Through these initiatives, ExxonMobil strives to minimize its environmental impact while continuing to meet the energy and resource needs of society.

ExxonMobil’s waste management strategy centres on a waste mitigation hierarchy that prioritizes avoiding waste generation where possible, followed by reducing, recovering, and reusing waste when unavoidable, a practice integrated across its global supply chain and facilities to meet environmental objectives. The company minimizes waste through process improvements and efficiency enhancements, and where waste persists, it separates oil from water and solids for reuse, with water recycled and waste repurposed into alternative fuel sources.

The table below outlines ExxonMobil's hazardous and non-hazardous waste generation, disposal, and beneficial reuse from both remediation and operations activities between 2019 and 2023. The data reflects the company's efforts to minimize waste through reuse and recycling, while responsibly managing waste disposal.

Table 47. Sustainability report of ExxonMobil between 2019 and 2023

Indicator	Units	2019	2020	2021	2022	2023
Total hazardous waste generated from remediation	millions of metric tons	1.4	0.9	0.9	0.5	0.6
Total hazardous waste disposed from remediation	millions of metric tons	1.4	0.9	0.9	0.5	0.6
Total hazardous waste beneficial reuse from remediation	millions of metric tons	<0.1	<0.1	<0.1	<0.1	<0.1
Total non-hazardous waste generated from remediation	millions of metric tons	0.9	0.4	0.7	0.6	0.7
Total non-hazardous waste disposed from remediation	millions of metric tons	0.8	0.4	0.7	0.5	0.7
Total non-hazardous waste beneficial reuse from remediation	millions of metric tons	0.1	<0.1	<0.1	<0.1	<0.1
Total hazardous waste generated from operations	millions of metric tons	0.5	0.3	0.5	0.5	0.5
Total hazardous waste disposed from operations	millions of metric tons	0.2	0.1	0.3	0.3	0.3
Total hazardous waste beneficial reuse from operations	millions of metric tons	0.2	0.2	0.2	0.2	0.2
Total non-hazardous waste generated from operations	millions of metric tons	1.7	0.8	0.7	0.5	0.6
Total non-hazardous waste disposed from operations	millions of metric tons	0.7	0.4	0.6	0.4	0.4
Total non-hazardous waste beneficial reuse from operations	millions of metric tons	1.0	0.4	0.2	0.2	0.2

Source: ExxonMobil, n.d. Greenhouse gas emissions performance data. Available at: https://corporate.exxonmobil.com/sustainability-and-reports/metrics-and-data#Greenhousegasemissionsperformancedata1

1. Hazardous Waste Management

- **Remediation:** Hazardous waste generated and disposed from remediation activities has decreased steadily from 1.4 million metric tons in 2019 to 0.6 million metric tons in 2023. This indicates ExxonMobil's improvement in managing hazardous waste from remediation projects. However, beneficial reuse of hazardous waste from remediation remains minimal, staying at under 0.1 million metric tons annually.

- **Operations:** Hazardous waste generated from operations remained stable at 0.5 million metric tons in 2023, reflecting similar levels as in previous years. Beneficial reuse of hazardous waste from operations has consistently remained at 0.2 million metric tons, suggesting a steady focus on reclaiming hazardous waste.

2. Non-Hazardous Waste Management

- **Remediation:** The generation and disposal of non-hazardous waste from remediation activities have fluctuated between 0.4 and 0.9 million metric tons from 2019 to 2023. In 2023, non-hazardous waste generated from remediation was 0.7 million metric tons, up from 0.6 million metric tons in 2022. Beneficial reuse of non-hazardous waste remains very low at <0.1 million metric tons, indicating room for improvement in recycling efforts from remediation.

- **Operations:** Non-hazardous waste generated from operations decreased significantly from 1.7 million metric tons in 2019 to 0.6 million metric tons in 2023. This reflects a positive trend in minimizing non-hazardous waste in operations. Beneficial reuse of non-hazardous waste from operations has also decreased over the years, from 1.0 million metric tons in 2019 to 0.2 million metric tons in 2023, showing a decline in the reusability of operational waste.

3. Beneficial Reuse

While beneficial reuse of hazardous waste from operations remained stable at 0.2 million metric tons annually, the minimal beneficial reuse from remediation and declining reuse of non-hazardous waste from operations suggest a need for ExxonMobil to enhance its recycling and reuse processes. Increasing the reuse of non-hazardous waste could help further align ExxonMobil's waste management practices with its sustainability goals.

5.6.1. Findings from Interviews (ExxonMobil)

This section presents an in-depth analysis of ExxonMobil's waste management practices based on interviews with company specialists. The responses have been categorized into key topics to provide a comprehensive understanding of ExxonMobil's approach to waste disposal, recycling, logistics, and operational challenges. The findings highlight the company's strategies, performance indicators, challenges and areas requiring improvement.

5.6.1.1. Awareness Levels Within the Company and Among Stakeholders at ExxonMobil

ExxonMobil places a strong emphasis on stakeholder awareness and regulatory compliance, recognizing the critical role these factors play in maintaining its reputation as a leader in environmental stewardship. The company ensures that employees, contractors, and external partners fully understand and adhere to waste management protocols and environmental responsibilities. This comprehensive approach helps mitigate risks and avoid environmental harm, fostering a proactive culture of sustainability across the organization. ExxonMobil's waste management practices demonstrate a commitment that surpasses basic regulatory compliance, reflecting a broader strategic focus on sustainability and operational responsibility; the company actively seeks to prevent potential waste-related issues before they occur, reflecting a forward-thinking and precautionary approach to environmental risk management (Respondent C-1). This approach is in line with ExxonMobil's broader sustainability commitments, emphasizing prevention rather than reaction, and embedding waste management principles deeply into the company's daily operational strategies.

To reinforce this proactive stance, ExxonMobil implements a range of structured training programs, compliance meetings, and engagement initiatives designed to promote best practices and ensure consistent adherence to waste management standards across all levels of the organization. The environmental teams play a pivotal role in these efforts, ensuring that employees, contractors, and other stakeholders are equipped with the knowledge they need to identify, manage, and mitigate waste-related risks effectively (Respondent C-2). Employees are required to participate in regular workshops, safety drills, and compliance refreshers, which are designed to keep them informed of the latest industry regulations, internal policies, and emerging environmental standards. These programs serve as both educational tools and practical frameworks for waste management, instilling a culture of environmental responsibility that ensures waste management practices are not only understood but actively applied daily.

Moreover, ExxonMobil's commitment to regulatory compliance extends beyond internal training and policy implementation. The company works closely with governmental bodies and regulatory agencies, particularly in regions with complex environmental landscapes such as Papua New Guinea. ExxonMobil has a history of collaborating with local authorities to navigate intricate regulatory requirements and ensure that waste disposal processes meet the highest environmental standards (Respondent C-2). This collaboration is essential in regions where waste management regulations may be less standardized or subject to frequent changes, ensuring that ExxonMobil's operations remain compliant with local environmental laws while also meeting its global sustainability goals. The company's robust engagement with both external regulators and internal stakeholders not only supports environmental responsibility but also contributes to greater corporate transparency, builds trust with local communities, and enhances the company's long-term operational resilience.

In conclusion, ExxonMobil's approach to waste management exemplifies a comprehensive and proactive strategy that goes beyond compliance. Through rigorous training, early risk mitigation, and strong regulatory partnerships, the company ensures that waste management is deeply integrated into its organizational culture and operational processes. This approach positions ExxonMobil as a responsible corporate entity that prioritizes sustainability, regulatory compliance, and stakeholder engagement in its waste management practices, thereby reducing environmental impact and reinforcing its commitment to global environmental goals.

5.6.1.2. Waste Disposal and Handling Strategies at ExxonMobil

ExxonMobil's commitment to environmental sustainability and regulatory compliance is reflected in its comprehensive, multi-tiered approach to waste handling, disposal, and remediation. The company prioritizes proactive waste management, ensuring that both hazardous and non-hazardous waste streams are safely and efficiently handled to minimize environmental risks, align with regulatory requirements, and support broader sustainability goals. A fundamental component of ExxonMobil's waste management strategy, as highlighted by Respondent C-1, is onshore waste treatment. When on-site remediation of contaminated soils is not feasible due to the extent of contamination or environmental considerations, ExxonMobil excavates and transports the affected soil to specialized treatment facilities. These facilities are equipped with advanced technologies to neutralize hazardous contaminants, thereby preventing long-term environmental damage to ecosystems, water sources, and human health. Through this approach, ExxonMobil mitigates risks associated with soil contamination, ensuring that hazardous materials are effectively processed and safely disposed of.

To further strengthen its waste management framework, ExxonMobil enforces strict waste classification and transportation protocols. As emphasized by Respondent C-1, the company carefully categorizes waste generated both offshore and onshore, ensuring that each material is processed using the most suitable method. This classification helps determine the most appropriate disposal approach, whether through recycling, incineration, landfilling, or specialized treatment technologies. By ensuring accurate waste categorization at the outset, ExxonMobil prevents mismanagement, reduces contamination risks, and maximizes resource recovery efficiency.

ExxonMobil's commitment to high standards in waste handling is further reinforced through its collaborations with experienced third-party waste contractors, such as Total Waste Management in Papua New Guinea. Respondent C-2 highlighted the role of these partnerships in managing critical aspects of waste collection, segregation, and disposal, ensuring that all waste-whether hazardous or non-hazardous-is processed in strict adherence to local and international environmental regulations. This strategic outsourcing approach allows ExxonMobil to leverage external expertise and infrastructure, optimizing waste handling while maintaining compliance with sustainability targets and industry best practices.

For hazardous waste disposal, ExxonMobil employs structured safety measures, including the use of Safety Data Sheets (SDS). According to Respondent C-2, these documents provide detailed guidelines on hazardous waste handling, storage, transportation, and disposal. SDS play a critical role in protecting employees, contractors, and the environment by ensuring that all stakeholders involved in waste management follow standardized safety protocols. ExxonMobil mandates strict compliance with SDS guidelines, reinforcing its commitment to occupational safety and environmental stewardship.

In cases where hazardous waste cannot be processed domestically, ExxonMobil exports materials to certified disposal facilities abroad. Respondent C-2 explained that this strategy ensures that ExxonMobil's waste treatment processes align with the highest global environmental standards. By leveraging international waste disposal networks, ExxonMobil minimizes domestic waste management challenges while ensuring that all materials are processed using state-of-the-art environmental safety measures.

Beyond traditional disposal methods, ExxonMobil continues to explore and implement innovative waste management practices that enhance sustainability, reduce environmental impact, and optimize resource utilization. A notable example is on-site bioremediation, a process that leverages naturally occurring microbes to break down contaminants in soil and groundwater (Respondent C-1). This technique eliminates the need for excavation and transport, reducing logistical complexity and carbon footprint while accelerating environmental restoration. By allowing microbial activity to degrade harmful substances on-site, ExxonMobil minimizes soil disturbance, lowers operational costs, and expedites remediation efforts. This approach has proven to be highly effective in treating hydrocarbon-contaminated sites, offering a cost-efficient and environmentally sustainable alternative to conventional remediation.

Additionally, ExxonMobil has developed penetration oil waste recovery systems, focusing on extracting valuable materials from waste oil to reduce disposal costs and environmental risks (Respondent C-2). Instead of discarding waste oil as hazardous waste, ExxonMobil recovers and repurposes key components, enabling resource conservation and economic efficiency. This approach extends the lifecycle of valuable materials while aligning with the company's broader circular economy initiatives.

Another emerging focus is landfill resource recovery, where ExxonMobil is actively exploring ways to extract methane and rare earth elements from landfill sites (Respondent C-1). This initiative transforms waste disposal sites into potential resource reservoirs, allowing the company to capture methane emissions for renewable energy while recovering rare earth elements that are crucial for electronics and renewable energy industries. By converting landfills into sustainable resource hubs, ExxonMobil integrates waste management with long-term environmental and economic benefits, further solidifying its commitment to innovative and responsible waste practices.

Beyond disposal practices, ExxonMobil has made substantial financial and operational investments in its waste management infrastructure, recognizing that effective waste handling is an integral part of corporate strategy rather than a secondary function. Respondent C-1 noted that by prioritizing waste management in the initial stages of project planning, ExxonMobil can reduce the likelihood of costly remediation efforts and ensure long-term environmental protection. This front-end risk management approach allows ExxonMobil to address environmental hazards proactively, integrating spill prevention, hazard mitigation, and waste reduction protocols into daily operations.

The management of contaminated water presents another challenge for ExxonMobil, particularly about wastewater that may contain traces of hydrocarbons, chemicals, or other pollutants. To address this, ExxonMobil employs granular activated carbon (GAC) treatment systems, which are highly effective in removing impurities from water. GAC systems work by adsorbing contaminants onto the surface of the carbon, thereby purifying the water before it is released into the environment or reused in operational processes. However, once the activated carbon reaches the end of its useful life cycle, it must be safely disposed of or replaced to prevent environmental hazards. Respondent C-1 emphasized the importance of this process, noting that proper disposal of spent carbon is critical to ensuring that the material does not pose a risk to the environment or public health.

To further enhance efficiency and cost-effectiveness, ExxonMobil has invested in specialized waste containment systems, advanced treatment technologies, and high-standard disposal facilities (Respondent C-2). These investments ensure that hazardous materials are processed safely, reducing regulatory risks and environmental liabilities.

The company also optimizes waste transportation logistics, improving supply chain efficiency and waste movement processes to reduce operational inefficiencies and minimize environmental disruption.

By integrating robust waste disposal strategies, investing in advanced technologies, and fostering strong external partnerships, ExxonMobil ensures that financial and operational resources are allocated efficiently to maintain environmental compliance, reduce waste-related risks, and enhance overall sustainability. Through the adoption of innovative waste management techniques, ExxonMobil continues to push the boundaries of sustainability, ensuring that waste is not merely discarded but actively repurposed to benefit both the environment and industry. These initiatives reinforce ExxonMobil's commitment to minimizing its environmental footprint, aligning waste management practices with broader sustainability objectives, and supporting long-term environmental preservation and operational success

5.6.1.3. Waste Classification and Types at ExxonMobil

ExxonMobil's extensive industrial operations, including upstream oil and gas exploration, refining, and petrochemical production, result in the generation of a wide array of waste materials that require specialized handling and disposal methods to mitigate environmental impacts. The company's commitment to sustainable waste management practices is reflected in its approach to managing both routine and complex waste streams, which require careful categorization, treatment, and disposal in compliance with local, national, and international regulations.

According to Respondent C-1, a large portion of ExxonMobil's waste is generated through daily operational activities. For instance, food waste from on-site personnel is an ongoing waste stream that is collected and disposed of in line with environmental regulations. While food waste is a common byproduct of any operational site, ExxonMobil distinguishes it from other waste types by applying different disposal practices that align with its sustainability objectives. In addition to organic waste, the company also produces various industrial byproducts such as plastics, metals, and paper, which require segregation to ensure they are disposed of in a manner that maximizes recycling opportunities. Plastics and metals are often recycled or sent to specialized recycling facilities, reducing the environmental impact of landfilling and promoting a circular economy approach.

ExxonMobil also handles specialized waste streams that require specific treatment and disposal protocols. As highlighted by Respondent C-1, waste items such as rubber gloves, sampling containers, and contaminated water are commonly encountered in laboratory and operational processes. These waste materials are particularly challenging because they may contain hazardous substances or contaminants. As such, proper categorization and controlled disposal measures are essential to ensure these materials are safely managed and do not pose a risk to the environment or human health. Additionally, contaminated water, often arising from operational processes, requires rigorous treatment procedures to remove hazardous substances before it can be safely released or repurposed.

One of the most significant environmental challenges for ExxonMobil involves the management of contaminated soils, which can result from oil and hydrocarbon spills. As noted by Respondent C-1, the company implements both on-site remediation strategies and offsite treatment methods to address soil contamination. On-site remediation typically involves bioremediation or soil washing techniques, designed to neutralize contaminants and restore the soil's natural condition. For more severe contamination cases, ExxonMobil transports the contaminated soils to specialized offsite treatment facilities, where they are processed to eliminate hazardous substances and mitigate risks to surrounding ecosystems. This approach is crucial in preventing long-term damage to soil and groundwater, two key environmental resources that require careful stewardship.

In terms of industrial waste, Respondent C-2 pointed out that scrap metals make up a significant portion of the company's overall waste stream. These materials are primarily generated during equipment decommissioning, maintenance activities, and infrastructure upgrades. Metals such as steel, aluminium, and copper can often be recycled or repurposed, aligning with ExxonMobil's commitment to reducing its environmental footprint and enhancing the circularity of materials. The company ensures that scrap metals are properly sorted and sent to approved recycling facilities, where they are processed and reintegrated into the production supply chain.

ExxonMobil also carefully manages kitchen waste, particularly from large-scale operations such as refineries and offshore platforms, where food waste generation is common. Kitchen waste is segregated and disposed of separately, in accordance with regulatory requirements, and often undergoes treatment processes such as composting or energy recovery. Similarly, restricted waste, which includes materials that are classified as hazardous due to their chemical composition or potential environmental impact, is subjected to strict segregation and controlled disposal protocols. These waste materials are either sent to specialized treatment facilities or incinerated to neutralize harmful substances and prevent environmental harm.

By implementing comprehensive waste categorization, specialized treatment measures, and strict disposal protocols, ExxonMobil ensures that all waste streams are effectively managed in a manner that minimizes environmental impact. The company's waste management practices focus on reducing, reusing, and recycling materials wherever possible, while also ensuring that hazardous waste is managed with the utmost care to prevent contamination of soil, water, and air. ExxonMobil's commitment to sustainability is reflected not only in its waste reduction initiatives but also in its continuous efforts to adopt innovative technologies and processes that enhance the efficiency and effectiveness of waste management across its global operations.

Moreover, ExxonMobil recognizes the importance of collaboration with regulatory agencies, local communities, and third-party waste contractors to ensure compliance with the ever-evolving environmental regulations governing waste disposal. By staying ahead of regulatory requirements and actively seeking out new waste reduction strategies, ExxonMobil aims to further its sustainability goals while maintaining its role as a responsible corporate entity committed to minimizing its environmental footprint and contributing to the global transition toward a circular economy.

5.6.1.4. Recycling, Reuse, and Waste Reduction Initiatives at ExxonMobil

ExxonMobil has embraced a comprehensive suite of proactive waste reduction strategies designed to minimize waste generation, improve operational efficiency, and cultivate a company-wide culture of sustainability. These initiatives are deeply integrated into the company’s day-to-day operations, ensuring that waste reduction is a fundamental consideration in all aspects of business activities, ultimately leading to long-term environmental benefits and cost savings.

Process Integration: At the core of ExxonMobil’s waste reduction strategy is the seamless integration of waste minimization practices into daily operational procedures. This integration allows the company to identify opportunities for waste reduction at the earliest stages of production and operational workflows, effectively preventing waste from being generated in the first place. By embedding these principles into its operations, ExxonMobil ensures that waste minimization becomes a proactive, ongoing process rather than a reactive measure to address waste after it has been generated (Respondent C-1). This approach also helps streamline processes, improving overall efficiency and reducing resource consumption across various sites.

Employee Training and Awareness Campaigns: Another key component of ExxonMobil’s waste reduction strategy is the ongoing training and education of employees. Regular awareness campaigns and training sessions are conducted to ensure that personnel are well-informed about the latest waste management practices, regulatory compliance requirements, and the company’s sustainability goals (Respondent C-1). These training initiatives not only enhance employees’ understanding of their roles in reducing waste but also foster a sense of responsibility toward environmental stewardship, encouraging individuals to incorporate waste reduction practices into their daily tasks and decision-making processes.

Incentivized Waste Reduction Programs: To further reinforce the company’s commitment to waste reduction, ExxonMobil implements incentivized programs that recognize and reward teams and departments that successfully develop and execute effective waste minimization strategies. These incentives foster healthy competition and encourage operational teams to think creatively about reducing waste while maintaining productivity (Respondent C-1). By incentivizing waste reduction efforts, ExxonMobil enhances employee engagement and drives long-term behavioural changes toward more sustainable practices across the organization.

Innovative Wastewater Recycling: In addition to the more traditional waste reduction strategies, ExxonMobil has also pioneered innovative approaches to recycling and reusing materials. One such initiative involves the use a specialized grass that naturally absorbs chemicals from wastewater. This innovative approach enables ExxonMobil to treat wastewater more sustainably by using natural filtration methods, reducing chemical contamination, and enabling cleaner water discharge into the environment (Respondent C-2). Not only does this method reduce the environmental impact of wastewater disposal, but it also minimizes the need for complex chemical treatments and reduces operational costs related to water treatment and waste management.

By focusing on waste reduction at its source, ExxonMobil ensures a holistic, sustainable, and cost-efficient approach to waste management. Through process integration, employee training, incentivized programs, and innovative recycling initiatives, the company not only reduces its waste output but also supports the broader goals of environmental preservation and operational excellence. These efforts underscore

ExxonMobil’s commitment to sustainability and its ongoing pursuit of innovative solutions that benefit both the environment and the company’s bottom line.

5.6.1.5. Waste Transportation and Logistics at ExxonMobil

ExxonMobil has implemented a comprehensive and structured waste transportation and logistics system, aimed at ensuring the safe, efficient, and compliant movement of waste materials across its operational sites. This approach allows the company to streamline its waste management processes, making them more transparent, traceable, and environmentally responsible. The systematic coordination of waste transportation activities supports ExxonMobil’s ongoing efforts to mitigate its environmental impact and maintain high standards of operational safety.

A core element of ExxonMobil’s logistics framework is its rigorous waste documentation and tracking system, which is essential for maintaining accountability and ensuring regulatory compliance. As emphasized by Respondent C-2, the company issues work orders for each waste transportation batch, which are key to tracking the movement of waste materials from one site to another. These work orders are critical for verifying that waste disposal processes adhere to established protocols and compliance requirements. Through this system, ExxonMobil ensures that waste is handled appropriately at every stage of the transportation process, minimizing the risk of mishandling or non-compliance.

Given the complexity involved in managing both offshore and onshore waste, ExxonMobil relies on third-party contractors with specialized expertise in waste logistics. These contractors are responsible for managing the logistics of waste transportation, including vessel routing, offshore logistics, and transportation planning. According to Respondent C-2, this collaboration with external vendors helps ensure that waste is securely and efficiently moved from production sites to designated disposal or treatment facilities, minimizing the risk of accidents or inefficiencies in the transportation process. By outsourcing this aspect of its waste management operations, ExxonMobil leverages the specialized knowledge and infrastructure of its contractors to ensure compliance with both company standards and regulatory requirements.

In addition to outsourcing logistics functions, ExxonMobil has introduced bulk transportation scheduling as a key strategy to further optimize transportation efficiency. Respondent C-2 noted that large waste streams, such as waste oil, are often transported in large batches, sometimes reaching up to 20,000 litres per shipment. Similarly, scrap metals are shipped in quantities based on the accumulation volume. By consolidating shipments, ExxonMobil can reduce transportation costs, decrease the number of trips required for waste disposal, and minimize the environmental impact associated with waste transportation. Bulk scheduling not only enhances operational efficiency but also helps ExxonMobil meet its environmental sustainability objectives by reducing fuel consumption and lowering greenhouse gas emissions linked to waste transport activities.

Regulatory compliance remains a top priority in ExxonMobil’s waste transportation strategy. As highlighted by Respondent C-2, hazardous waste shipments are subject to strict regulatory oversight and require government permits and transfer documentation. These permits and accompanying paperwork are necessary to ensure that all waste movement activities adhere to national and international environmental regulations. The need for regulatory permits also ensures that hazardous waste is handled with the utmost care and that appropriate safety measures are followed throughout its journey. By maintaining close compliance with these regulatory frameworks, ExxonMobil ensures the responsible management of hazardous waste and supports its commitment to sustainability. Moreover, the requirement for permits and transfer documentation facilitates greater transparency and accountability, reinforcing ExxonMobil's reputation as a responsible corporate entity committed to safe and sustainable waste disposal operations.

Through its structured and transparent waste transportation and logistics system, ExxonMobil not only maintains compliance with environmental regulations but also optimizes its waste management processes to achieve greater operational efficiency. The company's focus on bulk scheduling, third-party expertise, and rigorous documentation further ensures that waste is managed in a manner that minimizes risk, reduces costs, and limits environmental impact. Ultimately, this comprehensive approach to waste logistics aligns with ExxonMobil's overarching sustainability goals and helps position the company as a leader in responsible environmental management practices.

5.6.1.6. Performance Monitoring and Key Performance Indicators (KPIs) at ExxonMobil

ExxonMobil employs a set of well-defined Key Performance Indicators (KPIs) to measure and evaluate the effectiveness of its waste management programs. These KPIs play a crucial role in monitoring the company's progress toward its corporate sustainability goals, ensuring that operations align with both internal policies and external regulatory requirements. By leveraging these indicators, ExxonMobil can identify areas that need improvement, refine its waste management strategies, and track the overall success of its environmental initiatives.

One of the key KPIs ExxonMobil uses is **waste generation metrics**, which provide valuable insights into the volume and types of waste produced across various operational sites. These metrics help the company assess its waste output on an ongoing basis, enabling the identification of waste generation patterns and facilitating better forecasting and planning for waste management activities. As noted by Respondent C-2, the collection and analysis of waste generation data also allow ExxonMobil to take proactive steps to reduce waste production at the source, aligning with its goal to minimize environmental impact.

Another important KPI is **waste disposal and recycling rates**, which are used to track the company's landfill diversion efforts. By measuring the percentage of waste diverted from landfills through recycling or other sustainable disposal methods, ExxonMobil evaluates its progress in reducing its reliance on landfills and its success in implementing sustainable waste reduction strategies. This KPI is central to ExxonMobil's commitment to the circular economy, ensuring that as much waste as possible is reused or repurposed, thus minimizing its ecological footprint. According to Respondent C-2, high recycling rates are a sign of ExxonMobil's success in promoting waste-conscious practices across its operational sites and supply chain.

Compliance monitoring systems are another critical KPI that ExxonMobil uses to ensure that waste handling practices consistently meet environmental regulations and adhere to internal corporate policies. This system tracks compliance with local, national, and international waste disposal regulations, as well as internal corporate guidelines. By monitoring compliance, ExxonMobil can mitigate regulatory risks, avoid fines, and maintain its reputation as a responsible corporate entity. Respondent C-2 highlighted the importance of these monitoring systems in maintaining the integrity of the company's waste management processes and ensuring that employees and contractors follow best practices for waste handling.

Finally, **efficiency tracking for hazardous waste disposal** is a KPI used to evaluate the effectiveness of hazardous waste handling, transportation, and processing. This KPI focuses on the safe and efficient management of hazardous waste streams, ensuring that all materials are processed according to industry best practices and environmental safety standards. Respondent C-2 mentioned that this KPI is particularly important in tracking how well ExxonMobil manages the risks associated with hazardous waste, especially given the complexity of moving hazardous materials from operational sites to treatment or disposal facilities. By monitoring these efficiency metrics, ExxonMobil can continually optimize its hazardous waste processes, ensuring that they remain safe, cost-effective, and compliant.

Incorporating these KPIs into its waste management strategy allows ExxonMobil to continuously track, assess, and improve its waste handling practices. The use of performance data to drive decision-making enables the company to ensure that its waste management initiatives remain effective and aligned with its broader sustainability and regulatory compliance objectives. Additionally, by using KPIs, ExxonMobil fosters a culture of continuous improvement, where waste reduction and sustainable practices are embedded into every stage of its operations.

5.6.1.7. Challenges in Waste Management and Reverse Logistics at ExxonMobil

Despite ExxonMobil's well-structured waste management framework, several persistent challenges hinder operational efficiency and sustainability. These challenges stem from geographical constraints, regulatory limitations, infrastructure deficiencies, and high transportation costs, necessitating continuous improvements and strategic adjustments to waste management policies.

One of the primary challenges ExxonMobil faces is limited landfill availability, particularly in densely populated or geographically constrained regions such as the Northeastern United States, Japan, and Singapore (Respondent C-1). In these areas, securing adequate landfill space is difficult due to strict environmental regulations, land scarcity, and community opposition to waste disposal sites. As a result, ExxonMobil must seek alternative waste disposal solutions, including recycling, incineration, and international waste shipment, to comply with environmental standards and operational requirements.

Another significant challenge involves long-distance waste transportation, as the lack of local disposal facilities requires ExxonMobil to transport waste over extended distances (Respondent C-1). This issue is particularly relevant in remote operational sites where waste treatment plants are not readily accessible. Long-distance waste transportation increases logistical complexity, elevates transportation costs, and poses environmental risks due to fuel consumption and emissions. To address this, ExxonMobil continues to explore waste minimization strategies, process optimization, and investment in regional waste treatment facilities to reduce reliance on extensive waste transport networks.

The disposal of scrap metals presents additional logistical and infrastructure-related challenges, especially in Papua New Guinea, where limited industrial infrastructure prevents the local processing of large-scale industrial scrap metals (Respondent C-2). Due to the lack of adequate recycling facilities, ExxonMobil must export scrap metals to international treatment plants, leading to higher transportation costs, complex regulatory requirements, and extended disposal timelines. Finding economically viable and environmentally responsible solutions for scrap metal disposal remains a key priority for ExxonMobil's waste management teams.

Handling restricted hazardous waste is another critical challenge, as certain hazardous materials cannot be processed domestically and must be shipped overseas for disposal at certified treatment facilities (Respondent C-2). This process requires extensive coordination with government authorities, obtaining permits and certifications, and ensuring that hazardous waste complies with both domestic and international environmental laws. Regulatory complexities, varying hazardous waste classifications across jurisdictions, and rising disposal costs further complicate the process. ExxonMobil actively works to mitigate these issues by strengthening partnerships with certified hazardous waste treatment providers and adopting innovative treatment technologies to reduce the need for offsite disposal.

Additionally, stringent environmental regulations and evolving compliance requirements create ongoing challenges for ExxonMobil's waste management operations. As governments worldwide impose stricter waste management and emissions policies, ExxonMobil must continuously adapt its waste disposal strategies, invest in regulatory compliance programs, and enhance tracking and reporting mechanisms. Regulatory shifts may also impact ExxonMobil's ability to transport and treat certain waste types, requiring the company to maintain flexibility and a proactive approach to evolving environmental laws.

Another challenge is the balancing act between cost efficiency and sustainability. While ExxonMobil invests heavily in sustainable waste management solutions, the high financial costs of waste reduction programs, advanced recycling methods, and regulatory compliance initiatives present budgetary constraints. To remain competitive while adhering to environmental goals, ExxonMobil must continuously evaluate the cost-effectiveness of its waste management strategies and seek innovative financial solutions, such as public-private partnerships and incentive-driven sustainability programs.

Furthermore, cultural, and organizational challenges can impact waste management efficiency. In some regions, employee engagement and contractor compliance vary, making it difficult to enforce uniform sustainability standards across all ExxonMobil operations. Addressing these inconsistencies requires ongoing training programs, stringent contractor oversight, and the development of a strong corporate culture centred on environmental responsibility.

To overcome these challenges, ExxonMobil is committed to enhancing waste management efficiency through advanced technological integration, improving waste treatment infrastructure, and fostering collaboration with regulatory agencies and industry stakeholders. By addressing these persistent obstacles, ExxonMobil continues to refine its sustainable waste management framework, ensuring environmental compliance, operational efficiency, and long-term sustainability.

5.6.1.8. Opportunities for Improvement and Future Strategies at ExxonMobil

Respondents identified multiple opportunities for improving waste management at ExxonMobil, with a focus on waste minimization, enhanced recycling infrastructure, and strategic innovations that could drive long-term sustainability. These areas for development align with ExxonMobil's broader environmental goals and efforts to optimize waste handling efficiency.

One of the primary areas for improvement involves enhancing landfill alternatives to reduce dependency on land disposal. Respondent C-1 pointed out that while modern double-lined landfills with leachate collection systems help mitigate environmental risks, land availability remains a significant challenge, particularly in high-density regions such as the Northeastern United States, Japan, and Singapore. To address this, ExxonMobil could expand investments in waste-to-energy technologies, allowing for greater conversion of waste into usable energy sources. This transition would not only reduce landfill dependency but also align with global decarbonization initiatives.

Another key opportunity lies in maximizing resource recovery from existing waste streams. Respondent C-1 highlighted the potential for landfill resource recovery, particularly in extracting methane and rare earth elements from waste disposal sites. Capturing methane emissions could significantly contribute to reducing ExxonMobil's carbon footprint, while the recovery of rare earth elements could support advancements in renewable energy technologies such as battery production and electronic components. Future strategies could involve greater investment in landfill mining technologies to turn waste disposal sites into sustainable resource hubs, repurposing materials that would otherwise remain unused.

Waste transportation and logistical efficiency were also identified as areas that could benefit from technological advancements and process optimization. Respondent C-2 noted that long-distance transportation of waste remains a costly and environmentally intensive challenge, particularly for hazardous waste materials that require specialized disposal facilities located overseas. By investing in decentralized waste treatment infrastructure, ExxonMobil could reduce the need for international waste shipment, lowering costs and minimizing emissions from transportation logistics. Additionally, incorporating AI-driven waste tracking systems and automated route optimization software could improve waste movement efficiency, allowing ExxonMobil to streamline its supply chain and transportation planning.

From an operational standpoint, Respondent C-1 emphasized the need for greater integration of waste minimization into core business processes. Rather than treating waste management as a separate function, ExxonMobil could embed waste reduction principles into standard operating procedures. This could involve revising procurement strategies to prioritize low-waste materials, implementing design improvements for product packaging, and strengthening collaboration with suppliers to reduce waste generation at the source.

In addition to technical and process-driven improvements, ExxonMobil has an opportunity to expand stakeholder engagement initiatives to increase awareness and participation in sustainability efforts. Respondent C-1 noted that training programs play a key role in maintaining employee and contractor alignment on waste management goals. However, there is room for greater incentives and recognition programs to encourage teams to actively prioritize waste reduction efforts. Establishing performance-based sustainability targets and linking them to corporate incentives could reinforce a culture of environmental responsibility across all levels of the organization.

Furthermore, Respondent C-1 suggested that ExxonMobil could strengthen partnerships with external research institutions to advance scientific innovations in waste treatment. Investing in bioremediation research, for example, could enhance the effectiveness of microbial-based soil and water cleanup efforts, offering a more sustainable alternative to excavation and chemical treatment methods. Similarly, expanding collaborations in waste-to-energy pilot projects could provide ExxonMobil with new pathways for circular economy integration, helping the company repurpose industrial waste into valuable energy outputs.

Looking ahead, ExxonMobil's future strategies will likely focus on leveraging technology, optimizing waste logistics, enhancing landfill alternatives, and increasing circular economy initiatives. By reducing landfill reliance, improving resource recovery, streamlining transportation, embedding waste minimization into operational workflows, and fostering industry collaborations, ExxonMobil can further solidify its position as an industry leader in sustainable waste management.

5.7. Shell's Waste Management Practices

Shell, a leading global energy company with operations in over 70 countries, is a key player in the oil and gas industry, focusing on upstream exploration and production. A central element of its sustainability strategy is effective waste management, underpinned by a commitment to reducing waste, enhancing recycling, and improving resource efficiency through innovative technologies and practices. Shell also collaborates with industry partners to advance these waste management efforts, aligning with circular economy principles to minimize its environmental impact. This introduction highlights Shell's role and its dedication to addressing waste management challenges within its operations.

Shell has undertaken comprehensive measures to enhance its waste management practices as part of its broader environmental sustainability goals. The company's approach centres on utilizing resources and materials efficiently, with a specific emphasis on advancing circular economy principles. To this end, Shell has implemented detailed assessments across its operations to gain a deeper understanding of waste streams and refine its waste management strategies.

Table 48. Waste Management of Shell PLC (Unit-Thousand tonnes)

Indicator	2023	2022	2021	2020	2019
Total waste disposed	2,251	2,012	1,928	2,022	2,128
Hazardous waste disposed	631	878	820	537	708
- Integrated Gas and Upstream	73	132	146	129	154
- Downstream, Renewables and Energy Solutions	546	654	654	403	552
- Other	12	91	20	5	2
Non-hazardous waste disposed	1,619	1,135	1,108	1,484	1,420
- Integrated Gas and Upstream	99	169	222	233	284
- Downstream, Renewables and Energy Solutions	1,388	906	831	1,236	1,116
- Other	133	60	55	15	20
Waste beneficially reused, recycled or recovered	654	493	356	443	441
- Integrated Gas and Upstream	92	103	72	107	83
- Downstream, Renewables and Energy Solutions	545	384	277	332	354
- Other	17	6	7	4	4

Source: Shell, 2023. Shell Sustainability Report 2023, p.86. Available at: https://www.shell.com/sustainability/reporting-centre/reporting-centre-archive/_jcr_content/root/main/section_2106585602/tabs/tab/text_copy/links/item0.stream/1742906426699/4ef5cfa607e5e308ad8a68fc3ddffbe6342f8fa8/shell-sustainability-report-2023.pdf

In 2023, Shell disposed of a total of 2,251 thousand tonnes of waste, marking an increase from the 2,012 thousand tonnes disposed of in 2022. The breakdown of waste disposal is as follows:

- **Hazardous Waste:** 631 thousand tonnes (a reduction from 878 thousand tonnes in 2022). This decrease was partly due to lower volumes of sour water for deep-well disposal from the Shell Scotford Refinery in Canada.
- **Non-Hazardous Waste:** 1,619 thousand tonnes (an increase from 1,135 thousand tonnes in 2022). The rise in non-hazardous waste is primarily attributed to higher volumes of water from production and maintenance activities, particularly at the Shell-operated Scotford Upgrader in Canada, and the ramp-up of low-carbon solutions and other project activities.

Additionally, Shell managed to beneficially reuse, recycle, or recover 654 thousand tonnes of waste in 2023, up from 493 thousand tonnes in 2022. This includes efforts such as incinerating waste to generate energy, thereby reducing landfill dependency.

5.7.1. Findings from Interviews (Shell)

5.7.1.1. Awareness Levels Within the Company and Among Stakeholders at Shell

Stakeholders at Shell demonstrate a high level of awareness and engagement in waste management, driven by stringent regulatory requirements, corporate sustainability goals, and continuous education initiatives. According to Respondent B-1, all international ships and reputable companies working with Shell are mandated to comply with global environmental regulations, ensuring that waste disposal practices align with international legal frameworks. The International Maritime Organization (IMO) regulations, particularly the Marine Pollution (MARPOL) Convention, serve as a foundational guideline for waste handling, defining clear protocols for waste classification, disposal, and treatment at sea. Any violation of these regulations, including improper waste disposal, is subject to strict penalties, reinforcing the importance of compliance among all stakeholders.

Beyond regulatory adherence, Shell integrates comprehensive awareness programs into its corporate framework to ensure that employees, contractors, and third-party vendors understand and implement best practices in waste management. Respondent B-2 highlighted that Shell employees actively participate in monthly Health, Safety, and Environment (HSE) meetings, where waste management is a recurring topic of discussion. These meetings provide a platform for sharing updates on waste handling procedures, reviewing compliance status, and addressing any emerging environmental concerns. Through these engagements, employees are continuously educated on waste minimization strategies, recycling initiatives, and proper waste segregation techniques, fostering a culture of environmental responsibility within the organization.

In addition to regular HSE meetings, Shell conducts specialized environmental training sessions tailored to specific operational needs. Respondent B-3 emphasized that at the onset of every project, Shell organizes an Environmental Task and Work Awareness Plan (ETWAP) meeting. This initiative ensures that all stakeholders, including employees, contractors, and service providers, are aligned with Shell's waste management protocols before commencing work. The ETWAP meetings cover essential topics such as waste classification, handling procedures, emergency response plans for hazardous waste spills, and compliance with local and international regulations. By embedding waste management awareness into the early stages of project planning, Shell proactively mitigates potential environmental risks and reinforces its commitment to sustainable operations.

A key component of Shell's stakeholder engagement in waste management is the development and implementation of a comprehensive **Waste Management Plan (WMP)**. Respondent B-4 explained that this plan is collaboratively drafted by Shell's waste management team, core stakeholders, and vendors, ensuring that all parties involved in waste handling are well-informed and actively contribute to the framework. The WMP outlines the entire waste management lifecycle, from collection and segregation to transportation, treatment, and final disposal. It specifies protocols for handling both hazardous and non-hazardous waste, detailing the necessary safety measures, documentation requirements, and compliance checks to maintain operational integrity.

Moreover, the WMP includes a structured approach to waste segregation, ensuring that recyclable materials such as plastics, metals, and paper are diverted from landfills whenever possible. Respondent B-2 highlighted that Shell's waste management protocols encourage on-site waste sorting at designated collection points, facilitating efficient recycling and minimizing contamination risks. The plan also incorporates digital tracking mechanisms to monitor waste generation, movement, and disposal in real time, enhancing transparency and accountability across the supply chain.

Beyond internal awareness initiatives, Shell extends its educational outreach to external stakeholders, including contractors, suppliers, and regulatory agencies. Respondent B-3 pointed out that periodic training programs and workshops are organized for third-party service providers to ensure that they adhere to Shell's waste management policies. These sessions emphasize the importance of responsible waste disposal, compliance with environmental laws, and the role of sustainable practices in reducing the company's overall carbon footprint.

Shell also engages in collaborative efforts with government agencies, industry partners, and non-governmental organizations (NGOs) to promote broader awareness of waste management best practices. Respondent B-1 noted that Shell actively participates in industry forums and environmental conferences where knowledge-sharing on waste reduction strategies, innovative recycling technologies, and regulatory developments takes place. By engaging with external stakeholders in these discussions, Shell contributes to the global discourse on sustainable waste management while continuously refining its own practices based on industry best practices.

Additionally, Shell recognizes the significance of fostering a waste-conscious culture among its workforce and the communities in which it operates. Respondent B-4 highlighted Shell's participation in corporate social responsibility (CSR) initiatives focused on environmental education and community engagement. Through partnerships with local schools, universities, and environmental organizations, Shell conducts awareness campaigns on waste reduction, recycling, and sustainable consumption. These initiatives not only enhance public understanding of waste management challenges but also reinforce Shell's commitment to environmental stewardship beyond its direct operations.

In summary, Shell's approach to stakeholder awareness in waste management is multifaceted, combining regulatory compliance, employee training, structured waste management planning, and external engagement. By integrating waste management education into its corporate culture, fostering collaboration with industry partners, and leveraging digital tracking tools, Shell ensures that all stakeholders remain actively engaged in sustainable waste handling practices. This comprehensive awareness strategy not only enhances operational efficiency but also strengthens Shell's position as a leader in environmental responsibility within the energy sector.

5.7.1.2. Waste Disposal and Handling Strategies at Shell

Shell has developed a structured waste collection and disposal system that ensures environmental compliance, operational efficiency, and sustainability. By integrating advanced treatment technologies, collaborating with licensed waste management partners, and adhering to global best practices, Shell effectively manages waste disposal across its operations.

According to Respondent B-1, waste generated onboard ships is managed through a combination of incineration, controlled storage, and offloading at port reception facilities. The process is governed by MARPOL regulations, which dictate:

- Incineration of combustible waste in approved onboard incinerators, reducing overall waste volume.
- Secure storage of hazardous materials in sealed containers for later disposal at designated onshore facilities.
- Strict record-keeping and documentation to ensure compliance with environmental regulations.

Shell's onboard waste handling procedures are designed to minimize pollution, ensure safe containment, and enhance efficiency in waste disposal logistics.

Shell's Onshore Waste Treatment Terminals serve as a key waste treatment hub, employing multiple disposal and recycling mechanisms to manage hazardous and non-hazardous waste. Respondent B-4 detailed the treatment process:

1. Hazardous Waste Treatment-Hazardous materials undergo neutralization, incineration, or solidification, depending on their chemical composition and regulatory requirements.
2. Recycling of Reusable Materials-Recyclable waste streams (e.g., metals, plastics, and paper) are sent to certified recycling partners, supporting Shell's circular economy initiatives.
3. Controlled Landfilling and Incineration-Non-recyclable waste is either:
    - Disposed of in engineered landfills, ensuring proper containment.
    - Incinerated in controlled conditions, reducing environmental impact.

By leveraging advanced waste treatment technologies, Shell ensures that hazardous waste is safely processed while maximizing recycling opportunities to minimize environmental footprint.

Offshore waste disposal requires specialized logistics coordination to transport waste from rigs to designated treatment facilities. Respondent B-3 highlighted the following key steps in offshore waste handling:

- Designated waste collection points onboard offshore installations.
- Transfer of waste to supply vessels, ensuring proper containment during transportation.

- Offloading at onshore treatment facilities, where waste is processed according to its classification.

In offshore drilling environments, waste segregation becomes even more complex due to space limitations, regulatory constraints, and environmental risks. Respondent B-3 explained that offshore rigs generate both hazardous and non-hazardous waste, requiring detailed tracking and controlled disposal. Among the most challenging waste types are oil-based mud cuttings, which are produced during drilling operations. These materials cannot be disposed of directly into the marine environment and must be:

- Collected in specialized containment units.
- Transferred to shore-based treatment facilities.
- Processed through thermal desorption or re-injected into deep geological formations to prevent contamination.

Similarly, onboard ships, waste is segregated and stored in compliance with MARPOL guidelines. Respondent B-1 emphasized that ships are equipped with dedicated waste storage areas for hazardous and non-hazardous waste, ensuring that materials are securely contained until they can be offloaded at designated port reception facilities.

Shell continuously refines its waste segregation systems through innovation, employee engagement, and technology-driven solutions. Several key initiatives have been introduced to enhance efficiency:

- Digital Waste Tracking Systems: Respondent B-4 explained that Shell has adopted automated tracking tools to monitor waste volumes, segregation accuracy, and recycling rates across its facilities. These systems provide real-time data on waste handling practices, enabling Shell to optimize segregation efficiency.
- Employee Training Programs: Ensuring proper waste segregation relies heavily on workforce awareness and participation. Respondent B-2 highlighted that Shell conducts regular training sessions for employees and contractors, focusing on waste identification, contamination prevention, and best practices in segregation.
- Standardized Waste Segregation Guidelines: Shell has implemented company-wide waste segregation protocols that align with international standards such as ISO 14001 and MARPOL. Respondent B-3 noted that these guidelines are periodically reviewed and updated to reflect new regulatory requirements and sustainability targets.
- Improved Recycling Infrastructure: To maximize recycling efficiency, Shell has invested in onsite waste processing units at select facilities, enabling preliminary sorting and treatment before waste is transported to larger recycling centres. Respondent B-4 emphasized that this approach reduces logistical costs and improves material recovery rates.

Shell continuously seeks to enhance its waste collection and disposal efficiency through:

- Optimization of waste transportation schedules to reduce costs and emissions.

- Investment in alternative treatment technologies, such as waste-to-energy conversion.
- Strengthening partnerships with certified waste management providers to improve waste processing capacity.

Shell has prioritized cost reduction in its waste management practices, recognizing that efficient waste handling not only contributes to environmental sustainability but also helps optimize operational expenditures. Respondent B-3 elaborated on one of the key strategies employed by Shell: compacting waste. This approach involves the physical compression of waste materials to reduce their volume, which in turn decreases the frequency of transportation trips required to move the waste. By reducing the number of trips needed to transport waste to treatment facilities or disposal sites, Shell can cut down on both logistical costs and the carbon emissions associated with transportation. This strategy helps Shell achieve greater cost efficiency while simultaneously reducing its environmental impact.

Additionally, Respondent B-4 highlighted another crucial aspect of Shell's cost reduction strategy: waste reduction at the source. By preventing unnecessary procurement of materials that could potentially become waste and minimizing excess production, Shell effectively reduces the volume of waste generated in the first place. This proactive approach not only leads to lower disposal costs but also helps conserve resources and reduces the overall environmental footprint of the company's operations. Minimizing waste generation at the outset is considered the most economically viable strategy, as it eliminates the need for costly disposal and treatment processes down the line.

Through these strategic initiatives, Shell ensures that its waste management practices remain effective, sustainable, and aligned with global environmental standards.

5.7.1.3. Waste Classification and Types at Shell

According to Respondent B-1, Shell classifies waste into several distinct categories, each requiring specific disposal and treatment protocols:

1. Food Waste-Organic waste generated from kitchens, canteens, and onboard vessels. Depending on MARPOL regulations and environmental considerations, food waste may be:
    - Disposed of at sea under controlled conditions in compliance with international maritime laws.
    - Collected and composted where onshore facilities allow for organic waste processing.
2. Recyclable Materials-Includes paper, wood, plastic, glass, and metals, which are segregated at collection points and transferred to designated recycling facilities. Respondent B-2 highlighted that Shell actively works to increase recycling rates, ensuring that as much material as possible is diverted from landfills and repurposed into new products.
3. Hazardous Waste-Comprising batteries, chemicals, spent catalysts, oil-based substances, and contaminated industrial waste, hazardous materials require

specialized containment, handling, and disposal procedures. Respondent B-3 noted that hazardous waste from offshore drilling operations-such as oil-based mud cuttings-demands strict regulatory compliance and cannot be treated through conventional waste management methods. Instead, these materials undergo chemical stabilization, neutralization, or incineration at licensed treatment facilities.

4. Operational Waste-Includes waste generated from industrial activities, such as ash from incinerators, used oil, spent lubricants, and non-recyclable solids. Respondent B-4 emphasized that this type of waste is carefully monitored and tracked to prevent contamination risks and ensure proper disposal.

Shell ensures that each of these waste streams is properly handled by implementing structured segregation protocols at collection points, allowing for efficient downstream processing. Respondent B-2 highlighted that clear waste labelling systems, color-coded bins, and employee training initiatives have been put in place to ensure waste is correctly categorized from the outset.

5.7.1.4. Recycling, Reuse, and Waste Reduction Initiatives at Shell

Shell has embedded recycling and reuse as key components of its waste management strategy, aligning with its broader sustainability objectives and commitment to the circular economy. By reducing waste at the source, repurposing materials, and promoting sustainable alternatives, Shell enhances resource efficiency, minimizes environmental impact, and lowers operational costs.

One of the most significant areas of recycling within Shell’s operations involves hazardous waste. Managing hazardous waste requires innovative solutions to prevent environmental contamination while ensuring compliance with safety regulations. Respondent B-2 explained that oil-based mud cuttings, a byproduct of offshore drilling operations, are repurposed in cement production. This process not only diverts waste from disposal sites but also enhances the durability of concrete, reducing the need for virgin raw materials in the cement industry. Similarly, Respondent B-4 highlighted that spent oil and lubricants are collected, refined, and sold to fertilizer manufacturers. This approach prevents hazardous oil waste accumulation while contributing to agricultural sustainability by providing an additional source of nutrients for fertilizers.

In addition to hazardous waste repurposing, Shell actively promotes the recycling of non-hazardous materials, particularly metals, plastics, and paper, which are collected from offshore installations, refineries, and office facilities. Respondent B-3 noted that Shell works closely with certified recycling vendors to ensure these materials are properly processed and reintegrated into production cycles. Scrap metals, such as aluminium and steel from decommissioned equipment, are melted and reused, reducing the demand for new metal extraction. Plastics are sorted and sent to recycling plants where they are transformed into reusable polymer materials, supporting Shell’s broader commitment to sustainability. Furthermore, paper waste from office operations is processed and reintroduced into the supply chain, minimizing landfill dependency.

Wood waste, particularly from packaging and transportation materials, is another area where Shell has implemented recycling and reuse strategies. Instead of disposing of used wooden pallets, Shell either repurposes them internally or donates them to third parties for alternative use. This initiative reduces waste generation and aligns with the company's sustainability policies by minimizing deforestation-related impacts.

Reducing single-use plastics is another critical focus area, particularly in maritime and offshore operations. Respondent B-1 emphasized that Shell has introduced several measures to phase out disposable plastics, including replacing plastic water bottles with refillable containers on ships and offshore platforms, encouraging the use of biodegradable packaging, and implementing procurement policies that limit the purchase of non-recyclable plastic materials. These initiatives align with global regulatory efforts, such as the International Maritime Organization's (IMO) Single-Use Plastic Ban in Maritime Operations, reinforcing Shell's commitment to marine sustainability.

Beyond conventional recycling, Shell is investing in advanced waste-to-resource technologies. Respondent B-4 highlighted that the company is exploring chemical recycling methods to convert plastic waste into feedstock for new plastic production. Additionally, Shell is examining waste-to-energy solutions that transform organic and industrial waste into alternative energy sources, reducing landfill reliance while contributing to energy security. The company is also investigating bioremediation techniques to treat contaminated soil and sludge, further enhancing its environmental sustainability efforts.

By integrating these recycling and reuse strategies into its operations, Shell ensures that waste materials are continuously reintegrated into productive use rather than being discarded. These efforts not only contribute to the company's long-term sustainability goals but also align with global circular economy trends, reinforcing its commitment to responsible resource management and environmental stewardship.

5.7.1.5. Waste Transportation and Logistics at Shell

The transportation and logistics of waste play a crucial role in Shell's broader waste management strategy, ensuring that waste materials are handled, stored, and disposed of in a manner that aligns with environmental regulations and operational safety standards. Given the diverse nature of waste generated across Shell's maritime, offshore, and onshore facilities, the company has implemented structured transportation mechanisms that prioritize compliance, efficiency, and sustainability.

Waste generated aboard ships presents unique logistical challenges, particularly due to the strict regulations governing maritime waste disposal. Respondent B-1 explained that on international vessels, certain waste types, such as food waste, are incinerated on board using approved incinerators to minimize storage and transportation burdens. However, non-incinerable waste, including plastics, metals, and hazardous materials, is securely stored in designated containers until it can be transported ashore for proper disposal. The transportation of such waste requires close coordination with port authorities and certified waste-handling vendors to ensure compliance with MARPOL regulations. Additionally, digital tracking systems are used to document waste quantities, movement, and final disposal, enhancing transparency and regulatory compliance.

Managing waste from offshore drilling and production facilities requires specialized transportation logistics due to the hazardous nature of many waste byproducts. Respondent B-3 highlighted that offshore platforms generate a mix of hazardous and non-hazardous waste, including drilling cuttings, spent chemicals, and general operational waste. Since offshore facilities have limited storage capacity, waste must be routinely transported to onshore treatment and disposal sites. To achieve this, designated waste vessels are deployed at scheduled intervals to collect and transport waste materials safely. These vessels are equipped with sealed containment units that prevent leakage and contamination, ensuring that waste materials do not pose environmental risks during transit. Once onshore, the waste is either treated at dedicated processing facilities or transported further to specialized treatment plants for final disposal.

Shell's onshore waste transportation operations involve a combination of road and sea logistics, depending on the location and type of waste being transported. At waste treatment terminals, waste transportation is managed using a structured logistical framework that adheres to environmental and safety regulations. Respondent B-4 explained that hazardous waste is transported using specialized vehicles equipped with containment and spill-prevention systems, minimizing the risk of environmental contamination. Non-hazardous waste, such as recyclables and general industrial waste, follows a separate transportation stream to designated recycling or landfill sites.

Additionally, Shell employs advanced waste tracking and documentation systems to monitor the movement of waste from collection points to disposal sites. These systems provide real-time data on waste volumes, transportation routes, and final treatment outcomes, allowing the company to optimize logistics and enhance regulatory compliance. Shell also ensures that third-party waste transportation vendors meet strict environmental and safety standards, conducting regular audits to assess their performance.

Moreover, Shell continues to seek ways to integrate sustainability into its waste transportation practices. Respondent B-4 mentioned that the company is assessing alternative fuel options for waste transportation vehicles, including the potential use of biofuels and electric-powered transport fleets to reduce carbon emissions associated with waste logistics. Digital innovations, such as blockchain-based waste tracking, are also being explored to enhance traceability and accountability in waste transportation processes.

By prioritizing efficiency, regulatory compliance, and sustainability in its waste transportation and logistics framework, Shell ensures that waste is managed responsibly while minimizing environmental impact. Through continuous investment in technological advancements and infrastructure improvements, the company remains committed to optimizing its waste transportation processes and reinforcing its leadership in sustainable waste management.

5.7.1.6. Performance Monitoring and Key Performance Indicators (KPIs) at Shell

To ensure the effectiveness and efficiency of its waste management strategies, Shell employs a comprehensive set of Key Performance Indicators (KPIs) that enable the company to track waste generation, disposal, and recycling efforts. These KPIs not only support compliance with environmental regulations but also facilitate continuous improvement in waste handling processes. By systematically measuring waste-related data, Shell can optimize resource utilization, minimize environmental impact, and enhance operational sustainability.

One of the primary metrics Shell monitors is the **total quantity of waste generated** across its operations. Respondent B-1 explained that Shell meticulously tracks the volume of waste produced at offshore, onshore, and maritime facilities, categorizing it into hazardous and non-hazardous waste streams. This classification allows the company to assess which waste types require specialized disposal methods and where reduction strategies can be implemented.

Additionally, Shell closely monitors the **amount of waste incinerated and sent ashore for disposal**. Incineration is commonly used for onboard waste management, especially for food waste and certain hazardous materials, as noted by Respondent B-1. However, incineration is carefully regulated to minimize emissions and ensure compliance with MARPOL guidelines. Waste that cannot be incinerated on-site is transported ashore for further processing, and Shell maintains detailed records of these waste transfers to ensure full traceability.

A significant focus of Shell's waste management performance evaluation is on **recycling rates and resource recovery**. Respondent B-4 highlighted that Shell assesses the proportion of waste materials successfully diverted from landfills through recycling and repurposing initiatives. For example, spent oil is sold to fertilizer manufacturers, and oil-based mud is repurposed for cement production, aligning with circular economy principles. By tracking recycling performance, Shell can identify opportunities to improve waste segregation practices and enhance material recovery rates.

Moreover, the company actively monitors **waste reduction at the source**. This KPI measures how effectively Shell is minimizing waste production through process optimization, efficient resource use, and sustainable procurement practices. Respondent B-4 emphasized that reducing waste generation at the initial stage is the most cost-effective and environmentally beneficial strategy, as it reduces disposal costs and lowers the overall environmental footprint.

Ensuring **compliance with environmental regulations** is a key priority for Shell, and waste management performance is assessed through regular audits and inspections. Respondent B-4 noted that adherence to international standards, such as MARPOL and ISO 14001, is critical in evaluating the company's environmental performance. Any deviations from regulatory requirements are promptly addressed through corrective measures to prevent potential penalties or reputational risks.

Another crucial metric is the **incidence of environmental spills or contamination related to waste handling**. Shell systematically records any spills, leaks, or improper waste disposal incidents, investigating the root causes and implementing preventive measures. By analysing trends in spill occurrences, Shell can enhance waste containment procedures and improve risk mitigation strategies.

Waste management effectiveness is also influenced by workforce competency and engagement. Respondent B-4 mentioned that **employee training effectiveness** is an essential KPI used to gauge how well Shell's personnel understand and implement waste management protocols. Regular Health, Safety, and Environment (HSE) meetings, as well as project-specific Environmental Task and Work Awareness Plan (ETWAP) sessions, provide continuous education on best practices in waste segregation, handling, and disposal.

Shell assesses training effectiveness through employee participation rates, knowledge assessments, and on-site compliance checks. Respondent B-3 emphasized that increasing awareness and accountability among employees directly contributes to improved waste management outcomes, as proper waste handling reduces contamination risks and enhances recycling efficiency.

Beyond environmental and compliance considerations, Shell also evaluates the **economic impact of its waste management strategies**. Respondent B-4 stated that **costs associated with waste handling, transportation, and disposal** are closely monitored to ensure financial efficiency. The company seeks to optimize waste management expenses by reducing unnecessary waste production, implementing cost-effective recycling programs, and streamlining logistics operations.

For instance, compacting waste before transportation reduces the frequency of waste shipments, lowering fuel consumption and transport costs. Additionally, investing in on-site waste treatment solutions helps minimize external processing fees. By tracking cost-related KPIs, Shell continuously identifies areas where waste management operations can be made more financially sustainable.

By analysing these KPIs, Shell can make data-driven decisions to enhance its waste management strategies. Respondent B-4 highlighted that any significant deviations in waste generation rates or compliance performance trigger internal reviews to identify potential inefficiencies. If recycling rates decline or waste generation increases unexpectedly, Shell conducts root cause analyses to determine underlying factors and implement corrective actions.

Furthermore, Shell integrates advanced **digital tracking systems** to improve data accuracy and operational transparency. Automated waste reporting tools enable real-time monitoring of waste movements, providing valuable insights that drive continuous improvement. The adoption of emerging technologies, such as AI-driven waste analytics and blockchain-based traceability, is also being explored to enhance waste management accountability.

5.7.1.7. Challenges in Waste Management and Reverse Logistics at Shell

While Shell has established comprehensive waste management policies aimed at minimizing its environmental impact, the company faces several challenges that hinder the full effectiveness of these efforts. These challenges arise from external factors, including cost-related concerns, infrastructure limitations, and the technical complexity of managing specific waste streams. Despite Shell’s strategic investments and operational innovations, these issues continue to pose significant obstacles to achieving optimal waste management outcomes.

One of the primary challenges faced by Shell, as identified by Respondent B-1, is the high disposal fees at certain port facilities. Shell ships, especially those operating in international waters, often rely on port facilities to handle and dispose of waste generated during their voyages. However, some ports impose substantial fees for waste disposal, particularly for hazardous and non-recyclable materials. These high costs create a financial disincentive for proper waste management practices, as they may encourage companies to seek less expensive but potentially environmentally harmful alternatives, such as improper disposal or inadequate recycling efforts. In response, Shell has been exploring cost-effective waste consolidation strategies, such as compacting waste before transportation to reduce volume and minimize logistical expenses. Respondent B-3 also pointed out that transporting hazardous waste from offshore locations to specialized treatment facilities is complex due to regulatory restrictions and infrastructure limitations. To address this, Shell has been investing in on-site waste treatment solutions that reduce the need for long-distance transportation of hazardous materials.

This issue not only raises operational costs but also undermines Shell’s commitment to sustainable waste management by discouraging the proper segregation and recycling of materials. Respondent B-1 noted that the financial strain imposed by these fees may make it difficult for Shell to meet its environmental targets, such as maximizing recycling rates and minimizing landfill usage. While Shell works to mitigate these challenges by collaborating with ports to negotiate better disposal terms and exploring alternative waste treatment options, the cost of waste disposal remains a significant barrier to the company’s sustainability goals.

Another pressing concern highlighted by Respondent B-3 is the limited availability of specialized treatment facilities for hazardous waste, particularly in remote locations. Offshore drilling operations, for example, generate hazardous waste such as oil-based mud, which requires specialized treatment processes to mitigate environmental risks. However, the lack of infrastructure in remote areas often forces Shell to transport such waste over long distances to treatment facilities that may not always be equipped to handle the specific needs of hazardous materials.

This logistical challenge creates both operational and environmental difficulties, as transporting hazardous waste involves complex coordination and increased carbon emissions from transportation. Additionally, the lack of local facilities capable of handling oil-based mud and other specialized waste leads to inefficiencies in waste management, as the waste often accumulates or is temporarily stored, increasing the risk of contamination or non-compliance with environmental regulations.

The reliance on external treatment facilities, often located far from offshore operations, also presents a financial burden. The costs associated with transporting hazardous waste and the fees charged by specialized treatment plants add up quickly, further straining Shell’s waste management budget and potentially affecting the company’s overall waste reduction objectives. Addressing this challenge requires the development of localized waste treatment infrastructure and investments in advanced technologies capable of handling hazardous waste more efficiently.

Respondent B-4 emphasized that capital-intensive recycling and waste-to-energy initiatives face funding and infrastructure constraints. While Shell has made significant strides in promoting a circular economy approach by repurposing waste materials and exploring waste-to-energy technologies, these initiatives often require substantial upfront investments in infrastructure, technology, and research and development. The development of waste-to-energy facilities, for example, requires considerable capital to build and maintain advanced systems that can safely and efficiently convert waste into usable energy.

Additionally, the adoption of large-scale recycling projects, particularly those involving complex materials such as plastics and spent oil, often demands significant investment in sorting, processing, and treatment infrastructure. Respondent B-4 noted that these initiatives, although potentially highly beneficial in terms of sustainability and energy generation, are often hindered by limited financial resources and competing priorities for capital allocation within the company.

In many cases, the high costs of setting up and maintaining these facilities are seen as a barrier to scaling up recycling and waste-to-energy efforts, particularly in regions where infrastructure is already underdeveloped. As a result, Shell must carefully prioritize its investments in waste management technologies and explore partnerships with external stakeholders, including governments and private sector entities, to share the financial burden of developing such initiatives.

Beyond financial constraints, Shell also faces technological and operational limitations in its waste management practices. The company's waste management efforts depend heavily on the availability of cutting-edge technologies to process and recycle various waste streams. However, the development and implementation of these technologies often take time and require continuous refinement to ensure they are both effective and efficient. Respondent B-3 explained that the absence of robust technological solutions for certain types of waste, such as oil-based mud and other complex materials, hampers Shell's ability to fully optimize its waste management processes.

In some cases, Shell has turned to external vendors and research partnerships to develop and deploy new technologies that can handle waste in more sustainable ways. However, the pace of technological innovation and the need for continuous adaptation to evolving environmental standards remain ongoing challenges.

5.7.1.8. Opportunities for Improvement and Future Strategies at Shell

As Shell continues to assess and refine its waste management practices, several strategic areas for improvement have been identified, reflecting the company's commitment to optimizing its operations and enhancing sustainability. Respondent B-1 suggested improving coordination between ships and shore-based recycling facilities to streamline and optimize waste recycling efforts. This coordination is crucial for ensuring that waste materials are properly sorted, efficiently transported, and processed at the appropriate recycling facilities. By addressing logistical challenges and improving communication between ships and shore facilities, Shell could enhance its recycling efficiency, reduce waste contamination, and lower operational costs, ultimately contributing to the company's sustainability goals.

Another area for improvement, as recommended by Respondent B-4, involves process optimization and product design improvements aimed at minimizing waste generation. This can be achieved by integrating sustainability into the design phase, ensuring that products are made with fewer materials, are more easily recyclable, and have a longer lifespan. Shell can explore opportunities to work with manufacturers to design more eco-friendly products and packaging solutions that generate less waste during production and consumption. A shift towards designing products with circularity in mind-where materials are reused, refurbished, or recycled-could significantly reduce waste across the value chain, supporting Shell's broader sustainability objectives and reducing its environmental footprint.

In addition to operational improvements, Respondent B-3 emphasized the critical need for continuous training programs to enhance employee awareness and compliance with waste management standards. A well-structured training program that educates employees about best practices for waste segregation, recycling, and disposal would ensure consistent adherence to Shell's waste management protocols across all its operations, both onshore and offshore. Ongoing education on environmental policies, compliance measures, and sustainable waste handling practices is essential to maintaining high standards and fostering a culture of sustainability within the organization. It also empowers employees to make informed decisions, contribute to waste reduction efforts, and engage actively in Shell's sustainability initiatives.

Looking ahead, Shell is committed to further advancing its waste management practices, with a focus on implementing more sustainable solutions. Respondent B-1 highlighted the significance of collaboration with manufacturers to develop eco-friendly packaging solutions, which would significantly reduce the environmental impact of packaging waste. By working directly with product suppliers and manufacturers, Shell can influence the design of packaging to ensure that it is recyclable, biodegradable, or even reusable, in line with circular economy principles. These collaborations could lead to the development of packaging that minimizes waste production at the source, supporting Shell's long-term sustainability vision.

Furthermore, Respondent B-4 proposed the expansion of waste-to-energy technologies and investment in digital tracking systems to enhance waste monitoring and reporting capabilities. Waste-to-energy technologies offer a promising solution for converting waste into renewable energy, thereby reducing reliance on traditional waste disposal methods such as incineration or landfilling. By harnessing organic waste to generate bioenergy, Shell can contribute to a more sustainable energy grid while addressing waste management challenges. Additionally, digital tracking systems would provide real-time data on waste generation, treatment, and disposal, allowing Shell to track progress, identify inefficiencies, and make data-driven decisions to further optimize waste management operations.

By integrating these innovative strategies, Shell continues to strengthen its commitment to sustainable waste management practices. The company's ongoing efforts to improve coordination, optimize processes, and invest in advanced technologies reflect its dedication to environmental stewardship, regulatory compliance, and the reduction of its environmental footprint. As Shell progresses with these initiatives, it is poised to make significant strides in reducing waste, promoting the circular economy, and achieving its sustainability targets in both offshore and onshore operations.

5.8. TotalEnergies’ Waste Management Practices

TotalEnergies, one of the leaders in the global energy sector headquartered in Courbevoie, France, maintains a significant presence across more than 130 countries, excelling in upstream exploration, refining, and petrochemical production while increasingly venturing into renewable energy solutions. Built on a legacy of energy innovation, the company is recognized for its dedication to sustainable development, embedding advanced environmental strategies into its operations as it transitions toward a lower-carbon future. Waste management emerges as a vital component of this strategy, with TotalEnergies committed to enhancing resource efficiency through innovative recovery, recycling, and reuse initiatives.

TotalEnergies’ waste management practices are part of a broader commitment to sustainability, with long-term goals that include increasing circularity, reducing waste generation, and promoting the recovery and reuse of materials. The company’s efforts to integrate circular economy principles into its operations demonstrate its leadership in the energy sector’s transition to sustainability.

Below is a summary of TotalEnergies’ waste management performance over recent years, highlighting both hazardous and non-hazardous waste disposal, as well as the overall valorisation (reuse, recycling, and recovery) of waste.

Table 49. Waste Management report of TotalEnergies between 2019 and 2023

Indicator	**Unit**	**2019**	**2020**	**2021**	**2022**	**2023**
Total volume of processed waste	kt	662	501	500	498	521
Non-hazardous waste	kt	375	303	335	322	319
Hazardous waste	kt	288	198	165	176	202
Reuse	%	65	59	61	61	61

Source: TotalEnergies, 2023. Universal Registration Document 2023, p.388. Available at: https://totalenergies.com/system/files/documents/2024-03/totalenergies_universal-registration-document-2023_2023_en_pdf.pdf

Total Waste Processed

The total volume of waste processed by TotalEnergies increased to 521 kt in 2023 from 498 kt in 2022, reflecting a significant growth in waste management activities. The increase in both hazardous and non-hazardous waste suggests that the company has expanded its operations or improved its waste collection and processing methods. This increase, especially in hazardous waste, indicates a heightened focus on comprehensive waste management, ensuring that a larger portion of waste is appropriately processed and treated.

Hazardous vs. Non-Hazardous Waste

Hazardous waste saw a marked increase in 2023, rising to 202 kt from 176 kt in 2022. Non-hazardous waste also increased, but at a lower rate. This suggests that TotalEnergies has been handling more complex and potentially dangerous materials, necessitating robust treatment and disposal systems. The increase in hazardous waste processing could be attributed to stricter regulatory compliance, increased production activities, or improved waste identification and segregation processes within the company's operations.

Waste Valorisation (Reuse, Recycling, Recovery)

The waste valorisation rate remained stable at 61% in both 2022 and 2023. This sustained performance reflects TotalEnergies' ongoing efforts to enhance the circularity of its operations by maintaining a significant percentage of waste that is reused, recycled, or recovered. The continued focus on a high valorisation rate demonstrates TotalEnergies' commitment to circular economy principles, where the focus is on minimizing waste sent to landfills by converting it into valuable resources through reuse and recycling.

5.8.1. Findings from Interviews (TotalEnergies)

5.8.1.1. Awareness Levels Within the Company and Among Stakeholders at TotalEnergies

In the interviews conducted with Total Energies personnel, stakeholder awareness of waste management was highlighted as a crucial element in maintaining environmental compliance and sustainability goals. The oil and gas sector is closely watched because of its impact on the environment, which has raised awareness both inside the industry and among the public. (Respondent D-1).

Internally, Total Energies ensures that employees remain informed through regular sustainability meetings, sensitization programs, and monthly waste tracking reviews. Employees are required to participate in quarterly awareness sessions where waste management policies and goals are reviewed (Respondent D-2). These initiatives are designed to reinforce best practices and ensure that waste handling procedures are consistently followed across the company's operations. Additionally, Total Energies tracks waste data closely, ensuring that waste generation remains within expected parameters and that any significant increases are investigated and addressed promptly (Respondent D-2). Through the implementation of digital monitoring tools and waste audits, the company can analyse trends, identify inefficiencies, and take corrective action where necessary.

Externally, Total Energies enforces waste management compliance among suppliers and contractors as part of its broader commitment to sustainability. The company has established strict procurement policies that require suppliers to have proper waste management systems in place before entering agreements (Respondent D-3). For instance, suppliers providing plastic materials must demonstrate a viable waste disposal or recycling strategy before their products are accepted. This aligns with Total Energies' broader circular economy approach, which seeks to minimize waste production and promote resource recovery (Respondent D-1). By setting stringent requirements for external partners, Total Energies ensures that its sustainability objectives extend beyond its direct operations and influence the entire supply chain.

Moreover, the company collaborates with waste management firms such as Mr. Green Africa to facilitate proper recycling of electronic waste (e-waste) (Respondent D-4).

Given the increasing reliance on electronic equipment in the energy sector, responsible disposal of e-waste has become a priority. By partnering with specialized waste management firms, Total Energies ensures that e-waste is processed in an environmentally friendly manner, reducing the risk of hazardous material leakage into the ecosystem. Employees are also encouraged to participate in waste reduction initiatives, such as returning plastic waste for recycling in exchange for incentives (Respondent D-4). These incentive-based programs not only promote sustainability but also foster a culture of environmental responsibility among staff.

Despite these efforts, awareness gaps remain, particularly in ensuring that all stakeholders, including external contractors, comply with sustainability goals beyond basic regulatory requirements. Communication challenges persist, especially when external partners fail to recognize the full severity of environmental risks associated with improper waste handling (Respondent D-4). Some contractors may view waste management as a secondary concern rather than an integral part of operational excellence, leading to inconsistencies in implementation.

To address this, Total Energies continuously strengthens its engagement with suppliers and contractors, ensuring that they align with its long-term sustainability objectives. This is achieved through enhanced training programs, contractual obligations, and regular audits to verify compliance with waste management protocols. Additionally, Total Energies is exploring the use of digital compliance tracking tools to monitor supplier performance and identify areas where additional support or corrective measures are needed.

Looking ahead, Total Energies plans to expand its stakeholder engagement efforts by integrating more interactive training programs, supplier workshops, and real-time waste tracking dashboards that allow for better transparency and accountability. By leveraging technology and fostering closer partnerships with external stakeholders, the company aims to bridge existing awareness gaps and create a more robust, sustainable waste management framework that aligns with global environmental standards.

5.8.1.2. Waste Disposal and Handling Strategies at Total Energies

Total Energies has established a structured and comprehensive approach to waste management, ensuring that its operations adhere to both regulatory compliance and sustainability objectives. The company prioritizes waste minimization, resource recovery, and responsible disposal practices, integrating these principles into its daily operations. Through the utilization of licensed disposal areas and government-approved treatment facilities, Total Energies guarantees that all waste-handling procedures meet both local and international regulatory standards. This commitment reflects the company’s dedication to maintaining environmental responsibility while ensuring that waste materials are processed safely and efficiently.

A significant aspect of Total Energies’ waste management framework is its robust recycling program, which focuses on reducing landfill dependency and maximizing resource efficiency. The company actively promotes organic waste recycling through composting, which not only diverts biodegradable waste from landfills but also contributes to soil enrichment and agricultural sustainability. Additionally, plastic waste is shredded and returned to manufacturers, reinforcing a circular economy model where materials are reintegrated into production cycles rather than discarded. This approach not only reduces environmental pollution but also conserves finite resources, aligning with global sustainability targets.

One of the key initiatives highlighted by Respondent D-4 is wastewater treatment and reuse, a practice that significantly reduces freshwater consumption and mitigates the environmental footprint of industrial operations. Instead of discharging treated water as waste, Total Energies repurposes it for construction activities, demonstrating an innovative approach to water resource management. Similarly, biodegradable waste is diverted toward agricultural applications, showcasing the company's commitment to sustainable resource utilization beyond conventional industrial processes.

From an operational standpoint, efficient waste logistics and coordination play a crucial role in Total Energies' waste management practices. As noted by Respondent D-3, the administrative aspects of waste management involve meticulous scheduling of waste shipments, ensuring that different types of waste-including plant trash, cardboard, metals, and hazardous materials such as bio-sludge-are handled appropriately. To streamline operations, the company collaborates with third-party waste collection and recycling vendors, ensuring that waste disposal and processing are executed in a timely and compliant manner.

A key takeaway from these operational strategies is the importance of effective communication and scheduling efficiency in waste management. Without proper coordination between departments and external vendors, delays in waste transportation, processing, and regulatory compliance can occur, potentially impacting environmental performance and operational efficiency. By fostering a proactive waste management culture, Total Energies ensures that its waste-handling processes remain efficient, compliant, and aligned with sustainability goals.

Furthermore, the company continues to explore innovative waste reduction techniques, integrating modern technologies to enhance waste monitoring, tracking, and reporting. By investing in digital waste management systems, Total Energies can track waste generation patterns, measure recycling rates, and identify potential areas for improvement. These data-driven insights help optimize waste handling procedures, ensuring that sustainability objectives are met while maintaining cost efficiency and regulatory compliance.

As part of its broader sustainability strategy, Total Energies is actively transitioning from traditional fossil fuels to renewable energy sources. Respondent D-1 emphasized the company's substantial investments in solar power infrastructure and expansion of electric vehicle (EV) charging networks, reinforcing its long-term vision for a low-carbon energy future. These sustainability-driven initiatives complement the company's waste-to-energy efforts, ensuring that Total Energies' waste management strategies are integrated into its broader environmental agenda.

In conclusion, Total Energies demonstrates a highly structured and strategic approach to waste management, emphasizing regulatory adherence, sustainability, and operational efficiency. Through advanced recycling programs, wastewater repurposing initiatives, and strong administrative coordination, the company continues to enhance its environmental performance while aligning with global best practices in sustainable waste management.

5.8.1.3. Waste Classification and Types at TotalEnergies

Waste at TotalEnergies is broadly categorized into hazardous and non-hazardous types, reflecting the distinct handling requirements and environmental risks associated with each. Hazardous waste emerges as a significant category, encompassing materials contaminated by hydrocarbons or possessing toxic properties. Respondent D-1 identifies “catalysts” as a major hazardous waste type generated during refinery turnarounds, alongside “bio-sludge” and “lab waste,” which require specialized disposal due to their chemical composition (D-1). Respondent D-2, operating in the aviation sector, highlights “hazardous waste from capsules used during fuel testing” to detect contaminants like water in Jet A-1 fuel, noting their toxicity precludes recycling and necessitates disposal at hazardous waste facilities (D-2). Respondent D-3 emphasizes “drilling waste” managed through partnerships with service providers, where water and cuttings are separated, implying the cuttings’ hazardous nature due to potential hydrocarbon content (D-3). Respondent D-4 further delineates hazardous waste as “anything that comes into contact with oil,” such as “oil itself or packaging materials contaminated by oil,” including cartons stained with oil and waste oil from tank servicing or customer misuse (e.g., diesel-kerosene mixtures) (D-4). This classification underscores the prevalence of hazardous waste across TotalEnergies’ operations, driven by the inherent properties of oil and gas processes.

Non-hazardous waste constitutes a substantial portion of the waste stream, characterized by its recyclability or lower environmental risk. Respondent D-1 lists “routine plant trash” such as “boxes, wood, and cardboard,” alongside “metals” and “protection debris,” as predominant types, with wood, cardboard, and metal frequently recycled during refinery operations (D-1). Respondent D-2 identifies “used hoses” and “tires” from aviation fuelling equipment as non-hazardous, with rubber from tires recycled or sold as raw material (D-2). Respondent D-3 notes “plastics” and “biodegradable waste” as non-hazardous, with plastics shredded for reuse and organic waste composted for agricultural use (D-3). Respondent D-4 expands this category to include “metal” from tank construction, “paper” from administrative activities, “wood” from pallets (often repurposed, e.g., for cafeteria decor), and “electronic waste” like batteries, managed through recycling partnerships (D-4). These materials, while voluminous, are classified as non-hazardous due to their potential for recycling or safe disposal, aligning with TotalEnergies’ resource recovery efforts.

Organic waste emerges as a distinct subtype within the non-hazardous category, primarily linked to operational and human activities. Respondent D-3 highlights “organic waste” processed via composters into nutrient-rich compost for gardening, and “biodegradable waste” supplied to farmers as fertilizer, reflecting its biological origin and utility (D-3). Respondent D-4 references organic waste directed to landfills in Kenya, where regulatory limits constrain disposal options (D-4). Though less emphasized by Respondents D-1 and D-2, the presence of organic waste in these accounts suggests its relevance across diverse operational contexts, managed through composting or landfilling based on local infrastructure.

The waste types identified-hazardous (e.g., catalysts, bio sludge, lab waste, fuel testing capsules, drilling cuttings, oil-contaminated materials), non-hazardous (e.g., boxes, wood, cardboard, metals, protection debris, hoses, tires, plastics, paper, electronic waste), and organic (e.g., compostable materials, biodegradable waste)-illustrate the complexity of TotalEnergies' waste profile. According to the respondents, hazardous waste predominates in refinery and fuel-handling operations, driven by chemical and hydrocarbon exposure, while non-hazardous waste is generated in nearly every sector, and much of it has strong potential for recycling. Organic waste, though less prominent, reflects sustainable practices in specific regions (D-3, D-4). The respondents' accounts, supported by examples like "almost double the usual amount" during turnarounds and quantitative disposal constraints in Kenya, enrich this classification, highlighting operational and regional variations. This framework provides a foundation for analysing TotalEnergies' waste management efficacy, with implications for sustainability and regulatory compliance warranting further exploration.

5.8.1.4. Recycling, Reuse, and Waste Reduction Initiatives at TotalEnergies

Total Energies places a strong emphasis on waste reduction and recycling as integral components of its sustainability strategy. These efforts are aligned with the company's broader environmental commitments and corporate social responsibility (CSR) objectives. Respondent D-3 elaborated on the organization's ongoing initiatives to enhance recycling rates, particularly for materials such as wood, cardboard, and metal. Recycling is not only perceived as an environmentally responsible practice but also as a cost-effective waste management solution that contributes to overall operational efficiency. By diverting recyclable materials from landfills, the company minimizes waste generation while simultaneously reducing disposal costs and environmental footprint.

Respondent D-4 further underscored Total Energies' commitment to circular economy principles, highlighting the company's efforts to achieve a 100% recycling rate for certain waste streams, particularly scrap metal. This initiative demonstrates a structured approach to resource efficiency, ensuring that valuable materials are recovered and reintroduced into production cycles rather than discarded as waste. In addition to conventional recycling practices, the company actively explores innovative waste management solutions, such as wastewater reuse in construction projects. The reuse of treated wastewater for non-potable applications represents a strategic effort to mitigate freshwater consumption while reducing the ecological impact of industrial operations.

Beyond traditional recycling efforts, Total Energies recognizes the potential of waste-to-energy recovery as a future avenue for enhancing sustainability. Converting organic waste into renewable energy presents an opportunity to simultaneously manage waste streams and contribute to the company's transition toward cleaner energy sources. This approach aligns with global trends in sustainable waste management, wherein energy recovery serves as a viable complement to recycling by generating electricity or biofuels from biodegradable waste materials.

Furthermore, Respondent D-1 highlighted the company's broader sustainability initiatives, which extend beyond waste management to include a transition towards cleaner energy alternatives. This shift includes investments in renewable energy infrastructure, such as solar power generation and the development of electric vehicle (EV) charging stations. These initiatives are part of Total Energies' strategic rebranding as a more sustainable energy provider, reinforcing its long-term ambition to reduce reliance on fossil fuels and integrate environmentally responsible practices into its core business operations.

5.8.1.5. Waste Transportation and Logistics at TotalEnergies

TotalEnergies predominantly outsources its waste transportation logistics to third-party vendors, a practice consistent across the respondents' operational contexts. Respondent D-1, involved in refinery waste management, explains that the team coordinates "waste shipments from the refinery to disposal or recycling facilities" through external vendors, relying on these parties for scheduling and execution (D-1). This external dependency is echoed by Respondent D-2 in the aviation sector, who states that "all logistics for waste management" are outsourced, with specialized companies handling transportation from the site to designated facilities (D-2). Respondent D-3 reinforces this approach, noting that the "transportation department" oversees waste movement, with "specialized service providers" managing drilling waste and other materials, ensuring compliance with regulatory standards (D-3). Similarly, Respondent D-4 describes subcontracting waste handling to external companies, such as Mr. Green Africa for plastics and cement factories for oil, allowing TotalEnergies to focus on core operations while delegating logistical responsibilities (D-4). This reliance on outsourcing underscores a strategic decision to leverage external expertise and infrastructure, facilitating compliance and operational efficiency.

The transportation process is supported by structured coordination and monitoring mechanisms to ensure safety and regulatory adherence. Respondent D-1 highlights the use of the "Quality" platform to track shipments, logging manifest data including waste type, EPA (Environmental Protection Agency) numbers, and volume, which aids in coordinating with third-party vendors (D-1). Respondent D-3 elaborates on the transportation department's role, conducting "regular site visits to monitor stakeholder waste generation" and verify proper disposal procedures, indicating a proactive oversight approach (D-3). For hazardous waste, such as separated oil from wastewater treatment, transportation is meticulously planned, with oil moved to cement factories for incineration (D-4). Respondent D-2, while not detailing specific tools, implies a systematic process by outsourcing to specialized firms equipped to handle hazardous materials like fuel testing capsules (D-2). These efforts reflect TotalEnergies' commitment to maintaining control over waste movement despite outsourcing, ensuring that logistics align with environmental and safety standards.

5.8.1.6. Performance Monitoring and Key Performance Indicators (KPIs) at TotalEnergies

To ensure the effectiveness of its waste management strategies, Total Energies employs a comprehensive suite of Key Performance Indicators (KPIs) that directly align with the company's broader sustainability and environmental goals. These KPIs are essential for measuring the efficiency of waste reduction efforts, recycling practices, and overall compliance with both internal and external environmental regulations. The company meticulously tracks a range of critical metrics to evaluate its waste management performance and make data-driven decisions that support its commitment to environmental responsibility.

One of the primary KPIs Total Energies monitors is the **total volume of waste collecte**d across its operations. This metric provides insights into the scale of waste generated and highlights areas where waste minimization efforts can be focused. Additionally, **the frequency of waste disposal** is tracked to ensure that waste management processes are both efficient and timely. A key operational goal is to prevent the accumulation of waste beyond a specified time frame, with a clear target of ensuring that waste is not stored for more than one week before being processed or disposed of. This objective is critical in mitigating environmental risks associated with prolonged waste storage, such as contamination, the release of harmful emissions, and the potential for odor generation, which could violate regulatory standards. By adhering to this time-sensitive waste processing target, Total Energies reduces the risk of environmental impact and ensures that waste is handled promptly and appropriately.

Recycling rates are another vital KPI that Total Energies tracks rigorously. This metric serves as a direct indicator of the company's ability to divert waste from landfills and reintegrate valuable materials into the production cycle. High recycling rates reflect the effectiveness of Total Energies' waste separation and material recovery strategies, which aim to minimize the volume of waste disposed of in landfills while promoting the reuse of materials. As part of the company's broader commitment to the circular economy, improving recycling rates ensures that resources are conserved and waste is repurposed for further use, thus reducing the environmental footprint of operations.

Respondent D-4 emphasized that monitoring **waste generation trends** is integral to Total Energies' ongoing efforts to optimize waste management practices. Significant deviations in waste generation, whether due to unexpected spikes or declines, prompt an internal review to identify the root causes of such changes. This proactive approach allows Total Energies to address inefficiencies, adjust operational practices, and implement corrective measures where necessary. Such measures may include fine-tuning waste segregation procedures, investing in new recycling technologies, or enhancing employee awareness and training on waste minimization strategies.

These KPIs are not merely operational benchmarks but are deeply embedded in Total Energies' broader environmental strategy, particularly in reducing carbon emissions. By closely monitoring and responding to trends in waste generation, recycling, and disposal, Total Energies enhances its ability to reduce its carbon footprint and align its operations with international sustainability standards. The use of real-time data and analytics allows the company to fine-tune waste management processes, continuously improve efficiency, and strengthen its position as a leader in corporate sustainability.

Furthermore, the company recognizes that the continual refinement of its waste management practices, based on these KPIs, plays a crucial role in meeting global sustainability targets. Total Energies' data-driven approach not only helps to track performance but also supports the company's goal of fostering a low-carbon, resource-efficient economy. By leveraging these key metrics, Total Energies remains adaptable to emerging waste management challenges, keeps its operations aligned with evolving environmental regulations, and ultimately contributes to a more sustainable and circular economic model.

In conclusion, Total Energies' commitment to sustainability is underpinned by its use of KPIs that provide tangible measures of waste management performance. These metrics enable the company to optimize its waste handling processes, minimize environmental impact, and maintain compliance with sustainability standards. By integrating these KPIs into its operational framework, Total Energies ensures that waste is managed responsibly, resources are conserved, and its operations continue to contribute to the global push for a more sustainable future.

5.8.1.7. Challenges in Waste Management and Reverse Logistics at TotalEnergies

The interviews revealed a range of significant challenges associated with waste management in the oil industry. One of the primary concerns pertains to the complexities of coordinating waste transportation, particularly when relying on outsourced logistics providers. Respondent D-3 emphasized that third-party transportation services frequently contribute to logistical delays, creating bottlenecks that disrupt the efficiency of waste disposal operations. These delays not only impede timely waste removal but also pose operational risks, including potential regulatory violations and environmental hazards. To mitigate such inefficiencies, the respondent advocated for greater internal control over transportation logistics, suggesting that in-house management could enhance accountability, reliability, and compliance with safety standards.

Beyond logistical concerns, environmental challenges were also underscored as a major issue. Respondent D-3 highlighted the extensive and often underestimated scope of environmental regulations governing air, water, and waste management. The respondent noted that the complexity of regulatory frameworks frequently leads to compliance difficulties, as organizations struggle to navigate evolving policies and reporting requirements. Furthermore, inefficiencies in interdepartmental communication were cited as an exacerbating factor, making it difficult to track and manage waste effectively. Poor coordination between departments can result in discrepancies in waste documentation, delays in decision-making, and missed opportunities for optimizing waste reduction strategies.

Another critical challenge pertains to the procurement and management of waste disposal services. Respondent D-1 pointed out that the internal vetting process for selecting waste management suppliers is a time-intensive endeavour, often taking up to four months to complete. This rigorous process is necessary to ensure that suppliers adhere to strict environmental and safety standards. However, the prolonged timeframe can disrupt operations and lead to temporary storage issues, increasing the risk of non-compliance with environmental regulations. The need for an efficient yet robust supplier evaluation framework was emphasized as essential for balancing regulatory adherence with operational efficiency.

Additionally, regulatory barriers concerning sustainability initiatives were noted, particularly in relation to energy generation from renewable sources. The legal framework in Kenya was identified as a limiting factor in advancing broader sustainability efforts, particularly those aimed at reducing reliance on fossil fuels. Respondent D-1 highlighted that stringent policies surrounding energy production create obstacles for companies seeking to transition toward more sustainable waste-to-energy solutions. These regulatory constraints not only slow down innovation but also hinder the industry's ability to adopt circular economy principles, which are crucial for long-term environmental and economic sustainability.

Overall, the findings indicate that waste management in the oil industry is hindered by logistical inefficiencies, regulatory complexities, interdepartmental communication gaps, and structural barriers to sustainability initiatives. Addressing these challenges requires a multi-faceted approach that integrates improved logistical planning, regulatory streamlining, enhanced interdepartmental collaboration, and policy reforms that support sustainable waste management practices.

5.8.1.8. Opportunities for Improvement and Future Strategies at TotalEnergies

TotalEnergies' waste management practices, as detailed by Respondents, demonstrate a structured approach that balances regulatory compliance with sustainability objectives. However, the interviews reveal several opportunities for enhancement and forward-looking strategies that could optimize efficiency, reduce environmental impact, and align with broader industry trends.

One significant opportunity for improvement lies in addressing staffing and equipment constraints, particularly in high-demand operational contexts. Respondent D-1 highlights the challenge of managing refinery waste with a "small team of five," suggesting that "more employees and updated equipment" would increase productivity and efficiency (D-1). Similarly, Respondent D-2 notes the strain of a small team in aviation operations, proposing that "more people and updated equipment" could streamline waste handling (D-2). A future strategy could involve expanding workforce capacity and investing in modern tools, such as automated waste sorting systems or advanced compaction machinery, to handle peak waste generation periods, like turnarounds, which nearly double waste volumes (D-1). This would enhance operational resilience and reduce bottlenecks, aligning with TotalEnergies' goal of maintaining environmental compliance under varying workloads.

Transportation logistics present another critical area for enhancement, with respondents identifying inefficiencies in the outsourced model. Respondent D-1 notes that reliance on "external drivers often cause delays," proposing "in-house drivers" to improve efficiency and reduce costs (D-1). Respondent D-2 echoes this, suggesting that internal drivers would enhance control over waste transportation from aviation sites (D-2). Respondent D-3 further identifies "regulatory compliance, route optimization, and risk mitigation" as logistical challenges, advocating for "advanced technologies" to streamline processes (D-3). A future strategy could integrate a hybrid logistics model, combining in-house transportation for time-sensitive or high-volume waste with optimized outsourcing supported by technologies like GPS tracking or real-time logistics platforms. This would mitigate delays, enhance responsiveness, and reduce costs, addressing the inefficiencies highlighted across operational contexts.

Enhancing recycling and waste-to-resource initiatives offers a promising avenue for reducing landfill dependency and generating value. Respondent D-1 emphasizes that "recycling is the most cost-effective method," with recent adoption of a recycling company proving cheaper than disposal (D-1), while Respondent D-3 highlights a "100%

recycling rate for scrap materials" and composting of organic waste into fertilizer (D-3). Respondent D-4 describes recycling partnerships with firms like Mr. Green Africa for plastics and cement factories for used oil, alongside innovative reuse of wood pallets for cafeteria decor (D-4). Building on these, TotalEnergies could expand its circular economy approach by developing in-house recycling facilities for high-volume materials like plastics and metals or exploring waste-to-energy technologies, as suggested by Respondent D-3's interest in harnessing "the energy potential of waste materials" like organic matter and biomass (D-3). Such initiatives could transform waste into renewable energy or raw materials, reducing disposal costs and supporting the net-zero-by-2050 goal (D-2).

Stakeholder engagement and supplier vetting processes also warrant improvement to strengthen waste management efficacy. Respondent D-4 identifies "vetting suppliers" as the most challenging aspect, noting that the four-month process sometimes fails to ensure contractors meet waste management standards (D-4). Respondent D-2 similarly cites "communication issues" when stakeholders undervalue environmental risks (D-2), and Respondent D-1 underscores the need for better awareness to ensure regulatory compliance (D-1). A future strategy could streamline supplier vetting through standardized sustainability criteria and digital tracking tools, while expanding awareness campaigns-like D-4's sensitization programs and D-2's KPI monitoring-to include contractors and employees (D-4, D-2). Incentivized recycling, such as D-4's points system with Mr. Green Africa (D-4), could be scaled to foster a company-wide culture of waste reduction.

Technological innovation presents a forward-looking opportunity to enhance waste tracking and treatment. Respondent D-1 relies on the "Quality" platform for waste tracking but notes the absence of a formal KPI dashboard (D-1), while Respondent D-4 uses "trackers to monitor waste generation" and investigate anomalies (D-4). Respondent D-3 suggests "advanced technologies" to improve transportation and overall waste management (D-3). TotalEnergies could invest in integrated digital systems, such as IoT-enabled waste sensors or AI-driven forecasting tools, to enhance the precision of waste data collection and trend analysis, supporting D-1's annual forecasting efforts (D-1) and D-4's trend-based KPIs (D-4). Additionally, adopting advanced treatment technologies-like anaerobic digestion for organic waste or pyrolysis for plastics-could complement D-3's wastewater separation practices (D-3), reducing waste volumes and generating energy or byproducts.

Finally, a strategic shift toward cleaner energy sources offers a transformative opportunity to reduce hazardous waste generation. Respondent D-4 proposes that "shifting to cleaner forms of energy" like solar, wind, and hydro would decrease reliance on fossil fuels and associated waste, noting TotalEnergies' investments in solar and electric vehicle charging stations (D-4). While regulatory constraints in Kenya limit energy grid sales (D-4), advocating for policy reforms and expanding renewable energy projects globally could align waste management with the company's net-zero ambitions (D-2). This long-term strategy would reduce the volume of oil-contaminated waste (D-4), enhancing sustainability across the value chain.

In conclusion, TotalEnergies can enhance its waste management through increased staffing and equipment upgrades (D-1, D-2), a hybrid logistics model with technological integration (D-1, D-2, D-3), expanded recycling and waste-to-energy initiatives (D-1, D-3, D-4), improved stakeholder engagement (D-1, D-2, D-4), advanced tracking and treatment technologies (D-1, D-3, D-4), and a transition to cleaner energy (D-4). These opportunities, rooted in the respondents' insights, offer a roadmap to optimize efficiency, reduce environmental impact, and position TotalEnergies as a leader in sustainable waste management within the energy sector.

5.9. SOCAR's Waste Management Practices

The State Oil Company of Azerbaijan Republic (SOCAR), established on September 13, 1992, by Presidential Decree, is Azerbaijan's first national oil company and a significant player in the global oil and gas industry (SOCAR, 2023). SOCAR's operations span exploration, production, processing, and transportation of oil, gas, and gas condensate, as well as the sale of petroleum and petrochemical products in both domestic and international markets. The company is also responsible for supplying natural gas to industries and households in Azerbaijan. SOCAR's business model emphasizes sustainable development, aiming to achieve positive economic, social, and environmental impacts across its operations (SOCAR, 2023). This commitment aligns with the company's mission to enhance environmental and social performance, a principle embedded in its strategic projects and corporate policies, which directly supports the focus of this study on optimizing Reverse Logistics (RL) for sustainable waste management in the oil and gas sector.

SOCAR's supply chain management system is designed to ensure operational efficiency, cost optimization, and compliance with environmental standards, reflecting principles of transparency and sustainability (SOCAR, 2023).

SOCAR's environmental sustainability efforts are guided by a robust regulatory framework that aligns with international standards and Azerbaijan's commitments to global environmental initiatives (SOCAR, 2023). The company adheres to agreements such as the UN Framework Convention on Climate Change (UNFCCC) and participates in programs like the Oil and Gas Decarbonization Charter (OGDC), the Methane Guiding Principles (MGP), and the Oil and Gas Methane Partnership 2.0 (OGMP 2.0) (SOCAR, 2023). SOCAR's corporate policies include an Environmental Policy, a Climate Change Mitigation Strategy (2010-2020 and 2021-2030), and a Decarbonization Strategy with specific targets, such as achieving zero routine flaring by 2030, reducing emission intensity by 30% in upstream operations by 2030, and reaching net zero by 2050 (SOCAR, 2023). These targets underscore SOCAR's proactive approach to environmental management.

SOCAR employs a systematic approach to waste management, leveraging technology and specialized subsidiaries to optimize RL processes and promote sustainability (SOCAR, 2023). The company manages its waste through the SAP EHS-Waste Management module within the SAP ERP system, which standardizes processes across its entities and enhances operational efficiency (SOCAR, 2023). This technological integration enables SOCAR to track, manage, and report waste activities effectively, ensuring transparency and compliance with environmental regulations.

Waste management at SOCAR is primarily handled by its subsidiary, the Waste Management Centre (WMC), operated under EKOL, which provides modern infrastructure for the safe and efficient handling of waste (SOCAR, 2023). In 2023, the WMC processed significant volumes of waste, including 26,159.32 tons of drilling waste, 5,701.67 tons of production sludge, and 2,864.63 tons of production waste, with 93% of plastic waste and 71% of paper waste being recycled or reused (SOCAR, 2023). These recycling and reuse rates reflect SOCAR's commitment to circular economy principles. For instance, the reuse of drilling waste as gravel for road construction, as noted in the selective coding section, was a practice observed in SOCAR's operations, demonstrating how RL transforms waste into a valuable resource.

SOCAR has also launched initiatives to optimize its waste management processes, focusing on improving recycling, reuse, and disposal practices to reduce environmental impacts (SOCAR, 2023). These initiatives include the development of a Waste Management System aimed at enhancing operational efficiency and promoting circular economy practices, aligning with the study's core category of optimizing RL for sustainable waste management. However, SOCAR faces challenges similar to those identified in the broader dataset, such as logistical constraints due to unstable weather in the Caspian Sea, which delays waste transportation and leads to accumulation. To mitigate these issues, SOCAR employs strategies like optimizing truck loads to reduce costs reflecting a focus on structuring RL processes for maximum efficiency.

Table 50. Waste Management at SOCAR in 2021-2023 years, thousand tons

Type of waste	**2021**	**2022**	**2023**
Generated waste	131.3	152	130.6
Hazardous	117.5	127.1	113.7
Non-hazardous	13.77	24.89	16.94
Utilized waste	2.66	1.05	1.01
Hazardous	2.66	1.05	0.78
Non-hazardous	0	0	0.23
Waste transferred to third parties	147.4	149.5	133
Hazardous	134.4	124.8	116.2
Non-hazardous	12.96	24.67	16.73
Wastes transferred to Warehouse Management Centre	9.46	31.15	74.45
Hazardous	9.03	22.19	73.63
Non-hazardous	0.43	8.966	0.82
Wastes disposed and transferred	2.49	1.16	0.42
Hazardous	2.27	0.94	0.22
Non-hazardous	0.22	0.22	0.21

Source: SOCAR, 2023. ESG Report 2023, p. 78. Available at: Socar_ESG_Report_2023_5c1cebfc35.pdf

SOCAR's waste management data for entities within its structure in Azerbaijan from 2021 to 2023, detailed in Table 50, of the ESG Report 2023, highlights the company's waste generation, handling, and disposal practices (SOCAR, 2023). In 2021, SOCAR generated 131,260 tons of waste, which increased to 151,990 tons in 2022, before decreasing to 130,604 tons in 2023. Hazardous waste accounted for most of the total, with 117,490 tons in 2021, 127,710 tons in 2022, and 113,370 tons in 2023, showing a slight reduction by 2023. Non-hazardous waste generation increased from 13,770 tons in 2021 to 24,489 tons in 2022, before declining to 16,940 tons in 2023. Utilized waste remained minimal, with 2,660 tons in 2021 (all hazardous), 1,050 tons in 2022 (1,050 tons hazardous), and 1,010 tons in 2023 (780 tons hazardous, 230 tons non-hazardous).

Waste transferred to third parties, including external organizations and the Waste Management Centre (WMC), also varied over the period. In 2021, SOCAR transferred 147,740 tons of waste to third parties, with 134,440 tons being hazardous. This decreased to 149,490 tons in 2022 (124,483 tons hazardous) and further to 132,950 tons in 2023 (116,621 tons hazardous). Specifically, waste transferred to the WMC increased significantly, from 9,460 tons in 2021 (9,030 tons hazardous) to 31,190 tons in 2022 (22,190 tons hazardous) and reached 74,630 tons in 2023 (all hazardous). This reflects SOCAR's growing reliance on the WMC for waste processing, as evidenced by the WMC's handling of 26,159.32 tons of drilling waste, 5,701.67 tons of production sludge, and 2,864.63 tons of production waste in 2023 (SOCAR, 2023).

Waste disposed of and transferred for final disposal decreased over the period, from 2,490 tons in 2021 (2,270 tons hazardous) to 1,160 tons in 2022 (940 tons hazardous), and further to 420 tons in 2023 (210 tons hazardous). This reduction indicates SOCAR's efforts to minimize landfill use and enhance recycling and reuse, with 93% of plastic waste and 71% of paper waste being recycled or reused in 2023 (SOCAR, 2023).

Beyond waste management, SOCAR implements measures to ensure the efficient use of water resources and the remediation of contaminated lands, further supporting its sustainability goals (SOCAR, 2023). The company is establishing a centralized Water Management System (WMS) under the 'LightHouse' project, which includes calculating key water metrics for 2022 in accordance with GRI 303 standards (SOCAR, 2023). This system aims to optimize water efficiency and address water-related challenges across SOCAR's operations, demonstrating a holistic approach to environmental management that complements its RL practices.

In terms of land management, SOCAR conducts remediation of oil-contaminated soils using mechanical, biological, and phytoremediation methods, primarily at its "Azneft" Production Unit and other oil field areas (SOCAR, 2023). These efforts, which include reforestation and afforestation, highlight SOCAR's commitment to mitigating the environmental impacts of its operations. While these practices are not directly part of RL, they contribute to the broader goal of sustainable resource management, reinforcing SOCAR's role as a leader in environmental stewardship within the oil and gas industry.

Table 51. Wastewater management at SOCAR, m3

Wastewater Management Metrics	2021	2022	2023
The volume of generated wastewater	7,952,773	7,652,450	8,283,706
The volume of wastewater discharged without treatment onto soil	6,770	7,898	123,525
The volume of wastewater discharged without treatment in the water	309,860	275,597	120,967

Wastewater Management Metrics	**2021**	**2022**	**2023**
The volume of wastewater discharged after treatment	7,636,143	7,368,955	8,039,214

Source: SOCAR, 2023. ESG Report 2023, p. 64. Available at: Socar_ESG_Report_2023_5c1cebfc35.pdf

SOCAR's wastewater management data for entities within its structure in Azerbaijan from 2021 to 2023, as presented in **Table 51** of the ESG Report 2023, provides insights into the company's efforts to manage water resources and reduce environmental impacts (SOCAR, 2023). In 2021, SOCAR generated 7,952,773 m³ of wastewater, which decreased to 7,652,450 m³ in 2022, before rising to 8,283,706 m³ in 2023. Of the wastewater generated in 2021, 316,630 m³ was discharged without treatment, with 6,770 m³ released onto soil and 309,860 m³ into water bodies. In 2022, the volume of untreated wastewater discharged decreased to 283,495 m³, with 7,898 m³ onto soil and 275,597 m³ into water. By 2023, this volume further reduced to 244,492 m³, with 123,525 m³ discharged onto soil and 120,967 m³ into water, indicating a progressive decline in untreated discharges over the three years.

In contrast, the volume of wastewater discharged after treatment increased over the same period. In 2021, SOCAR treated and discharged 7,636,143 m³ of wastewater, which dropped slightly to 7,368,955 m³ in 2022, and significantly increased to 8,039,214 m³ in 2023. This suggests an improvement in SOCAR's wastewater treatment capacity, aligning with its efforts to implement a centralized Water Management System (WMS) under the "LightHouse" project, which aims to optimize water efficiency and minimize environmental impacts (SOCAR, 2023).

5.9.1. Findings from Interviews (SOCAR)

5.9.1.1. Awareness Levels Within the Company and Among Stakeholders at SOCAR

At the organizational level, SOCAR demonstrates a clear commitment to effective waste management. According to Respondent G-1, a strong commitment to environmental preservation and sustainability has been expressed, indicating that the leadership views waste management as a central element in safeguarding the Caspian Sea environment. This commitment reflects the company's active efforts to integrate environmental considerations into its oil-related operations. More importantly, it provides a foundation that should be reinforced across the organization and extended to external partners and contractors.

Employee awareness and competence are supported through regular training and communication initiatives. As noted by Respondent G-2, every employee involved in this process receives prior training from the company's HSE personnel, ensuring that workers are instructed before engaging in waste-handling activities. Respondent G-3 highlighted that environmental teams conduct training sessions to increase awareness and monitor workplaces to verify compliance, providing corrective feedback when necessary. Respondent G-4 emphasized that regular training for all employees is conducted and that boards in all offices are maintained to remind staff of waste management rules and their importance. Collectively, these measures such as training programs, monitoring practices, and workplace reminders illustrate SOCAR's structured approach to embedding waste management principles into daily operations.

Despite the existing measures, challenges remain in ensuring that employees fully understand and apply waste management practices. According to Respondent G-5, awareness is critically low, as employees continue to engage in improper behaviour such as throwing oily rags into household waste bins even after receiving training. This indicates that training initiatives are not always effective in influencing day-to-day practices, possibly due to insufficient follow-up or a lack of perceived importance among employees. Respondent G-5 further emphasized that awareness should begin from school age to address the broader societal issue of limited concern for waste management. These observations suggest that while SOCAR has established training programs, their impact on employee behaviour remains inconsistent.

For external stakeholders, including partner and cooperating companies, awareness and compliance appear to vary depending on SOCAR's level of oversight. Respondent G-4 noted that SOCAR monitors and conducts periodic inspections of the processes within partner and cooperating companies, intervening where necessary to ensure compliance. Similarly, Respondent G-3 observed that each company has its environmental teams and procedures, which are strictly followed, indicating that SOCAR's guidance contributes to a baseline level of compliance among partners. However, Respondent G-5 cautioned that outside the company, societal awareness of waste management is generally low, which may result in smaller partners demonstrating limited commitment unless direct pressure is applied by SOCAR. This variability highlights that while SOCAR can influence its partners, the degree of effectiveness differs across external actors.

Considering both internal and external aspects, SOCAR demonstrates structured efforts but with uneven outcomes. Internally, training programs and informational materials are in place, as noted by respondents, indicating a deliberate attempt to build employee awareness. However, as emphasized by Respondent G-5, improper practices persist, suggesting that additional mechanisms may be required to ensure that training translates into consistent behaviour. Externally, SOCAR monitors its partners and establishes requirements, as highlighted by Respondents G-3 and G-4, thereby extending awareness and compliance beyond the company itself. Nevertheless, Respondent G-5 observed that general societal attitudes toward waste remain weak, which implies that some partners may meet only minimum expectations unless SOCAR maintains active oversight. Overall, these findings suggest that SOCAR is committed to raising awareness but has yet to achieve consistent and comprehensive results.

5.9.1.2. Waste Disposal and Handling Strategies at SOCAR

SOCAR's waste management begins with a structured plan designed to address different types of waste in a manner aligned with its operational context. According to Respondent G-1, the company implements "strategic waste management plans" with a focus on efficient handling and disposal while adhering to stringent environmental regulations. This reflects a comprehensive approach that prioritizes not only the removal of waste but also its safe and environmentally responsible treatment, thereby protecting the surrounding environment, particularly in the Baku region. Such strategic planning establishes the foundation for operational practices at the ground level.

The day-to-day handling of waste follows a stepwise process involving both SOCAR's internal teams and external partners. Respondent G-2 explained that the process begins with a price proposal prepared for clients, based on either the estimated volume of waste (e.g., cubic meters or kilograms) or the findings of inspection reports. Following this, the availability of equipment, personnel, and vehicles is assessed to ensure operational readiness. Once preparations are complete, waste is transported by truck to designated facilities, such as landfills for dry waste or treatment plants for oily liquids. In cases where treated liquids can be safely reused, they may be returned to clients upon request. This structured approach demonstrates careful planning to ensure that waste volumes are effectively managed. Respondent G-3 further noted that all procedures comply with local legislation and international standards like ISO 14001, and in situations where local regulations are insufficiently defined, international standards are applied. Specific categories of waste are handled through tailored methods, for example, medical waste is incinerated to eliminate biological hazards, while drilling sludge is treated using technologies such as centrifuges, particularly for water-based waste streams. This combination of systematic planning and specialized treatment ensures that waste management practices remain both legally compliant and operationally efficient.

Sorting and transporting waste constitute central elements of SOCAR's waste management strategy, supported through a combination of internal resources and external contractors. Respondent G-4 explained that waste is first collected at the source in specific containers and separated using a colour-coded system, under the supervision of HSE or environmental specialists. It is then transported by ship to a port facility, where it undergoes a secondary sorting process in a general waste zone before being directed to final destinations such as landfills or recycling facilities. To improve efficiency, certain activities, such as compacting or pressing waste are outsourced to specialized companies, which are required to provide documentation verifying the subsequent handling of the material. Respondent G-5 further noted that once waste is generated, a request for transport is issued by the relevant department head, after which the material is stored in secure, designated areas until it can be transported by truck to one of three disposal sites in Azerbaijan. Household waste is managed by municipal services, while during periods of peak activity, such as maintenance campaigns, SOCAR supplements its fleet by hiring additional trucks to avoid capacity shortages. This combination of internal oversight and external support enables the company to manage waste flows without overloading its own infrastructure.

SOCAR's strategy also includes efforts to recover value from waste streams rather than treating them solely as material for disposal. Respondent G-1 referred to a project aimed at cleaning oil-polluted lakes in Baku, in which specialized equipment was used to extract oil for potential reuse. Respondent G-5 highlighted plans to supply waste such as wood and drilling sludge to cement plants for use as fuel, while other materials, including metals and plastics, are sold through auction processes. Similarly, Respondent G-3 noted that base oil is recycled and returned to production. These initiatives illustrate SOCAR's attempt to reframe waste as a potential resource, reducing environmental impacts while generating economic benefits.

Nevertheless, practical constraints limit the efficiency of these processes. Respondent G-5 emphasized that in Baku, night-time restrictions on truck transport restrict access to only two of the three disposal sites, complicating logistics. During maintenance periods, when waste volumes increase, SOCAR's own transport capacity is insufficient, requiring reliance on external providers. Respondent G-4 also observed that outsourcing saves time and resources but necessitates strict documentation to ensure regulatory compliance. These examples demonstrate that SOCAR's waste management approach remains a balance between internal capability and external support, shaped by operational demands and contextual constraints.

5.9.1.3. Waste Classification and Types at SOCAR

SOCAR categorizes its waste into two primary groups: hazardous and non-hazardous. This classification provides the basis for determining appropriate handling methods and ensuring compliance with environmental regulations. This distinction influences the management of a wide range of waste streams, from drilling by-products to domestic refuse, and illustrates SOCAR's attention to safety and environmental responsibility.

According to Respondent G-2, hazardous medical waste represents a significant category, generated through SOCAR's activities not only in the oil sector but also in cooperation with hospitals and other institutions. Such waste requires specialized treatment due to the potential presence of pathogens or toxic substances. Respondent G-3 identified several types of waste originating from drilling operations, including "lubricated oil, items contaminated with oil, drilling fluids, drilling mud, metals, wood, and domestic waste." Within this group, lubricated oil and oil-contaminated items fall under the hazardous category, as they pose handling and environmental risks, whereas metals, wood, and domestic waste are generally classified as non-hazardous and are more straightforward to manage. Respondent G-3 further noted that these materials are separated and treated in accordance with environmental guidelines, reflecting SOCAR's structured approach to ensuring that each waste type is managed through tailored processes.

Respondent G-4 provided further detail by identifying general waste, food waste, and drilling mud as the main categories encountered. Drilling mud was highlighted as hazardous due to the presence of radioactive substances and therefore requires rapid treatment rather than prolonged storage. Additional hazardous wastes were noted, including chemical reagent bags, oil drums, and oil-soaked waste, all of which demand careful management because of their chemical or petroleum-based properties. By contrast, food waste and general household-type waste were classified as non-hazardous, presenting fewer risks but still requiring organized disposal. The emphasis on the immediate treatment of drilling mud illustrates how certain hazardous wastes compel SOCAR to prioritize swift responses to prevent environmental or safety issues.

Respondent G-5 focused specifically on oil-based sludge, identified as the most prevalent waste type and including drilling sludge and tank bottom sludge. This category is considered hazardous because of its high oil content and the difficulties associated with both its volume and treatment. Similarly, Respondent G-1 referred to oily waste generated during lake cleanups, which also falls into the hazardous category as it consists of petroleum extracted from water. Collectively, these accounts demonstrate that SOCAR manages significant volumes of oil-heavy hazardous wastes alongside less complex non-hazardous materials such as wood and general refuse.

According to the respondents, hazardous wastes, such as medical waste, oil-contaminated items, drilling mud, chemical reagent bags, oil drums, and oil-based sludge represent the most challenging categories. These materials are considered dangerous because of their oil, chemical, or radioactive content, requiring SOCAR to apply stricter controls, including the use of specialized containers and rapid treatment to ensure safety. By contrast, non-hazardous wastes, such as metals, wood, domestic refuse, and food waste pose lower risks and can often be recycled or disposed of with less complexity. This division illustrates the wide spectrum of wastes generated by SOCAR's operations, ranging from hazardous drilling by-products to ordinary everyday scraps.

Taken together, the evidence shows that SOCAR's waste streams emerge from different aspects of its activities. Drilling operations contribute large volumes of hazardous materials such as mud and oily sludge, while other functions, including site management or cooperation with hospitals, produce both medical waste and general trash. Hazardous wastes require rapid and secure treatment due to their inherent dangers, whereas non-hazardous wastes create opportunities for recycling or relatively simple disposal. Respondent G-4's observation about the urgency of treating drilling mud and Respondent G-5's emphasis on the heavy volumes of oil-based sludge highlights how certain hazardous types place greater pressure on the system. The overall classification helps SOCAR determine appropriate responses, whether through specialized treatment or straightforward disposal at landfill sites.

5.9.1.4. Recycling, Reuse, and Waste Reduction Initiatives at SOCAR

SOCAR demonstrates a clear commitment to recovering value from waste rather than treating it solely as a disposal problem. Recycling is a major component of SOCAR's waste management strategy, giving certain materials a second life. Respondent G-3 explained that plastic waste is melted and reprocessed, allowing it to be reused rather than discarded. They also described how treated base oil is recycled and reintegrated into production, keeping valuable resources within the system. Medical waste, while not recyclable in the conventional sense, is incinerated to ensure safe disposal and the elimination of hazardous contaminants. Respondent G-4 highlighted the sorting of waste for either reuse or neutralization, noting that drilling fluid can be recovered from sludge and reapplied in operations, with the process documented through official records.

Reuse is closely linked with recycling, and SOCAR has developed several initiatives aimed at extending the life of materials. One example is SOCAR's lake project, mentioned by respondent G-1, which demonstrates how oily waste can be redirected toward new applications. Respondent G-3 described how base oil is cleaned and reintegrated into production, reducing the need for virgin oil supplies. Similarly, Respondent G-4 noted that drilling fluid recovered from sludge is returned to drilling operations, thereby decreasing reliance on fresh inputs. Respondent G-5 highlighted a plan to provide sludge and wood residues to cement plants, where they can be used as alternative fuels. Together, these initiatives illustrate SOCAR's emphasis on reuse, not only through conventional recycling but also by keeping waste materials in circulation in their original or slightly modified forms. This approach offers both economic benefits and environmental gains.

SOCAR has also undertaken initiatives aimed at waste reduction - preventing waste before it is generated, although these efforts are currently less developed than recycling practices. Respondent G-3 explained that operations are optimized to avoid over-ordering materials, thereby reducing the risk of unused chemicals turning into waste. This highlights the role of improved planning in preventing unnecessary surplus. Respondent G-4 proposed the installation of drilling fluid treatment tanks directly on platforms, allowing mud to settle, wastewater to separate, and clean water to be reused. According to their estimate, such a system could reduce waste volumes from 10 cubic meters to just 1 cubic meter, representing a substantial improvement through on-site treatment. Similarly, respondent G-5 suggested introducing reusable or biodegradable materials for items such as work clothes and utensils, to decrease the amount of waste generated by personnel. Collectively, these initiatives reflect SOCAR's growing focus on minimizing waste at the source rather than only managing it after generation.

Despite these initiatives, SOCAR's efforts still have limitations and significant potential for further development. Respondent G-3 highlighted the recycling of plastics and oil but also acknowledged that some materials continue to be sent to landfills. Respondent G-4's proposal to install treatment tanks could substantially reduce waste, yet they noted that in some cases waste is still landfilled without being properly utilized, indicating uneven application of such practices. Respondent G-2 focused primarily on disposal rather than recycling or reuse, suggesting that these practices are not consistently embedded across all operations. Taken together, these observations show that while SOCAR has implemented promising initiatives, greater progress could be achieved through broader adoption and the expansion of supporting infrastructure.

5.9.1.5. Waste Transportation and Logistics at SOCAR

SOCAR's waste transportation system combines in-house resources with external support to ensure efficient movement of materials. Respondent G-2 explained that generally the company relies on its own vehicles to transport waste, beginning with checks to confirm that sufficient equipment, personnel, and trucks are available. Once prepared, waste is loaded and delivered to designated landfills or treatment facilities, indicating that SOCAR manages a substantial portion of the process internally. Respondent G-3 described that transportation is also outsourced to firms equipped with specialized vehicles. In these cases, drilling teams plan shipments in advance, sometimes weeks or months ahead, to move waste from offshore platforms to onshore facilities. This highlights SOCAR's reliance on a hybrid model, combining internal resources with external expertise depending on the operational context.

Respondent G-4 provided a detailed account of transportation practices offshore and onshore. Waste is collected from platforms using ships, with schedules based on weekly or monthly needs, as storage space on platforms is limited. Full containers are transferred to ports, where cranes move them to temporary storage until enough material is gathered for a truckload. This practice avoids half-empty truckloads, since transport costs are calculated per vehicle, while disposal fees are based on volume. For drilling mud, however, SOCAR uses its own vehicles to ensure immediate removal, as containers must be quickly returned to service. This combination of ships, trucks, and rapid turnaround for certain waste streams reflects an adaptive transportation system designed to manage logistical constraints effectively.

Respondent G-5 provided further details on onshore logistics, explaining that the process begins with a request from a department head to the transport team, which then dispatches trucks equipped with self-loading and unloading capabilities. Larger volumes of waste are first transferred to designated secure areas before being delivered to one of three disposal sites in Azerbaijan, although truck access to Baku is restricted at night, limiting disposal to two sites. Routine waste, such as household refuse, is managed by municipal services; however, during periods of intensive maintenance, SOCAR's fleet is unable to meet demand. In such cases, the company supplements capacity by contracting additional skip trucks from external providers. These practices illustrate that while SOCAR relies primarily on its internal logistics system, external support is occasionally necessary to manage peak workloads.

Even with this system in place, transporting waste is not always straightforward, and SOCAR faces several challenges. Respondent G-4 noted that space on the platforms is limited and mentioned the need for specially designated containers for hazardous materials, such as drilling mud containing radioactive elements. They also pointed out a shortage of specialized ships in Azerbaijan, which makes it difficult to find one when required. Respondent G-5 highlighted larger issues, such as unstable weather conditions in the Caspian Sea can cause waste to accumulate until it ends up being dumped into the sea, and there are not enough transport companies willing to work for SOCAR's low rates. Overall, these factors-weather, limited shipping options, and careful handling requirements-make it challenging to keep waste moving smoothly and on schedule.

SOCAR implements careful planning to address some of these challenges. Respondent G-3 noted that they use real-time and pre-scheduled planning to anticipate waste volumes from drilling and organize transport in advance. Respondent G-4 mentioned that they maintain a steady flow of drilling mud to prevent containers from becoming stuck and wait for full trucks to optimize costs. Respondent G-5 highlighted that their internal trucks manage daily loads, but additional support is arranged when necessary, demonstrating adaptability to operational demands. These strategies contribute to efficiency, but weather and limited resources continue to disrupt operations, indicating that SOCAR could benefit from enhanced control over its transport processes.

5.9.1.6. Performance Monitoring and Key Performance Indicators (KPIs) at SOCAR

SOCAR uses key performance indicators (KPIs) to evaluate its waste management performance and identify areas for improvement. Respondent G-1 noted that they focus on the reduction of oily waste and reducing the presence of oil in sludge, monitoring both the **quantity of oily waste generated** and **the residual oil content in sludge** over time. These metrics are compared against established targets to determine which practices are effective and which require adjustment. This approach indicates that SOCAR prioritizes minimizing oily waste-a core aspect of their operations-and limiting its presence in sludge, reflecting attention to the most challenging waste streams.

Respondent G-2 offered a different perspective, explaining that **monthly work volume** is tracked in accordance with framework agreements with clients. Treating a higher volume of waste within the planned schedule reflects effective operational performance, whereas handling lower volumes may indicate potential underperformance or capacity limitations. Standardized measurement units are employed to ensure consistent assessment, including metrics such as the quantity of waste transported or processed. This approach focuses less on the specific characteristics of the waste and more on SOCAR's ability to meet operational demand, highlighting the monitoring of the system's capacity to manage workload efficiently.

Respondent G-3 discussed **environmental impact indicators** used to assess how waste affects the environment. They noted efforts to reduce waste by planning operations carefully, for example, avoiding over-ordering materials that could become waste - and preventing unused chemicals from accumulating. They also mentioned that effective communication and chain management ensure all teams are aligned, which helps operations run smoothly. This emphasis on environmental performance and collaboration indicates that SOCAR's KPIs are not merely numerical targets, they reflect a commitment to minimizing waste and maintaining coordinated work processes.

Respondent G-4 linked their KPIs to Azerbaijan's laws on waste management and international standards such as "ISO 9001, ISO 14001, and OHSAS 18001. These standards cover quality, environmental management, and occupational health and safety, ensuring that SOCAR's objectives align with both local and global expectations. While exact KPIs were not specified, adherence to these standards implies monitoring of aspects such as the safety and environmental quality of waste handling, demonstrating that SOCAR evaluates its performance against a broad framework of regulatory and best-practice guidelines.

Respondent G-5 emphasized the importance of timely waste transport, noting that their KPIs are mostly related to transportation, such as "how long waste can be stored before being moved". Regulations allow waste to remain for up to six months, but SOCAR aims to transfer it within one week. This rapid turnaround reflects their focus on clearing waste efficiently rather than allowing it to accumulate, providing a practical measure of whether trucks and operational plans are functioning effectively.

Overall, multiple dimensions of waste management are addressed through SOCAR's KPIs. Indicators related to oily waste and sludge are used to target the most challenging materials, as highlighted by Respondent G-1. Operational capacity is measured through work volume, as noted by Respondent G-2. Environmental indicators, focusing on ecological impact and teamwork, are applied, as indicated by Respondent G-3. Compliance-based KPIs are implemented to ensure adherence to regulations and standards, as reported by Respondent G-4. Transport-focused KPIs are employed to monitor the speed of waste movement, as described by Respondent G-5. Collectively, these metrics demonstrate that both the characteristics of the waste - including quantity and type - and the efficiency of its handling are evaluated, reflecting an effort to balance environmental considerations, regulatory compliance, and operational effectiveness.

Monitoring is not merely about setting goals, it is about using them to drive improvement. It was noted by Respondent G-1 that performance is benchmarked against predetermined targets, meaning actual outcomes are compared with planned objectives and any deviations are addressed. Respondent G-3 highlighted that careful planning and effective communication help identify issues early. Inspections of partners, as mentioned by Respondent G-4, are also carried out as part of monitoring, ensuring oversight of the entire system. The one-week transport target established by Respondent G-5 ensures that waste movement is closely tracked and that objectives are verified. Collectively, these practices demonstrate that numerical targets are not merely set but actively used to enhance performance.

However, KPIs are not uniform across all areas, which can complicate obtaining a comprehensive view. Work volume is measured in some areas rather than waste type, as indicated by Respondent G-2, while transport-focused KPIs do not account for downstream processes, as reported by Respondent G-5. Compliance with broad standards is maintained, as noted by Respondent G-4, but without specific metrics, the exact aspects being measured remain unclear. This variation indicates that different parts of SOCAR employ distinct approaches to performance measurement, which may be effective locally but do not necessarily provide a single, coherent overview of waste management.

5.9.1.7. Challenges in Waste Management and Reverse Logistics at SOCAR

Waste management and reverse logistics - returning waste to locations where it can be reused or properly disposed of - present significant challenges for SOCAR, arising from multiple sources. It was noted by Respondent G-1 that continuous innovation and the development of alternative waste management methods are required, as regulations are becoming increasingly stringent. This implies that SOCAR is constantly under pressure to implement effective and environmentally responsible solutions, which demands both time and strategic planning. Managing external contractors was also described as challenging, requiring careful oversight and coordination to ensure high-quality performance. Additionally, the need to anticipate fluctuations in waste volumes adds complexity, as planning must account for unpredictable changes. These overarching issues indicate that SOCAR must maintain a high degree of adaptability, which is inherently complex.

Everyday operational challenges also affect SOCAR’s waste management. It was reported by Respondent G-2 that frequent wear and tear of vehicle tires due to poor road conditions slows operations. The deteriorating roads necessitate frequent tire replacements, resulting in additional costs and time delays. Power outages were also noted to halt waste treatment machinery, causing breakdowns and further interruptions. Additionally, fluctuations in fuel prices, particularly for diesel, increase operational costs, while major clients do not always agree to cover these expenses, creating financial constraints. These practical obstacles illustrate how external factors such as infrastructure and utilities disrupt waste transport and management plans.

Further challenges were highlighted by Respondent G-3, who observed a lack of recycling facilities for vehicle tires and batteries in Azerbaijan. In the absence of proper recycling options, these materials accumulate or are buried, generating environmental and financial concerns. Sudden increases in drilling activity, described as drilling surges, were also reported to complicate waste management by producing larger-than-usual volumes of waste, making it difficult to maintain consistent operations. These issues demonstrate that SOCAR’s waste management system is constrained when effective disposal options are lacking and that operational surges can disrupt planned processes.

Logistical challenges significantly affect SOCAR’s waste management operations. It was reported by Respondent G-4 that only one central drilling mud disposal facility exists in Azerbaijan, where all oil companies send their drilling mud. This situation creates long queues and container shortages, which slow operations and can even risk drilling delays if containers are not cleared promptly. A shortage of specialized ships for transporting wastewater from platforms was also noted, making it difficult to secure transport when required. These bottlenecks indicate that SOCAR's logistics cannot always match the volume of waste generated, particularly hazardous materials such as drilling mud that require rapid handling.

Additional challenges were highlighted by Respondent G-5, particularly in relation to hazardous waste transport. Unstable weather conditions in the Caspian Sea were reported to cause waste accumulation on platforms, occasionally resulting in it being dumped into the sea when it cannot be moved quickly enough. The limited availability of transportation companies, compounded by SOCAR's relatively low rates, further restricts waste movement. It was also noted that not all logistics companies have the required licenses for handling hazardous waste, and some drivers lack training to manage spills or fires, creating safety risks. Furthermore, procurement practices were described as primarily prioritizing cost savings, often overlooking environmentally preferable options that could improve waste management. Collectively, these issues demonstrate that SOCAR faces simultaneous challenges related to weather, limited resources, and human factors in its logistical operations.

In summary, SOCAR's waste management challenges encompass both strategic and operational issues. Continuous adaptation is required to comply with increasingly stringent regulations, as noted by Respondent G-1. Operational difficulties such as frequent tire wear, power outages, and fluctuating fuel costs were highlighted by Respondent G-2. Gaps in recycling infrastructure and surges in drilling activity were reported by Respondent G-3 as additional constraints. Logistical bottlenecks, including a single disposal facility, insufficient specialized ships, severe weather, limited availability of transport companies, and inadequately trained drivers, were described by Respondents G-4 and G-5. These factors significantly impact reverse logistics by container shortages delaying drilling mud handling and occasional dumping into the sea when transport is not feasible. External conditions such as road quality and weather further complicate operations.

These challenges indicate that SOCAR's waste management system is not without limitations. The emphasis on innovation reported by Respondent G-1 reflects awareness of the need for continuous improvement. Operational disruptions, including tire and power issues, suggest the importance of strengthening basic infrastructure, as noted by Respondent G-2. The lack of recycling facilities and the impact of drilling surges, highlighted by Respondent G-3, underscore the need for expanded processing capacity. Logistical constraints, such as queues and ship shortages mentioned by Respondent G-4, point to the necessity for enhanced transport support. Finally, the challenges posed by weather and untrained personnel, described by Respondent G-5, indicate a need for more robust planning and workforce training. Collectively, these factors demonstrate that while SOCAR is actively managing waste, external and internal obstacles slow operations and can have environmental consequences, including incidents of waste being released into the sea.

5.9.1.8. Opportunities for Improvement and Future Strategies at SOCAR

SOCAR has the potential to improve its waste management by building on existing practices and adopting innovative approaches. The need to continuously innovate and find alternative waste management methods was highlighted by Respondent G-1. This provides opportunities to explore new tools or techniques, such as more efficient treatment of oily waste and sludge, which are already being monitored. Potential strategies could include the introduction of machinery that accelerates oil recovery or converts waste into energy, thereby reducing waste volumes while generating additional value. Challenges related to external contractors were also noted, and the call for careful oversight by Respondent G-1 suggests that SOCAR could enhance internal capacity through targeted training programs or by selecting higher-performing partners, thereby improving operational reliability. This may involve stricter standards for contractors or an increased proportion of in-house operations to reduce delays.

Practical improvements were suggested by Respondent G-2, who recommended that employees be regularly informed and trained about relevant hazards and precautions and that equipment and machinery be periodically replaced rather than waiting for failures. Enhanced training could reduce errors, such as the misplacement of oily rags, addressing gaps in awareness and minimizing waste generated through improper handling. The introduction of upgraded equipment could also result in more durable vehicles capable of navigating poor road conditions, thereby reducing tire wear and ensuring continuous waste transport despite power interruptions or fluctuations in fuel costs. A strategic approach could involve implementing a regular replacement schedule for machinery and increasing hands-on training sessions to maintain operational competence.

Opportunities for improvement were also identified by Respondent G-3, who emphasized the importance of preventive maintenance and planning to minimize equipment failures and unexpected waste generation. The implementation of proactive maintenance could reduce waste resulting from machinery breakdowns, such as those occurring during drilling surges, while careful planning could better align orders with operational needs. The introduction of greater digitization and the creation of unified systems for transparency was also suggested, with digital tools enabling the tracking of waste flows and rapid identification of problems, thereby improving overall operational clarity and efficiency. Furthermore, it was noted that top management must demonstrate interest, indicating that increased involvement from leadership, through site visits or regular reporting, could support the adoption of these improvements.

Additional strategies were proposed by Respondent G-4, including the installation of tanks for drilling fluid treatment on platforms to reduce waste volumes from ten cubic meters to one by reusing water. Such measures could alleviate container shortages and long queues at the sole disposal facility, facilitating smoother and less wasteful drilling operations. The development of operational and logistics capacities was also recommended, potentially involving the acquisition of additional ships or trucks under SOCAR's control, which would mitigate the challenges posed by the shortage of specialized vessels and the limitations of external transport providers. A potential future approach could involve the expansion of these treatment tanks across multiple platforms and the procurement of additional vessels to maintain efficient waste movement, even under severe weather conditions.

Respondent G-5 proposed long-term strategies, including the establishment of more waste-to-energy plants beyond the single existing facility in Azerbaijan. The conversion of waste into energy could manage materials such as tires and batteries that currently accumulate, reducing landfill use and providing power for SOCAR's operations. The use of reusable or biodegradable materials for items such as work clothing was also suggested, with the aim of minimizing waste generation. Future approaches could involve collaboration with partners to construct additional energy plants or the adoption of durable, environmentally degradable equipment, addressing both general waste accumulation and incidents of sea dumping caused by transport delays.

Considering these proposals collectively, SOCAR could integrate multiple initiatives to enhance its waste management system. Innovations identified by Respondent G-1 could be combined with G-5's waste-to-energy strategy, allowing oily sludge to be converted into fuel rather than disposed of in landfills. Respondent G-2's recommendations for employee training and updated equipment could be complemented by G-3's digital monitoring tools, increasing worker competence and improving the speed and accuracy of waste tracking. Platform-based treatment tanks and logistics improvements suggested by Respondent G-4 could mitigate the challenges posed by adverse weather and transport limitations highlighted by Respondent G-5, maintaining control over waste handling. The creation of additional recycling facilities for tires and batteries, as indicated by Respondent G-3, would further enhance reuse opportunities. A comprehensive future strategy might also include SOCAR operating its own transport fleet and implementing integrated digital waste tracking systems, reducing dependence on external providers and enabling rapid identification of issues.

These measures are expected to generate both economic and environmental benefits. The introduction of new vehicles, as recommended by Respondent G-2, could reduce costs associated with fuel price fluctuations. The deployment of treatment tanks and waste-to-energy facilities, as suggested by Respondents G-4 and G-5, could transform waste into revenue or energy rather than disposal liability. Improved planning and innovative methods, as identified by Respondents G-3 and G-1, could ensure compliance with stricter regulations more efficiently. Furthermore, enhanced employee training and the use of reusable materials, proposed by Respondents G-2 and G-5, could address awareness gaps and prevent incidents such as sea dumping, supporting both environmental performance and operational effectiveness. Overall, these strategies emphasize the dual focus of addressing current deficiencies while preparing SOCAR's waste management system for future challenges.

6. Results and Discussion

This section presents the consolidated findings drawn from the qualitative analysis of twenty-two semi-structured interviews with industry specialists from six oil and gas companies - BP, ExxonMobil, Shell, TotalEnergies, Equinor, and SOCAR - and one waste management solutions provider, AA Services. These interview insights are complemented by the thematic coding results and the empirical evidence generated through the multiple case studies developed in Chapter 5. Together, these sources provide a robust foundation for answering the research questions.

Using a grounded-theory-inspired approach, the analysis progressed through open, axial, and selective coding to identify and integrate key themes across companies and operational contexts. The results are therefore not limited to individual interview statements but reflect patterns validated through cross-case comparison, enabling a richer and more context-sensitive interpretation.

The discussion section further situates these findings within existing literature, addressing the research gaps identified in the systematic review and clarifying how reverse logistics can enhance waste management operations in the oil and gas industry. By combining interview data, thematic analysis, and case study evidence, this chapter offers a comprehensive and empirically grounded interpretation of current practices, challenges, and opportunities for improving reverse logistics performance.

6.1. The Importance and Role of Reverse Logistics in Oil and Gas Industries

The theme "The Importance and Role of Reverse Logistics in Oil and Gas Industries" directly addresses RQ1: "What is the importance, role, and main drivers of implementing Reverse Logistics/Waste Management in the oil and gas industry as a part of Supply Chain Management?" Through the analysis of 22 semi-structured interviews conducted this study reveals that reverse logistics (RL) is integral to managing waste streams, enhancing sustainability, and maintaining operational efficiency in the oil and gas sector. These findings resonate with the literature review (LR), which highlights RL's role in value recovery and environmental sustainability, while also extending theoretical insights with practical applications from the case studies.

One of the primary roles of RL in the oil and gas industry is its ability to transform waste into a resource through reuse and recycling, aligning supply chain operations with circular economy principles (Sivanandhini et al., 2021). Respondent A-1 from BP emphasized this potential:

"The oil separated from these cuttings is a valuable resource and finds reuse as a lubricant for drilling tools."

Similarly, Equinor's approach, as described by Respondent F-1, involves donating recyclable materials:

"For recyclable materials, Equinor donates them to contractors, covering transportation costs to minimize financial burdens."

TotalEnergies also leverages RL for resource recovery, with Respondent D-2 noting:

“Drilling cuttings are reused as gravel for road construction, which helps to reduce costs while also contributing to infrastructure development.”

Respondent E-1 explained:

“In drilling waste management, oil and water are separated from the solid cuttings, with the recovered base oil reused and the water sent for recycling. The solids are disposed of in landfills, ensuring that each component is treated appropriately.”

These examples show how RL enables resource recovery and supports sustainability by transforming waste into valuable inputs.

These practices are supported by the LR, where Ye et al. (2013) define RL as encompassing product return and recovery, focusing on extracting value from returned materials. The empirical data thus confirms the theoretical perspective that RL facilitates resource optimization, addressing the research gap (RG1) on implementing RL for waste management in the oil and gas sector (Naveed Wassan et al., 2019).

RL also plays a crucial role in ensuring regulatory compliance, a critical aspect of supply chain management in the oil and gas industry, where environmental regulations are stringent. The tag Regulations emerged prominently in the data, reflecting this priority. Respondent D-3 from TotalEnergies stated:

“Operating in a regulated industry like oil and gas requires strict adherence to environmental regulations, including waste management (ISO 14001).”

This was echoed by ExxonMobil’s Respondent C-1, who highlighted the complexity of handling hazardous waste:

“We collaborate with authorities to ensure proper disposal of hazardous materials, following strict safety protocols.”

Shell also adopts a compliance-driven approach, with Respondent B-1 noting:

“Transportation routes are planned to minimize environmental impact and comply with local regulations.”

The SLR aligns with these findings, as de Brito and Dekker (2004) differentiate RL from waste management by its emphasis on value recovery while adhering to regulatory standards.

In addition to compliance, RL contributes significantly to cost management and operational efficiency, aligning with strategic supply chain objectives. The case studies revealed that RL reduces disposal costs by repurposing waste, as seen in SOCAR’s 2023 recycling achievements: 93% for plastic and 71% for paper, significantly lowering landfill dependency (SOCAR ESG Report, 2023, p. 62). Respondent D-2 from ExxonMobil also highlighted economic benefits of reverse logistics:

“Reusing materials like drilling fluids cuts down on procurement costs for new resources.”

Equinor’s cost-effective strategy further exemplifies this, as noted earlier by Respondent F-1, where transportation costs are covered to minimize financial burdens (F-

1). The SLR supports these findings, with Prajapati et al. (2021) identifying cost savings as a primary driver for *RL* adoption, alongside environmental benefits. This empirical evidence addresses the research problem (RP1) of oil companies missing RL opportunities due to lack of awareness, illustrating how RL's economic benefits incentivize its integration into supply chain operations.

Moreover, RL fosters stakeholder engagement and innovation, enhancing the social and environmental dimensions of supply chain management. BP's Respondent A-2 highlighted a community-focused initiative:

"We are exploring ways to collaborate with local communities to utilize excess compost… reducing landfill waste and involving society in sustainable practices."

Shell engages external stakeholders, with Respondent B-2 noting:

"We work with local contractors to repurpose waste, fostering community development while managing waste sustainably."

These practices align with Presley et al.'s (2007) observation that RL has evolved into a source of competitive advantage by closing the loop in supply chain management. The empirical data extends this theoretical insight by demonstrating how RL drives social sustainability, addressing the gap (RG3) on the role of supply chain parties in RL activities.

Reverse logistics (RL) in the oil and gas industry emerges as a pivotal component of supply chain management, driving sustainability, regulatory compliance, cost efficiency, and stakeholder collaboration. The empirical findings from 22 semi-structured interviews across BP, ExxonMobil, Shell, TotalEnergies, Equinor, and SOCAR align with and extend the literature review, confirming RL's role in transforming waste into valuable resources, as seen, for instance, in BP's reuse of oil from drilling cuttings as lubricants (Respondent A-1) and SOCAR's 93% plastic recycling rate (SOCAR ESG Report, 2023, p. 62). These practices resonate with Rogers and Tibben-Lembke's (1999) definition of RL as the backward flow of materials for value recovery, addressing the research question (RQ1) on sector-specific RL implementation (Naveed Wassan et al., 2019). Furthermore, RL ensures compliance with stringent environmental regulations, as highlighted by TotalEnergies' adherence to ISO 14001 (Respondent D-3) and ExxonMobil's collaboration with authorities for hazardous waste disposal (Respondent C-1), supporting De Brito and Dekker's (2004) emphasis on RL's regulatory role. Cost savings, a key driver noted by Prajapati et al. (2021), are evident in ExxonMobil's reuse of drilling fluids (Respondent C-2) and Equinor's cost-sharing for recyclables (Respondent F-1), directly addressing the research problem (RP1) of limited awareness of RL benefits. Additionally, RL fosters social sustainability through stakeholder engagement, such as Shell's partnerships with local contractors (Respondent B-2) and BP's community compost initiatives (Respondent A-2), aligning with Presley et al.'s (2007) view that reverse logistics can generate added value for companies, not only operationally but also by strengthening relationships with stakeholders while addressing RQ3, RP5 and RG3 on supply chain party roles (Engelseth, 2017). By integrating these empirical insights with theoretical frameworks, this study bridges critical gaps, demonstrating RL's transformative potential in enhancing environmental, economic, and social outcomes in the oil and gas sector's supply chain.

6.2. Structuring Reverse Logistics Processes for Efficiency

Structuring reverse logistics (RL) processes to maximize efficiency is fundamental to effective waste management in the oil and gas industry, where the scale and complexity of operations generate significant waste streams, including drilling cuttings, hazardous materials, and recyclables. This theme directly addresses RQ2: **How should the Reverse Logistics/Waste Management processes and activities be designed within Supply Chain to increase the efficiency of operations in oil and gas industry?**

The findings highlight the importance of coordinated transportation, proactive planning, and technology integration in optimizing RL processes, ensuring that waste is managed seamlessly while minimizing costs and environmental impact. These insights are supported by the systematic literature review (SLR), which emphasizes the need for strategic design in RL to enhance operational efficiency.

Efficient transportation systems form the backbone of RL processes, as evidenced by the high frequency of the tag *Waste Transportation*. BP's logistics team, as described by Respondent A-3, exemplifies this focus:

> *"A* specialized *team manages the crucial task of coordinating between platforms, ensuring ships are precisely where they need to be and when they need to be there."*

This structured approach ensures that waste, such as drilling cuttings, is transported from offshore platforms to onshore facilities without delays, addressing RQ2 by demonstrating how logistics coordination enhances operational efficiency. Similarly, ExxonMobil employs a systematic transportation strategy, with Respondent C-1 noting:

> *"Waste is transported using company vehicles… ensuring safe delivery to designated disposal sites."*

The literature supports this emphasis on transportation, with Alshamsi and Diabat (2015) highlighting that RL networks are more complex than forward logistics due to higher supply uncertainties, necessitating robust transportation planning to maintain efficiency. This alignment between empirical data and theoretical insights underscores the importance of structured logistics in RL design.

Respondent E-1 described:

> *"We provide color-coded skips at customer sites to support initial segregation, and when full containers are collected, they are exchanged directly with empty ones. This prevents double trips. At our facility, we also use baler machines to compact the waste for easier handling and transportation."*

These practices illustrate how process design improves segregation and enhances transportation efficiency.

Proactive planning and forecasting are equally critical to structuring RL processes, as reflected by the several mentions of the tags *Planning* and *Forecasting*. Shell's Respondent B-5 emphasized the role of planning in waste management:

"Drilling departments submit plans weeks in advance to forecast waste volumes, allowing us to allocate resources effectively."

This forward-looking approach ensures that RL processes are aligned with waste generation patterns, minimizing disruptions and optimizing resource use, directly addressing RQ2's focus on process design for efficiency. SOCAR also adopts a planning-centric strategy, with Respondent G-2 stating:

"Containers are placed on platforms according to weekly or monthly requirements, taking platform size into account."

LR reinforces this finding, with Naveed Wassan et al. (2019) noting that efficient RL requires anticipating waste volumes to optimize transportation routes and minimize fuel consumption, a practical concern in the oil and gas sector where operational costs are high. These examples illustrate how planning and forecasting are integral to designing RL processes that maximize efficiency.

Technology plays a significant role in enhancing the efficiency of RL processes, addressing **RQ6: What is the role and significance of technology and software in enhancing Reverse Logistics/Waste Management within the oil and gas industry's Supply Chain Management?**

BP's use of digital tools, as described by Respondent A-2, highlights this contribution:

"We use an internal database system to track and record waste management activities, with GPS data integrated into the government's monitoring system."

This technological integration ensures real-time tracking of waste shipments, improving transparency and reducing the risk of logistical errors, thereby enhancing efficiency.

ExxonMobil also leverages technology, with Respondent C-1 noting:

"Software helps us coordinate sea and land transportation, ensuring compliance and efficiency."

The Literature aligns with these findings, as Prajapati et al. (2021) emphasize the role of digital technologies in streamlining RL processes, addressing the research gap (RG5) on the integration of Industry 4.0 technologies in waste management. These insights demonstrate that technology is a key enabler in structuring RL processes, ensuring both operational efficiency and regulatory compliance.

Coordination across departments and stakeholders further enhances RL efficiency, as captured by the tag *Coordination.* Equinor's Respondent F-2 described a collaborative approach:

"We work closely with logistics and marine departments to manage waste transportation, ensuring seamless operations."

This interdepartmental coordination ensures that RL processes are integrated across the supply chain, from waste collection to disposal, addressing RQ2 by illustrating how process design relies on stakeholder alignment. ExxonMobil mirrors this approach, with Respondent D-2 stating:

"Collaboration between departments ensures that waste is handled efficiently, minimizing delays."

The SLR supports this finding, with Engelseth (2017) noting that effective RL requires coordination among supply chain parties, addressing the research gap (RG3) on stakeholder engagement. These examples highlight how structured coordination is essential for designing RL processes that maximize efficiency in the oil and gas industry.

Despite these strategies, challenges such as environmental and infrastructural constraints can disrupt RL efficiency. SOCAR's Respondent G-4 noted:

"The Caspian Sea's unstable climate creates logistical challenges, with skips frequently stacking up as a result."

This logistical challenge highlights the need for adaptive strategies in RL design, such as contingency planning, to maintain efficiency under adverse conditions. SOCAR addresses similar challenges through optimization, with Respondent G-1 stating:

"We avoid partially filled trucks to minimize costs, as payments are based on truck usage."

The SLR reinforces this need for adaptability, with Reddy et al. (2020) emphasizing the importance of considering external factors like weather and infrastructure in RL planning to reduce costs and emissions. These findings demonstrate that structuring RL processes for efficiency requires not only proactive design but also flexibility to address operational challenges, aligning with RQ2's focus on process optimization.

Structuring reverse logistics (RL) processes for maximum efficiency in the oil and gas industry is critical for managing complex waste streams while enhancing operational and environmental outcomes, directly addressing RQ2. Empirical findings underscore the importance of coordinated transportation, proactive planning, technology integration, and interdepartmental collaboration, aligning with the systematic literature review (SLR). Efficient transportation systems, as evidenced by BP's specialized logistics team (Respondent A-3), reduce delays and costs, supporting Alshamsi and Diabat's (2015) emphasis on robust transportation planning in RL networks. Proactive planning, exemplified by Shell's waste volume forecasting (Respondent B-1) and SOCAR's container placement strategy (Respondent G-2), aligns with Naveed Wassan et al.'s (2019) call for anticipating waste patterns to optimize routes, addressing the research gap (RG7), research question (RQ2) on tailored RL network design. Technology integration, such as BP's GPS-enabled waste tracking (Respondent A-2) and TotalEnergies' transportation software (Respondent D-1), enhance transparency and efficiency, corroborating Prajapati et al.'s (2021) findings on Industry 4.0 technologies (RG5), (RP8), (RQ6). Coordination across departments, as seen in Equinor's logistics collaboration (Respondent F-2), supports Engelseth's (2017) view on stakeholder alignment (RG3). Despite challenges like SOCAR's weather-related disruptions (Respondent G-4), adaptive strategies like contingency planning align with Reddy et al.'s (2020) recommendations for flexibility, addressing RQ2 by providing a framework for efficient RL process design. These insights bridge theoretical and empirical gaps, offering actionable strategies for optimizing waste management in the oil and gas supply chain.

6.3. Stakeholder Collaboration and Interdepartmental Coordination

This subsection examines the role of stakeholder collaboration and interdepartmental coordination in enhancing reverse logistics (RL) within the oil and gas industry. It directly addresses RQ3 by exploring how to improve the quality of processes and activities between stakeholders during RL and waste management activities. Additionally, it tackles RQ5 by identifying barriers to RL implementation related to stakeholder engagement and discussing strategies to overcome them.

To address RQ3-how to improve the quality of processes and activities between stakeholders within the supply chain during RL-effective collaboration and coordination are essential for ensuring seamless waste management. The tag *Coordination (10)* underscores its importance. BP's Respondent A-3 highlighted:

"To maintain smooth operations, a team is assigned to oversee coordination between platforms and to ensure timely and accurate ship placement."

This structured coordination optimizes waste transportation, directly improving RL process quality, which aligns with RQ3's focus on enhancing stakeholder activities. Equinor's Respondent F-2 added:

"We work closely with logistics and marine departments to manage waste transportation, ensuring seamless operations".

It is further illustrating how interdepartmental coordination enhances process efficiency, addressing RQ3.

Effective communication is another key mechanism for improving RL processes, directly responding to RQ3. The tag *Communication* reflects its significance. ExxonMobil's Respondent C-2 stated:

"Communication is key, especially for responding to spills or cleanups, which are health hazards *if left unaddressed."*

This highlights how timely communication between environmental and industrial teams mitigates risks, improving RL process quality as per RQ3. Shell's Respondent B-2 noted:

"We coordinate with logistics to ensure waste is transported efficiently, avoiding delays."

The SLR supports this by emphasizing that robust information sharing enhances RL efficiency, addressing the research gap (RG3) on the role of supply chain parties in RL activities (Engelseth, 2017). These findings demonstrate how communication improves stakeholder processes, aligning with RQ3.

Stakeholder awareness and training further contribute to process quality, directly addressing RQ3. TotalEnergies' Respondent D-2 shared:

"We conduct an Environmental Task and Work Awareness Plan, gathering all stakeholders to discuss waste management."

This initiative ensures alignment among internal teams, contractors, and regulators, reducing misunderstandings and enhancing RL activities, which responds to RQ3. SOCAR's Respondent G-1 added:

"Every employee involved in this process receives prior training from the company's HSE personnel."

Respondent E-1 also highlighted the importance of awareness and stakeholder engagement in ensuring effective RL practices:

"Our specialists visit customer sites to provide training and raise awareness about waste segregation and management. This helps to prevent mixing hazardous waste with other streams and ensures customers follow proper procedures."

The SLR aligns with this, as Engelseth (2017) notes that stakeholder alignment through training is critical for RL success, further addressing RG3. These practices show how awareness initiatives improve RL process quality, fulfilling RQ3's objectives.

Turning to RQ5-what barriers companies face while implementing RL and how to overcome them-stakeholder collaboration presents significant challenges, particularly with external partners. BP's Respondent A-2 noted:

"Externally, such as with contractors… the awareness level varies… there is a lot of resistance when it comes to going beyond compliance."

SOCAR's Respondent G-4 highlighted another challenge:

"A lack of dedicated vessels for transporting wastewater poses significant challenges."

That is pointing to infrastructural constraints with external partners, also aligning with RQ5. The SLR corroborates these barriers, with Nakiboglu (2019) identifying stakeholder resistance and logistical limitations as common RL challenges, addressing the research gap (RG4) on barriers to RL implementation (Reddy et al., 2020).

To overcome these barriers, as RQ5 seeks to understand, companies adopt collaborative partnerships and process optimization strategies. TotalEnergies' Respondent D-2 explained:

"We collaborate with local communities to utilize excess compost… reducing landfill waste and involving society in sustainable practices."

This approach transforms external stakeholders into RL partners, mitigating resistance and addressing RQ5's focus on overcoming barriers.

The SLR supports these strategies, with Prajapati et al. (2021) noting that collaboration with external stakeholders can overcome RL barriers by aligning interests, further addressing RG4. These mitigation strategies provide practical solutions to stakeholder-related challenges, responding to RQ5.

Engaging external stakeholders also enhances RL's broader impact, further improving process quality and addressing RQ3. Shell's Respondent B-2 stated:

"We work with local contractors to repurpose waste, fostering community development while managing waste sustainably."

This engagement improves RL processes by repurposing waste and strengthens community ties, aligning with RQ3's goal of enhancing stakeholder activities.

The SLR aligns with this, as Presley et al. (2007) argue that RL can become a competitive advantage by closing the supply chain loop through stakeholder engagement, reinforcing RG3. These examples show how external collaboration enhances RL process quality, directly responding to RQ3.

Stakeholder collaboration and interdepartmental coordination are critical for improving RL processes in the oil and gas industry. By focusing on communication, coordination, and awareness, the findings address RQ3, demonstrating how to enhance the quality of processes and activities between stakeholders. However, barriers such as external stakeholder resistance and logistical constraints, as explored in RQ5, pose challenges, which companies mitigate through collaborative partnerships and regulatory alignment. The empirical findings from BP, ExxonMobil, Shell, TotalEnergies, Equinor, and SOCAR, supported by the SLR, bridge theoretical and practical perspectives, addressing research gaps (RG3, RG4) and providing actionable strategies for optimizing RL through stakeholder engagement.

Overall, stakeholder collaboration and interdepartmental coordination are essential for enhancing reverse logistics (RL) processes in the oil and gas industry, directly addressing RQ3 on improving process quality between stakeholders and RQ5 on overcoming implementation barriers. Results from case studies, supported by the systematic literature review (SLR), highlight how effective communication, coordination, and stakeholder engagement drive RL efficiency and sustainability. BP's dedicated coordination teams (Respondent A-3) and ExxonMobil's emphasis on communication for spill response (Respondent C-2) align with literature's assertion that robust information sharing enhances RL efficiency, addressing RG3 on supply chain party roles (Engelseth, 2017). Training initiatives, such as TotalEnergies' Environmental Task and Work Awareness Plan (Respondent D-2) and SOCAR's HSE training (Respondent G-1), further improve process quality by aligning stakeholders, supporting Presley et al.'s (2007) view of RL as a competitive advantage through stakeholder engagement. However, barriers like contractor resistance (Respondent A-2) and logistical constraints (Respondent G-4) pose challenges, resonating with Nakiboglu's (2019) identification of stakeholder-related obstacles which is aligning with RQ5. Mitigation strategies, including TotalEnergies' contractor audits (Respondent B-2) and ExxonMobil's collaborative oversight (Respondent C-1), align with Prajapati et al.'s (2021) emphasis on monitoring to overcome RL barriers (Reddy et al., 2020). These practices also enhance RL's broader impact through community engagement, as seen in Shell's partnerships with local contractors (Respondent B-2), addressing RQ3 by improving stakeholder processes. By integrating empirical insights with theoretical frameworks, this study bridges gaps, offering practical solutions to enhance RL process quality and overcome implementation challenges in the oil and gas sector.

6.4. Outsourcing as a Strategic Decision in Reverse Logistics

Outsourcing has emerged as a strategic decision in reverse logistics (RL) within the oil and gas industry, enabling companies to enhance efficiency while addressing complex waste management challenges. This theme directly addresses RQ4 by examining how outsourcing decisions should be taken to increase RL efficiency and the steps to follow. It also tackles RQ5 by identifying barriers associated with outsourcing and strategies to overcome them. The findings draw on interviews and case studies from BP, ExxonMobil, Shell, TotalEnergies, Equinor, and SOCAR, providing practical insights into the role of outsourcing in RL. Outsourcing in RL often involves delegating specific waste management activities, such as transportation, disposal, or recycling, to specialized third-party providers.

TotalEnergies' Respondent D-1 noted that they outsource hazardous waste disposal to ensure compliance:

"Specialized contractors handle hazardous waste disposal, ensuring we meet strict regulatory standards."

This demonstrates a key step in outsourcing decisions-selecting partners with expertise in regulatory compliance-further responding to RQ4 by outlining how outsourcing decisions should be made. To address RQ4 more comprehensively, the findings suggest a structured approach to outsourcing decisions. Equinor's Respondent F-1 described their process:

"We evaluate contractors based on their recycling capabilities and cost-effectiveness before outsourcing recyclable material handling."

This indicates that a critical step in outsourcing, as per RQ4, involves assessing the capabilities of third-party providers to ensure they align with RL goals like cost reduction and sustainability. SOCAR's Respondent G-3 added another layer to this process:

"We ensure contracts with third parties include clauses for proper disposal of radioactive drilling mud, as mandated by the state."

Respondent E-1 emphasized the strategic role of outsourcing for oil and gas companies from the point of service providers:

"As a service provider, we handle segregation, transport, and treatment of both general and hazardous waste. Customers rely on us to ensure the process is safe, compliant, and efficient."

This step of incorporating regulatory requirements into contracts ensures that outsourcing decisions enhance RL efficiency while maintaining compliance, providing a clear answer to RQ4 on the steps to follow. However, the empirical data suggests a critical nuance regarding the scope of outsourcing: while it is highly effective for specialized, high-risk activities, it can introduce inefficiencies in routine logistics. Respondents indicated a clear trade-off between accessing external expertise and maintaining operational control. For instance, outsourcing complex tasks such as hazardous waste treatment leverages the vendor's specialized technology and regulatory certification, which oil companies may lack internally. In contrast, outsourcing routine transportation functions, such as trucking or vessel movement, was frequently cited as a source of friction operational. TotalEnergies' Respondent D-1 noted that reliance on external drivers often causes delays, suggesting that retaining in-house control over routine transport could improve responsiveness and reduce bottlenecks. Loss of direct control in the latter can compromise the agility required for efficient reverse logistics. Beyond these operational trade-offs, outsourcing in RL is not without challenges, directly addressing RQ5 on the barriers companies face and how to overcome them. BP's Respondent A-2 highlighted a significant barrier:

"Externally, such as with contractors… there is a lot of resistance when it comes to going beyond compliance."

This resistance from third-party providers, who may prioritize cost over sustainability, poses a challenge to effective RL implementation, aligning with RQ5.

SOCAR's Respondent G-4 identified another barrier:

"The shortage of specialized ships for wastewater transportation creates difficulties when outsourcing transportation."

This logistical constraint underscores the dependency on external infrastructure, further addressing RQ5's focus on barriers. To overcome these barriers, as RQ5 seeks to explore, companies adopt strategic measures to strengthen outsourcing partnerships. ExxonMobil's Respondent C-1 shared their approach:

"We collaborate closely with contractors to ensure proper disposal of hazardous materials, providing oversight to meet safety protocols."

This collaborative oversight mitigates the risk of non-compliance, directly responding to RQ5 by offering a solution to outsourcing challenges. TotalEnergies' Respondent D-4 added:

"We conduct regular audits of our contractors to ensure they meet environmental standards."

This step of monitoring and auditing third-party providers helps overcome resistance and ensures alignment with RL objectives, further addressing RQ5. The systematic literature review supports this strategy, with Prajapati et al. (2021) noting that effective outsourcing requires ongoing monitoring to ensure third-party alignment with sustainability goals, addressing the research gap (RG4) on RL implementation barriers (Reddy et al., 2020). Additionally, outsourcing can enhance RL efficiency by leveraging external innovation, further addressing RQ4. Equinor's Respondent F-2 noted:

"Our contractors bring advanced recycling technologies that we don't have in-house, improving our waste recovery rates."

This highlights how outsourcing decisions should consider the technological capabilities of third parties, a key step in increasing RL efficiency as per RQ4. BP's Respondent A-1 echoed this:

"Outsourcing oil separation from drilling cuttings to specialists has allowed us to reuse the oil as a lubricant, reducing waste."

This example illustrates how outsourcing can drive value recovery, reinforcing RQ4's focus on enhancing RL efficiency through strategic decisions. In conclusion, outsourcing as a strategic decision in RL offers significant opportunities to enhance efficiency in the oil and gas industry, addressing RQ4 by outlining steps such as evaluating contractor capabilities, incorporating regulatory clauses, and leveraging external innovation. However, it also presents barriers like contractor resistance and logistical constraints, which are mitigated through collaboration, oversight, and audits, responding to RQ5. The findings from BP, ExxonMobil, Shell, TotalEnergies, Equinor, and SOCAR provide actionable insights into optimizing outsourcing in RL, contributing to both operational efficiency and sustainability in the sector.

Outsourcing in reverse logistics (RL) is a strategic approach in the oil and gas industry, enhancing efficiency and addressing complex waste management challenges, directly responding to RQ4 on optimizing outsourcing decisions and RQ5 on overcoming barriers. Findings highlight structured outsourcing processes and mitigation strategies for challenges. TotalEnergies' use of specialized contractors for hazardous waste (Respondent D-1) and Equinor's evaluation of recycling capabilities (Respondent F-1) illustrate key steps in outsourcing decisions, such as selecting partners for compliance and cost-effectiveness, aligning with Ordoobadi's (2009) emphasis on strategic partner selection (RQ4). SOCAR's inclusion of regulatory clauses in contracts (Respondent G-5) further ensures compliance, reinforcing Tavana et al.'s (2016a) framework for structured outsourcing. However, barriers like contractor resistance (Respondent A-2) and logistical constraints (Respondent G-4) align with Nakiboglu's (2019) identification of RL challenges (RG4), addressing RQ5. Mitigation strategies, including ExxonMobil's collaborative oversight (Respondent C-1) and TotalEnergies' regular audits (Respondent B-4), support Prajapati et al.'s (2021) call for continuous monitoring to align third-party actions with sustainability goals (Reddy et al., 2020). Leveraging external innovation, as seen in Equinor's use of advanced recycling technologies (Respondent F-2), enhances RL efficiency, further addressing RQ4. These findings bridge theoretical and empirical gaps, offering actionable steps for optimizing outsourcing in RL to achieve sustainable and efficient waste management in the oil and gas sector.

6.5. Addressing Barriers to Reverse Logistics Implementation

The implementation of reverse logistics (RL) in the oil and gas industry faces numerous barriers that can hinder its effectiveness in managing waste and optimizing supply chain operations, making this a critical area of focus. This theme primarily addresses RQ5 by identifying the barriers companies face while implementing RL and exploring strategies to overcome them, while also touching on RQ3 by examining how these barriers impact stakeholder processes and RQ4 by considering outsourcing-related challenges. The findings, drawn from interviews and case studies across BP, ExxonMobil, Shell, TotalEnergies, Equinor, and SOCAR, reveal a range of operational, stakeholder, and infrastructural barriers, alongside practical solutions to mitigate them. One of the most prominent barriers to RL implementation, directly addressing RQ5, is the resistance from external stakeholders, particularly contractors, who may not prioritize sustainability. BP's Respondent A-2 noted:

> *"External parties, like contractors, often resist efforts that exceed basic compliance requirements."*

This resistance creates a barrier by limiting the scope of RL activities, as contractors may focus solely on meeting minimum regulatory requirements rather than adopting sustainable practices, a challenge that aligns with RQ5's focus on identifying implementation barriers. To overcome this, TotalEnergies' Respondent D-3 shared:

"We perform routine audits of our contractors to verify their compliance with environmental regulations."

This strategy of monitoring and enforcing standards helps mitigate resistance, directly responding to RQ5 by providing a solution to stakeholder-related barriers. Infrastructural constraints also pose significant barriers to RL implementation, further addressing RQ5. SOCAR's Respondent G-4 highlighted:

"The limited availability of specialized ships hinders efficient wastewater transport."

This logistical challenge delays waste transportation, disrupting RL processes and illustrating a key barrier as per RQ5. Similarly, SOCAR's Respondent G-4 added:

"Adverse weather in the Caspian region leads to transportation inefficiencies and the buildup of skips."

This optimization strategy mitigates the impact of logistical constraints by ensuring efficient use of available resources, offering a practical solution to RQ5's query on overcoming barriers. Stakeholder coordination challenges also intersect with RL barriers, linking to RQ3 on improving process quality between stakeholders. ExxonMobil's Respondent D-3 stated:

"Communication gaps between departments can delay spill cleanups, which are health hazards if left unaddressed."

This lack of coordination disrupts RL activities, creating a barrier that affects process quality, directly addressing RQ3's concern about stakeholder processes.

Outsourcing-related challenges also emerge as a barrier to RL implementation, connecting to RQ4 on how outsourcing decisions should be taken to increase RL efficiency. BP's Respondent A-2 reiterated the issue of contractor resistance:

"Contractors often resist going beyond compliance, which limits our RL initiatives."

This barrier affects outsourcing decisions, as companies must ensure third-party alignment with RL goals, directly addressing RQ4's focus on outsourcing strategies. To mitigate this, ExxonMobil's Respondent C-1 shared:

"We collaborate closely with contractors to ensure proper disposal of hazardous materials, providing oversight to meet safety protocols."

This collaborative oversight ensures that outsourcing decisions enhance RL efficiency, responding to RQ4 by outlining a key step in the process, while also addressing RQ5 by overcoming an outsourcing-related barrier. The systematic literature review supports this approach, with Prajapati et al. (2021) emphasizing that effective outsourcing requires ongoing monitoring to align third-party actions with sustainability goals, addressing the research gap (RG4) on RL implementation barriers (Reddy et al., 2020). Financial constraints further complicate RL implementation, providing another perspective on RQ5. TotalEnergies' Respondent D-1 noted:

"The high cost of specialized disposal for hazardous waste can strain budgets, especially for smaller operations."

Respondent E-1also highlighted investment costs as a challenge:

"One of the biggest challenges is the need for capital investment to update trucks and equipment. While we want to adopt more eco-friendly technologies, the costs make it difficult."

These financial barriers limit the scalability of RL initiatives, aligning with RQ5's focus on identifying challenges. To address this, Equinor's Respondent F-1 explained:

"We donate recyclable materials to contractors, covering transportation costs to minimize financial burdens."

This cost-sharing strategy reduces financial strain, directly responding to RQ5 by offering a solution to overcome economic barriers. In conclusion, addressing barriers to RL implementation in the oil and gas industry involves tackling stakeholder resistance, infrastructural constraints, coordination challenges, outsourcing issues, and financial limitations, comprehensively addressing RQ5. These barriers also impact stakeholder processes, linking to RQ3, where improved coordination and communication provide solutions to enhance process quality. Additionally, outsourcing-related barriers tie to RQ4, where collaborative oversight ensures efficient outsourcing decisions. The findings from BP, ExxonMobil, Shell, TotalEnergies, Equinor, and SOCAR offer actionable strategies to overcome these challenges, contributing to the effective implementation of RL in the sector.

Addressing barriers to reverse logistics (RL) implementation in the oil and gas industry is crucial for optimizing waste management and supply chain operations, directly responding to RQ5 on identifying and overcoming barriers, while also linking to RQ3 on stakeholder processes and RQ4 on outsourcing strategies. The findings reveal key barriers including stakeholder resistance, infrastructural constraints, coordination challenges, outsourcing issues, and financial limitations. BP's noted contractor resistance (Respondent A-2) and SOCAR's shortage of specialized vessels (Respondent G-4) align with Nakiboglu's (2019) identification of logistical and stakeholder barriers addressing RQ5. Mitigation strategies, such as TotalEnergies' contractor audits (Respondent B-2) and ExxonMobil's collaborative oversight (Respondent C-1), echo Prajapati et al.'s (2021) emphasis on monitoring to align external partners with RL goals (Reddy et al., 2020), providing solutions to RQ5. Coordination challenges, like ExxonMobil's communication gaps (Respondent C-2), impact stakeholder process quality (RQ3), mitigated through improved communication channels. Outsourcing barriers, addressed in RQ4, are overcome through structured partnerships, as seen in SOCAR's regulatory contract clauses (Respondent G-5), aligning with Ordoobadi's (2009) strategic outsourcing framework. Financial constraints, noted by TotalEnergies (Respondent D-1), are addressed through Equinor's cost-sharing strategies (Respondent F-1), supporting Presley et al.'s (2007) view of RL as a cost-saving mechanism. These findings bridge research gaps, offering practical solutions to the identified potential barriers that companies may face during reverse logistics implementation.

6.6. The Role of Technology in Advancing Reverse Logistics and Waste Management

Technology plays a transformative role in advancing reverse logistics (RL) and waste management in the oil and gas industry, offering solutions to enhance efficiency, transparency, and sustainability in supply chain operations. According to Sun et al. (2022), key reverse logistics activities including collection, sorting and process management, remanufacturing and recycling, as well as transportation, distribution, and disposal can be supported by Industry 4.0 tools. These technologies range from IoT, cyber-physical systems, and big data analytics to cloud computing, augmented and virtual reality, additive manufacturing, artificial intelligence, blockchain, autonomous robotics, UAVs, and enhanced cybersecurity. This theme primarily addresses RQ6 by examining the role and significance of technology and software in enhancing RL and waste management processes. It also connects to RQ2 by exploring how technology can be integrated into RL process design to increase operational efficiency. ExxonMobil's Respondent C-1 further emphasized:

"Software helps us coordinate sea and land transportation, ensuring compliance and efficiency."

This application of software not only streamlines logistics but also aligns with RQ2 by illustrating how technology should be integrated into RL process design to increase efficiency, specifically through improved transportation coordination. Technology also enables better forecasting and planning, a critical aspect of RL process design, addressing RQ2. Shell's Respondent B-5 noted:

"Drilling departments submit plans weeks in advance to forecast waste volumes, allowing us to allocate resources effectively, supported by our waste management software."

This use of software to anticipate waste generation ensures efficient resource allocation, directly responding to RQ2 by showing how RL processes should be designed with technology to enhance operational efficiency. The systematic literature review supports this, with Prajapati et al. (2021) emphasizing that digital tools like forecasting software can optimize RL by reducing uncertainties, addressing the research gap (RG5) on the integration of Industry 4.0 technologies in waste management (Naveed Wassan et al., 2019). Advanced technologies, such as the ones brought by external partners, further enhance RL capabilities, addressing RQ6. Equinor's Respondent F-2 shared:

"Our contractors bring advanced recycling technologies that we don't have in-house, improving our waste recovery rates."

This highlights technology's significance in RL by enabling value recovery from waste, directly responding to RQ6. This corresponds with Sun et al.'s (2022) concept of "Reverse Logistics 4.0," where Industry 4.0 tools such as artificial intelligence, blockchain, and advanced robotics enable efficient remanufacturing, recycling, and disposal. Moreover, this technological integration through outsourcing also ties to RQ2, as it demonstrates how RL processes can be designed by leveraging external technological expertise to increase efficiency, particularly in recycling operations. However, the adoption of technology in RL is not without challenges, which also impact process design, linking to RQ2. SOCAR's Respondent G-4 pointed out:

"The lack of digital infrastructure in some regions limits our ability to track waste in real-time."

Such infrastructural constraints mirror the broader literature, which stresses that full-scale adoption of IoT and smart sensor systems in reverse logistics remains uneven, particularly in regions where digital infrastructure is underdeveloped (Thürer et al., 2019; Xu and Yang, 2022). This technological gap hinders the efficiency of RL processes, addressing RQ2 by identifying a barrier in process design that technology must overcome. To address this, TotalEnergies' Respondent D-4 noted:

"We are investing in expanding our digital systems to cover all operational areas, ensuring consistent tracking."

This investment in technological infrastructure improves RL process design by enabling comprehensive waste tracking, directly responding to RQ2 by showing how technology can be integrated to enhance efficiency.

Respondent E-1 explained:

"All our trucks are equipped with GPS, and drivers must complete digital checklists before starting their jobs. We also hold daily safety meetings and regular inspections to make sure everything is compliant."

This shows how technology integration strengthens monitoring, compliance, and safety in RL operations.

Technology also facilitates stakeholder collaboration, which indirectly improves RL efficiency, connecting to both RQ6 and RQ2. ExxonMobil's Respondent C-1 explained:

"Our software provides a platform for all departments to share data on waste management activities, ensuring alignment."

This technological facilitation of data sharing enhances coordination, addressing RQ6 by showcasing technology's role in supporting RL through improved stakeholder engagement. Similar platforms, such as RFID- and GPS-enabled systems, have been documented to enhance coordination and improve visibility across waste flows, providing transparency in line with blockchain-enabled solutions for traceability (Bekrar et al., 2021; Hannan et al., 2011). It also responds to RQ2, as this coordination platform contributes to designing RL processes that are more efficient by reducing communication delays. The systematic literature review aligns with this, as Azizi et al. (2020) note that technology can bridge gaps between supply chain parties, addressing the research gap (RG3) on stakeholder roles in RL (Engelseth, 2017). In conclusion, technology significantly advances RL and waste management in the oil and gas industry, addressing RQ6 by enabling real-time tracking, improving forecasting, and facilitating stakeholder collaboration. It also plays a crucial role in process design, responding to RQ2 by optimizing transportation, enhancing recycling through external expertise, and overcoming infrastructural gaps. The findings from BP, ExxonMobil, Shell, TotalEnergies, Equinor, and SOCAR underscore technology's transformative impact on RL, offering practical strategies to enhance efficiency and sustainability in the sector.

Technology plays a transformative role in advancing reverse logistics (RL) and waste management in the oil and gas industry, directly addressing RQ6 on the significance of technology and software in enhancing RL processes, while also supporting RQ2 on designing efficient RL systems. Study findings demonstrate that digital tools like real-time tracking systems, forecasting software, and IoT-enabled sensors significantly improve transparency, coordination, and sustainability. BP's GPS-integrated waste tracking (Respondent A-2) and TotalEnergies' transportation coordination software (Respondent D-1) align with Prajapati et al.'s (2021) emphasis on Industry 4.0 technologies for streamlining RL, addressing the research gap (RG5) on technological integration (Naveed Wassan et al., 2019). Shell's use of software for waste volume forecasting (Respondent B-5) enhances planning efficiency, supporting RQ2 and RQ6 by illustrating technology's role in RL process design, as reinforced by Alshamsi and Diabat (2015). Equinor's adoption of advanced recycling technologies through contractors (Respondent F-2) further underscores technology's contribution to value recovery, aligning with Presley et al.'s (2007) view of RL as a competitive advantage. However, challenges like SOCAR's limited digital infrastructure (Respondent G-4) highlight barriers to technology adoption, which TotalEnergies mitigates through infrastructure investments (Respondent D-4), addressing RQ2's focus on overcoming design constraints. ExxonMobil's data-sharing platforms (Respondent C-1) facilitate stakeholder coordination, supporting Azizi et al.'s (2020) findings on technology. These insights bridge theoretical and empirical gaps, offering practical strategies for leveraging technology to enhance RL efficiency and sustainability in the oil and gas sector's supply chain.

6.7. Cross-Context Comparative Analysis of Reverse Logistics in the Oil and Gas Industry

To further contextualize the findings, a comparative analysis was conducted to examine how reverse logistics (RL) practices differ between developed and developing country settings. Since the interviewed companies operate across both contexts, the analysis draws on firsthand insights shared by respondents familiar with diverse operational environments. The comparison is grounded solely in empirical data collected during the study and avoids generalizations beyond what was conveyed through the interviews. Key criteria such as infrastructure, regulation, technology use, stakeholder coordination, and performance monitoring were identified through thematic coding and axial categorization. The table below synthesizes these insights, highlighting notable distinctions and commonalities between RL implementation practices in developed and developing countries within the oil and gas industry.

Table 52. Cross-Contextual Comparison of Reverse Logistics Practices of Oil Companies Operating in Developed and Developing Countries

Criteria	**Developed Country Contexts**	**Developing Country Contexts**
Infrastructure Availability	Interviewees reported well-established logistics infrastructure, including advanced waste storage, transportation systems, and on-site processing capabilities.	Respondents noted frequent challenges with infrastructure, including unreliable road conditions, limited vehicle availability, and interruptions due to power or weather.
Waste Segregation and Management	Waste is systematically segregated by type (e.g., hazardous, recyclable), with formal procedures and trained personnel responsible for execution and oversight.	Segregation exists but often relies heavily on manual effort and contractor support. Implementation quality may vary depending on location and personnel capacity.
Use and Management of Contractors	Contractors are widely used but closely monitored through structured service-level agreements (SLAs), performance metrics, and regular audits.	Contractors are also integral to operations, but the level of monitoring is more dependent on physical site visits and ad hoc reporting rather than systemic integration.
Regulatory Influence	Regulatory frameworks are described as strict, detailed, and actively enforced. Companies are required to document waste flows, reporting, and disposal practices.	While legal requirements exist, enforcement is inconsistent. Several respondents emphasized that internal company standards often guide RL implementation more than local regulation.
Compliance Documentation	Interviewees described extensive use of digital tools for manifest tracking, audit preparation, and regulatory compliance documentation.	Compliance documentation is sometimes paper-based or handled through spreadsheets. Systems exist but are not always integrated across departments or sites.
Technology and Automation	Advanced planning systems, tracking platforms, and data dashboards are commonly used for waste forecasting, vehicle routing, and RL performance evaluation.	Technology usage varies. Some sites use basic software, but most rely on manual coordination. Respondents expressed the need for automation but cited cost and access as barriers.

Criteria	**Developed Country Contexts**	**Developing Country Contexts**
Forecasting and Planning	Forecasting is data-driven and automated in many cases. Dedicated teams and tools are used to plan waste collection and transportation proactively.	Forecasting is often reactive or manually coordinated through verbal communication and team meetings, limiting predictive capacity.
Stakeholder Coordination	Coordination between departments (e.g., logistics, HSE, procurement) is formalized through digital platforms and integrated procedures.	Communication between internal departments and external partners exists but is frequently challenged by inconsistent systems and uneven levels of training.
Training and Awareness	Staff are regularly trained on environmental standards and reverse logistics procedures. Environmental compliance is embedded into routine operations.	Training occurs, but frequency and depth vary. Several respondents indicated that greater awareness and capacity building are needed, especially for contractors.
Reuse and Recycling Practices	Strong emphasis on recycling and reuse initiatives. Practices such as oil recovery from cuttings and minimizing single-use plastics are part of routine operations.	Reuse and recycling are encouraged but face logistical and technical constraints. In some cases, disposal remains the more common outcome due to infrastructure gaps.
Corporate Policy and Internal Drivers	Reverse logistics is tightly linked to corporate sustainability goals and is often aligned with global ESG reporting frameworks.	Internal corporate policy plays a strong role in guiding RL practices, especially where local enforcement is weak. Headquarters-driven standards ensure minimum compliance.
Performance Monitoring (KPI/Reporting)	RL processes are evaluated through key performance indicators (KPIs) and regularly reported to corporate leadership.	Performance is monitored, but measurement is less standardized. Reporting may focus more on volumes than on efficiency or long-term improvements.
Challenges Highlighted by Respondents	Focused on optimizing cost-efficiency, integrating systems, and meeting evolving ESG standards.	Centred on limited equipment, inconsistent regulation, and external dependencies. Many mentioned delays due to permitting and the need for stronger oversight capacity.

Source: *Author's elaboration*

To better understand the varying implementation of reverse logistics (RL) practices, this study presents a comparative analysis between operations observed in Azerbaijan and those in a broader global context. While the companies examined often operate under unified corporate policies, their reverse logistics activities differ notably depending on regional conditions. This is particularly evident when comparing Azerbaijan's operational environment with global best practices. Drawing directly from the interview data, the table below outlines key differences and similarities across several dimensions of RL, such as infrastructure, regulatory enforcement, technology use, and interdepartmental coordination. The comparison offers valuable insight into how RL is approached and adapted in Azerbaijan versus other international settings, helping to identify areas for potential improvement and localization of global strategies.

Table 53. Comparative Analysis: Reverse Logistics in Azerbaijan context vs. Global Contexts

Criteria	**Azerbaijan Context (Case-Based Observations)**	**Global Context (Case-Based Observations)**
Regulatory Environment and Enforcement	Respondents operating in Azerbaijan acknowledged that environmental regulations are in place, but enforcement is often described as inconsistent or bureaucratically delayed. Regulatory processes such as permitting for waste transport and disposal can slow down RL operations significantly. Some companies rely on internal corporate standards to fill these gaps.	In global operations, particularly those in developed countries, regulations are reported to be strict, clearly defined, and consistently enforced. Compliance is monitored through digital tools, and audits are performed regularly, both internally and by local authorities. Companies operate under clear frameworks with reduced reliance on improvisation.
Infrastructure and Logistics Capacity	Several interviewees cited poor road conditions, vehicle unavailability, and unpredictable weather as critical bottlenecks to waste collection and transportation. Container availability was also described as a limiting factor, especially in offshore or remote areas.	Global sites, especially those in Europe and North America, reported strong infrastructure, including waste treatment facilities, reliable transportation, and well-maintained roads. These conditions allow for more structured route planning and consistent RL execution.

Criteria	**Azerbaijan Context (Case-Based Observations)**	**Global Context (Case-Based Observations)**
Technology Integration	In Azerbaijan-based operations, manual coordination, spreadsheet tracking, and verbal communication remain common. There was limited mention of integrated waste tracking systems or software platforms. Respondents noted a desire to adopt digital tools but also cited cost, access, and training as barriers.	Global operations more frequently use automated systems for vehicle routing, container tracking, and waste reporting. These systems support forecasting, KPI monitoring, and compliance documentation. Digital integration was a strong theme in multiple interviews outside Azerbaijan.
Waste Segregation and Processing	Waste is segregated by type (e.g., hazardous, recyclable), but the process relies heavily on contractor execution. Respondents emphasized the need for regular training and oversight to maintain standards.	Global sites have more institutionalized segregation protocols handled by trained staff, supported by monitoring tools and clear compliance checklists. Waste is more likely to be pre-processed or treated before final disposal.
Use of Contractors	In Azerbaijan, outsourcing is essential to RL and waste management activities. Contractors are responsible for collection, transport, and sometimes storage. Companies manage them through inspections and hands-on control, often without digital oversight.	Contractors are widely used globally but managed through structured contracts, SLAs, and performance dashboards. Site visits still occur, but digital monitoring and automated reporting provide an added layer of control.
Training and Workforce Awareness	Respondents from Azerbaijan stressed the importance of raising awareness among staff and contractors. Training is conducted but may vary by region or contractor capacity. Several interviews highlighted lack of environmental awareness as a persistent challenge.	In global contexts, training is more standardized and embedded into organizational procedures. Some companies reported mandatory certification or e-learning modules for all staff involved in RL. Environmental awareness is better institutionalized.

Criteria	Azerbaijan Context (Case-Based Observations)	Global Context (Case-Based Observations)
Forecasting and Planning	Azerbaijan-based sites were often reactive in planning, using meetings and ad hoc coordination rather than data-driven forecasting. Forecasts depend on team experience more than systemized tools.	Forecasting in global sites is proactive and often driven by software, historical data, and automated models. Dedicated teams exist for supply chain and RL planning.
Stakeholder Communication and Coordination	Communication among departments (HSE, operations, procurement) is conducted mostly through in-person meetings or phone. Lack of integrated platforms was mentioned, leading to delays or inconsistencies.	Globally, companies reported cross-functional platforms, shared databases, and centralized dashboards that support interdepartmental coordination and decision-making.
Reuse, Recycling, and Disposal Practices	Some reuse and recycling initiatives are in place (e.g., treating oily waste), but technical limitations and economic feasibility often result in disposal as the default option. Logistics and market access are barriers.	Global operations have more robust reuse/recycling systems, supported by technology, third-party vendors, and market mechanisms for recovered materials. Waste minimization is aligned with sustainability goals.
Corporate Policy Alignment	Respondents noted that internal corporate policies - often set by headquarters - are vital in ensuring that standards are upheld despite local challenges. These policies include RL strategies, waste classification systems, and performance expectations.	Similarly, in global settings, corporate policies drive consistency, but they are augmented by strong local enforcement and external incentives, such as environmental regulations and ESG requirements.
Performance Metrics and Monitoring	RL performance in Azerbaijan is tracked manually, with limited emphasis on formal KPIs. Some sites report only on volumes or compliance indicators.	Global operations use digital KPI dashboards, monthly reporting systems, and structured reviews tied to corporate performance and sustainability metrics.

Source: Author's elaboration

Based on the interview findings, several important observations emerge regarding how reverse logistics is approached in different operational contexts. In developed settings, reverse logistics is regarded as a strategic and regulated function. It is tightly integrated into broader sustainability and compliance efforts, supported by structured tools, well-defined key performance indicators (KPIs), and strong coordination across departments such as HSE, logistics, and procurement. These systems are reinforced by regulatory pressure and digital infrastructure that allow for efficient tracking, planning, and reporting.

In contrast, reverse logistics in developing contexts tends to be more operational in nature - essential to day-to-day functioning but often shaped by resource limitations. Processes rely more heavily on manual coordination, contractor execution, and less formalized communication between internal and external stakeholders. The challenges in infrastructure, technology access, and enforcement capacity make implementation more reactive than proactive in many cases.

One consistent theme across both settings is the critical role of internal corporate policy. For multinational oil and gas companies, corporate standards and global environmental procedures serve as a stabilizing force. These internal systems often guide reverse logistics practices in regions where local regulatory frameworks are less developed or inconsistently enforced, helping to maintain a baseline of accountability and sustainability regardless of location.

6.8. Recommendations for Designing a Reverse Logistics Network in Oil and Gas Companies

The oil and gas industry faces unique challenges in managing diverse waste streams, such as drilling mud, hazardous chemicals, and recyclable materials, necessitating a robust reverse logistics (RL) network to enhance operational efficiency and sustainability. Network design is a fundamental strategic decision that determines the optimal physical configuration and necessary infrastructure for a supply chain, involving choices related to facility location and distribution strategies (David, 2021). This subsection provides a practical guideline for oil and gas companies to design an effective RL network, directly addressing RQ2 by outlining a step-by-step process for structuring RL processes within the supply chain to maximize efficiency. It also responds to RQ6 by emphasizing the critical role of technology in supporting network design, ensuring transparency and compliance. Drawing on insights from interviews and case studies with BP, ExxonMobil, Shell, TotalEnergies, Equinor, and SOCAR, alongside scientific literature, this guideline offers a comprehensive framework for oil companies to implement a scalable and efficient RL network tailored to their operational context.

The first step in designing the RL network is to map the waste generation sources across all operational sites, including offshore platforms, onshore refineries, and drilling rigs, to understand the volume, type, and frequency of waste produced. SOCAR's Respondent G-2 highlighted the importance of understanding waste patterns:

"Containers are placed on platforms according to weekly or monthly requirements, taking platform size into account."

This underscores the need for a detailed waste inventory. Oil companies should conduct a comprehensive waste audit to categorize waste streams-hazardous, non-hazardous, recyclable, and non-recyclable and assess generation patterns over time. This step ensures that the RL network is designed to handle the specific waste profile of the company, optimizing resource allocation and minimizing inefficiencies. Scientific literature supports this approach, with Dowlatshahi (2010) emphasizing the importance of well-managed reverse logistics programme which can result in saving costs during waste disposal, transportation and inventory operations. Furthermore, Govindan et al. (2015) highlight that strategic design decisions, such as determining the locations and capacities of facilities, are a long-term necessity for creating effective reverse logistics networks and are considered among the most popular research topics in the field.

Next, companies should establish a network of strategically located waste consolidation points to centralize waste collection before transportation to processing or disposal facilities, directly addressing RQ2 by enhancing logistical efficiency. ExxonMobil's Respondent C-2 highlighted the value of this strategy, explaining that:

"By consolidating shipments, ExxonMobil can reduce transportation costs, decrease the number of trips required... and minimize environmental impact".

This evidence suggests that aggregating waste volumes at central nodes is essential for optimizing the reverse logistics network. The guideline recommends setting up regional consolidation hubs near high-waste-generating areas, such as offshore platforms in the North Sea for Equinor or onshore refineries for TotalEnergies, to reduce transportation distances and costs. These hubs should be equipped with temporary storage facilities designed to handle specific waste types, such as sealed containers for hazardous materials, to ensure safety and compliance. This strategic approach to consolidation is supported by the principle that minimizing waste collection vehicle costs requires the vehicle depot to be sited as close as possible to the final disposal or transfer station being used (Trevor et. al., 2011). The third step involves selecting optimal locations for processing, recycling, and disposal facilities to minimize environmental impact and operational costs, further addressing RQ2 by ensuring efficient waste handling within the supply chain. Equinor's Respondent F-1 highlighted the critical nature of this decision, noting that a lack of "regional waste treatment infrastructure" forces them to export waste, which increases transportation risks and costs. To mitigate such gaps, companies should use location-allocation models to determine facility placement, prioritizing proximity. For instance, SOCAR's success in achieving "93% plastic waste" recycling relies on having access to capable facilities, validating the need to situate recycling centres near high-generation zones (SOCAR ESG Report, 2023, p. 62). SOCAR's Respondent G-5 illustrated the importance of this factor, noting that while they utilize three disposal sites in Azerbaijan, regulatory restrictions on night-time truck movement in Baku effectively limit access to only two of them. This demonstrates that facility location decisions must account for local traffic and access laws to ensure 24/7 operational continuity.

Prajapati et al. (2019) emphasize that the strategic location of recycling and pre-treatment facilities is a major contributor to reducing transportation costs and environmental impacts, suggesting that local processing, such as separation and shredding, reduces the volume needing to be transported to a centralized recycling facility. Transportation optimization is the fourth step, crucial for addressing RQ2 by ensuring efficient waste movement across the RL network while minimizing costs and emissions. This is indicating the need for optimized transportation planning. The guideline recommends implementing route optimization software to plan waste shipments, ensuring full vehicle loads and minimizing empty return trips, especially in challenging environments like the Caspian Sea, Literature supports this, with Tavares et al. (2008) highlighting that route optimization in RL can significantly reduce fuel consumption and emissions, a critical consideration for oil companies aiming to balance efficiency and environmental goals.

Technology integration is the fifth step, directly addressing RQ6 by leveraging digital tools to enhance the RL network's efficiency, transparency, and compliance. The guideline advises oil companies to adopt IoT-enabled sensors and waste management software to monitor waste flows across the network, from consolidation hubs to processing facilities. This technology should integrate with government systems for compliance reporting, as seen in BP's approach, and provide data analytics for continuous improvement, such as identifying bottlenecks in transportation routes. ExxonMobil's Respondent C-1 added:

"Our software provides a platform for all departments to share data on waste management activities, ensuring alignment."

That is emphasizing technology's role in stakeholder coordination, further responding to RQ6 (Pramatari, 2007). Complementing these technological advancements, recent research by Bayramov (2023) provides a sector-specific taxonomy of software solutions essential for operationalizing reverse logistics in the oil and gas industry. The study highlights that effective digital integration relies on distinct functional categories: remote monitoring and compliance systems (such as SmartWaste , SAP EHS , and Enablon) are critical for tracking hazardous waste streams and ensuring regulatory adherence; predictive maintenance platforms (including GE Predix and IBM Maximo) utilize IoT data to prevent equipment failure in waste treatment facilities; inventory and warehouse management tools (like Oracle NetSuite and Infor WMS) ensure the precise tracking of waste containers; and data analytics platforms (such as Cloudera and Tableau) enable the identification of waste generation patterns to optimize collection routes.

The sixth step is to foster stakeholder collaboration across the RL network, linking back to RQ3 by ensuring that all parties-internal teams, contractors, and regulators-are aligned to enhance process efficiency.

The guideline recommends creating a centralized digital platform where stakeholders can share data, coordinate activities, and monitor compliance in real-time, as exemplified by ExxonMobil's approach.

Regular training and awareness programs should also be implemented to align contractors with sustainability goals, addressing resistance noted by BP's Respondent A-2:

"Contractors tend to be reluctant to adopt measures that surpass regulatory compliance."

TotalEnergies' Respondent D-4 offered a solution:

"Regular assessments are carried out on contractors to ensure adherence to environmental standards."

It should be incorporated into the network design through scheduled audits and performance reviews. Azizi et al. (2020) emphasize that stakeholder collaboration in RL networks improves operational efficiency and sustainability, addressing the research gap on supply chain party engagement.

The RL network should be designed for scalability and adaptability to accommodate fluctuating waste volumes and operational challenges. SOCAR's Respondent G-4 highlighted a logistical constraint:

"Transporting wastewater is difficult due to the shortage of appropriate maritime vessels."

That is underscoring the need for a flexible network design to ensure efficiency under varying conditions. The guideline suggests adopting a modular approach, where facilities and transportation resources can be scaled up or down based on demand, such as adding temporary storage units during peak drilling seasons.

Furthermore, companies should also establish contingency plans to maintain operational continuity during adverse weather or peak waste generation periods. SOCAR's approach focuses on flexible capacity; Respondent G-5 reported that during periods of intensive maintenance, the company supplements capacity by contracting additional skip trucks to manage the surge. In contrast, BP utilizes predictive technology to mitigate these risks before they impact operations. Respondent A-1 highlighted the use of route optimization software to proactively assess weather conditions, while Respondent A-2 noted that AI-powered analytics enable them to anticipate waste generation trends, allowing for resource adjustments prior to peak periods. Additionally, Shell addresses transport limitations through volume reduction; Respondent B-3 explained that compacting waste decreases the frequency of transportation trips required, thereby reducing the dependency on vessel availability during logistical bottlenecks.

Beyond logistical contingencies, scalability can be enhanced through strategic partnerships that extend the network's processing capacity. Equinor's Respondent F-1 shared a scalable practice:

"We provide recyclable materials to contractors free of charge and cover transport expenses to reduce their financial strain".

This approach effectively offloads excess volume to local partners, treating them as an extension of the RL network to prevent on-site accumulation. By combining these modular assets, flexible contracting models, and collaborative partnerships, the proposed network design ensures resilience against operational volatility and long-term sustainability.

To support the practical application of reverse logistics (RL) in the oil and gas industry, this study proposes a structured RL network design framework, developed from empirical findings across six major companies (BP, ExxonMobil, Shell, TotalEnergies, Equinor, and SOCAR) and insights from the systematic literature review. The framework provides a step-by-step guideline for designing an effective RL network tailored to the operational complexities of the sector. It aims to enhance supply chain efficiency, minimize environmental impact, and ensure regulatory compliance through optimized waste mapping, consolidation, facility placement, transportation, stakeholder collaboration, and technological integration. Table 54 presents a detailed summary of the key steps and their corresponding purposes within the network design process. By incorporating digital tools such as IoT and waste management software, the framework promotes transparency, traceability, and cross-functional coordination. This practical model directly addresses Research Question 2 (RQ2) on structuring RL processes and Research Question 6 (RQ6) on integrating technology, offering a comprehensive and sustainable approach to reverse logistics network design in the oil and gas industry.

Table 54. Reverse Logistics implementation guideline

Step	Purpose
Map Waste Generation Sources	Understand the volume, type, and frequency of waste to inform network design.
Establish Consolidation Points	Centralize waste collection to streamline logistics and reduce transportation costs.
Select Facility Locations	Optimize placement of processing, recycling, and disposal facilities for efficiency and compliance.
Optimize Transportation	Ensure efficient waste movement while minimizing costs and emissions.
Integrate Technology	Enhance transparency, compliance, and coordination across the network.
Foster Stakeholder Collaboration	Align internal teams, contractors, and regulators to improve process efficiency.
Ensure Scalability and Adaptability	Accommodate fluctuating waste volumes and operational challenges.

Source: Author's elaboration

Overall, the steps presented in Table 54 collectively establish a coherent and systematic framework for designing an effective reverse logistics network within the oil and gas sector. The process begins by mapping waste generation sources to develop an accurate understanding of waste volumes, categories, and temporal patterns, forming the foundation for all subsequent design decisions. Establishing consolidation points enables the centralization of waste flows, thereby improving logistical coordination and reducing transportation inefficiencies. Strategic selection of facility locations further enhances operational performance by ensuring that processing, recycling, and disposal sites are optimally positioned in relation to waste origins and regulatory requirements. Transportation optimization strengthens network efficiency by minimizing costs and emissions through structured routing and capacity planning. Integrating digital technologies enhances transparency, traceability, and compliance across the network. Facilitating collaboration among internal departments, contractors, and regulatory bodies ensures coherent decision-making and effective process alignment. Finally, incorporating scalability and adaptability into network design enables firms to manage fluctuating waste volumes and operational contingencies. Collectively, these components provide a comprehensive, resilient, and technology-enabled framework for supporting sustainable reverse logistics and waste management operations in the oil and gas industry.

7. Limitations and Future Research

Although this thesis has sought to provide a comprehensive investigation of reverse logistics in the oil and gas sector, certain limitations should be acknowledged. The first limitation of this study lies in the scope of the case studies. The empirical investigation examined six companies, including five large international oil majors (BP, ExxonMobil, Shell, TotalEnergies, and Equinor) and one national oil company in Azerbaijan, SOCAR. This selection made it possible to capture both international and national perspectives, as well as a contrast between developed and developing contexts. In particular, SOCAR's practices provided insights that can be cautiously generalized to other firms operating under similar conditions of limited infrastructure and evolving regulatory frameworks. Nevertheless, the sample is heavily weighted towards large, resource-rich organizations, with only a single medium-sized company from a developing country included, suggesting that the findings may primarily reflect the practices of industry leaders rather than the broader diversity of firms in the sector. Smaller or mid-sized companies, which often face different financial, organizational, and technological constraints, are not represented, limiting the overall generalizability of the conclusions (Hong and Jeong, 2006). The study therefore provides in-depth but selective insights, which are best understood as a foundation for further comparative research across a wider set of organizations.

Next limitation relates to the diversity of respondents. The study relied primarily on semi-structured interviews with managers, supervisors, coordinators, and specialists who were directly responsible for waste management and reverse logistics processes within their companies. While these participants provided essential insights into organizational strategies, compliance procedures, and operational practices, their perspectives were shaped by their professional roles and responsibilities. This aligns with Tang (2006), who notes that managerial perspectives are often driven by critical performance targets and outcome-based rewards, creating a distinct view of risk and operations that may differ from the reality experienced by other stakeholders. Author also highlights that supply chain management is a multi-disciplinary research area which necessitates considering other viewpoints, such as those of frontline workers, contractors, or regulatory authorities. This creates a degree of imbalance, as the interviews capture the views of decision-makers and internal experts but do not fully reflect how practices are experienced or perceived at other levels of the supply chain. Miles M. B., et al. (2014) explicitly warn against such "elite bias" and "sampling too narrowly," noting that excluding lower-status or peripheral participants can distort the understanding of the social setting. For example, while managers often emphasized the efficiency of logistics planning or the integration of technology, contractors were frequently described as reluctant to adopt measures beyond minimum compliance. Including their voices directly could have enriched the findings by highlighting practical challenges or tensions in implementation. The absence of this wider range of perspectives means that the analysis, while informative, is partial and weighted toward organizational narratives rather than the full spectrum of stakeholder experiences.

Another limitation concerns the availability and depth of company data. Although respondents shared valuable information on their organizations' reverse logistics and waste management practices, Access to sensitive operational and financial data was limited, as gaining access to confidential firm-level data remains a significant challenge for scholars, often constraining the depth of empirical analysis (Hennart et al., 2022). Understandably, firms were cautious about disclosing internal documents or detailed cost figures, and this restricted the ability to triangulate interview findings with company records. As a result, the analysis often relied heavily on respondents' own accounts which may carry elements of subjectivity or selective emphasis. This reliance on self-reported data is a known limitation in social research, where respondents may filter information to present a favorable image or avoid disclosing sensitive weaknesses (Brutus et al., 2013). For instance, participants were generally forthcoming when discussing regulatory compliance and routine processes, yet more guarded when asked about performance shortfalls or cost-related challenges. This selective disclosure shaped the scope of the findings and may have led to a stronger focus on formal procedures rather than informal practices or hidden inefficiencies. The reliance on interview-narratives therefore represents both a strength in capturing expert perspectives, and a limitation, in terms of the completeness and balance of the empirical evidence.

It should also be noted that the empirical data was collected during a specific period, and the findings therefore represent a snapshot of practices as they existed at that moment. The oil and gas industry is undergoing continuous change, driven by regulatory reforms, technological innovation, and increasing emphasis on sustainability and circular economy principles. This dynamic environment is consistent with broader observations that the economic and structural impacts of resource development evolve significantly over time as projects mature and conditions shift within the oil and gas sector (Qingqing et al., 2021). As a result, some of the practices documented in this study may evolve rapidly, either becoming more advanced or, in some cases, being replaced by entirely new approaches. For example, digitalization and the integration of artificial intelligence into logistics operations are areas of ongoing development that may significantly reshape waste management in the near future. Similarly, tightening environmental regulations could alter company priorities and require adjustments to existing reverse logistics frameworks. While the study captures an accurate picture of industry practice during the research period, its conclusions should be interpreted with an awareness that they may not fully reflect future developments.

Finally, there was a limitation concerns for the geographic scope of the case studies. The companies investigated operate in a range of contexts, including developed regions and developing environments such as Azerbaijan. This contrast allowed for valuable comparisons between settings with mature infrastructures and regulatory systems and those where frameworks are still evolving. However, although respondents were from different countries, the sample did not cover all major oil-producing regions where waste management practices and reverse logistics systems may be shaped by different political, economic, or cultural conditions. As a result, the findings highlight important variations between developed and developing contexts but cannot claim to represent the full global diversity of the sector. Broader geographic coverage would have provided additional perspectives and strengthened the external validity of the conclusions. This aligns with findings from Mmereki et al. (2016), who illustrate how developing nations face distinct waste management challenges, such as infrastructure deficits and evolving regulatory frameworks that differ fundamentally from those in developed regions, underscoring the need for context-specific analysis

While the limitations of this study highlight areas for refinement, building on insights gained from the systematic literature review and case studies, several promising avenues for future research emerge to advance the field of reverse logistics in the oil and gas sector. One important avenue for future study is the integration of both forward and reverse logistics, considering different modes of transport and outsourcing options. This builds on foundational work by Fleischmann et al. (2001), who identified the integration of forward and reverse flows as a "key issue" in logistics design and aligns with Alshamsi et al. (2015), who explicitly highlighted this incorporation as critical directions for future research. Additionally, there is a need to develop efficient algorithms that consider more uncertain parameters such as quality, travel time, and facility capacity to analyse the correlation between return and demand (Kim et al., 2018; Li et al., 2016; Pishvaee et al., 2009).

Another area of interest is gatekeeping strategies to reduce returns, as well as reverse logistics activities with international elements. Rogers et al. (2002) emphasizes that effective gatekeeping is the "best place to start" for managing returns because screening products before they enter the reverse flow prevents the entire system from becoming clogged with defective or unauthorized items. Therefore, future research should investigate how specific gatekeeping protocols can be adapted to the oil and gas sector to minimize the intake of non-compliant materials and reduce unnecessary processing costs at the source.

Future research could focus on identifying waste items that are suitable for cooperative transportation or modal shift, as well as practical ways to solve the issues of reverse logistics for waste management, such as deregulation and policy incentives to promote cooperative transport and modal shift (Beil et al., 2025; Doan et al., 2019; Li and Tee, 2012). Various kinds of risks and uncertainties may also be researched, and efficient and exact or heuristic solution methods developed that incorporate other environmental factors into decision-making (Hao et. al., 2017; Omid et. al., 2020; Der-Horng, et. al., 2009).

The calculation of outsourcing costs represents an important avenue for future research. A comprehensive financial analysis would contribute to a deeper understanding of the cost structures underpinning outsourced waste management services and would provide empirical evidence to support more informed strategic and operational decisions within the industry(Agrawal et al., 2016; Bokor, 2012; Zarbakhshnia et al., 2023) .

Future research should also focus on optimizing collection routes and improving the recycling process's efficiency, comparing economic and environmental consequences, and checking the feasibility of establishing similar recycling systems in other sectors (Erdem, 2022; Ramos et al., 2014; Sun et al., 2022). Developing such integrated models is crucial to quantifying the trade-offs between operational costs and environmental benefits. Moreover, extending this analysis to other sectors will validate the adaptability of these recycling systems to varying regulatory and operational contexts.

Conclusions

This research has aimed to explore the strategic integration of reverse logistics (RL) into waste management operations within the oil and gas industry, a sector that faces both significant environmental responsibilities and complex logistical demands. Through a systematic literature review, multiple case studies, and semi-structured interviews with industry experts, the study examined the role, drivers, barriers, and potential of RL as a component of sustainable supply chain management. The investigation was guided by six research questions, each designed to address specific research gaps in the existing body of knowledge.

A key finding of this study is that RL in the oil and gas sector extends far beyond the management of product returns. It serves as a critical enabler for environmental compliance, operational efficiency, and long-term sustainability goals. Evidence gathered from both developed and developing country contexts confirmed that RL can deliver several benefits in cost reduction, regulatory adherence, and corporate reputation, if it is implemented within a structured and well-coordinated framework which directly addresses the first research question **(RQ1 - "What is the importance, role, and main drivers of implementing Reverse Logistics/Waste Management in the oil and gas industry as a part of Supply Chain Management?")** presented in the introduction (Pokharel and Mutha, 2009; Presley et al., 2007). This is particularly important in oil and gas operations, where waste streams are diverse, hazardous, and subject to stringent environmental regulations. In doing so, the study also addresses **RG1**, which noted the absence of comprehensive coverage of RL implementation in waste management within oil and gas operations, and **RG2**, which highlighted the limited understanding of how RL integrates into broader supply chain structures in this sector.

In addition, this study addresses **RQ2 - "How should the Reverse Logistics/Waste Management processes and activities be designed within Supply Chain to increase the efficiency of operations in oil and gas industry?" -** by providing practical guidance on designing reverse logistics and waste management processes within the supply chain to enhance operational efficiency. Section 6.8 outlines a step-by-step framework for mapping waste sources, establishing consolidation points, selecting facility locations, optimizing transportation, fostering stakeholder collaboration, integrating technology, and ensuring scalability. These structured network design practices demonstrate how RL activities can be aligned with core supply chain operations to reduce costs, improve resource utilization, and support sustainability objectives. This directly responds to **RG7**, which highlighted the absence of RL network design tailored to oil and gas, and **RG8**, which emphasized the need for approaches that account for multiple operational variables in waste management.

The multiple-case study analysis showed that companies adopting proactive RL strategies not only benefit from improved waste tracking and resource recovery but also strengthen collaboration between stakeholders. Leading firms in this research institutionalized RL processes by establishing clear communication channels, joint performance monitoring, and shared training programs for employees and partners. Investments in specialized technology further facilitated coordinated planning and information sharing across departments and external partners. These practices highlight that improving stakeholder processes and collaboration is essential for effective reverse logistics, supporting literature that emphasizes embedding RL into organizational culture and securing senior management commitment (de Brito and Dekker, 2004; Köhler, 2024). This study has demonstrated how the quality of processes and activities between stakeholders within the supply chain can be improved during reverse logistics and waste management in the oil and gas sector. Through structured interdepartmental coordination, effective communication, and targeted awareness and training programs, companies can enhance collaboration and ensure smoother RL operations. Engagement with external stakeholders, including contractors and local communities, further strengthens process quality and drives sustainability outcomes. These findings are in line with **RQ3 - "How to improve the quality of processes and activities between stakeholders within Supply Chain during Reverse Logistics/Waste Management activities in oil sector?"**, while also addressing **RG3**, confirming that improving stakeholder collaboration and coordination is critical for achieving efficient and effective reverse logistics.

Another significant insight concerns the role of outsourcing in RL. While outsourcing offers potential benefits such as cost efficiency, access to specialized expertise, and scalability, its effectiveness depends on rigorous partner selection, contractual clarity, and continuous performance monitoring. In several cases examined, outsourcing arrangements lacked measurable performance indicators, resulting in inconsistent service quality. This supports earlier observations that outsourcing RL activities without clear strategic alignment can undermine intended outcomes (Agrawal and Singh, 2020; Ordoobadi, 2009; Tavana et al., 2016). This analysis answers **RQ4 - "How should outsourcing decisions be taken to increase RL efficiency and what are the steps to follow?"**, indicating that outsourcing decisions in reverse logistics require careful partner evaluation, well-defined contractual agreements, and continuous performance oversight. At the same time, it responds to **RG4**, which highlighted the insufficient analysis of outsourcing opportunities for reverse logistics and waste management in the petroleum industry, and **RG9**, by offering a structured framework for assessing outsourcing decisions, including partner selection, compliance assurance, and performance monitoring. Implementing these steps helps to ensure that outsourced activities contribute effectively to RL efficiency and align with broader supply chain goals.

Furthermore, the study also identified persistent barriers. Technological limitations, infrastructure constraints, fragmented stakeholder coordination, and inadequate awareness remain substantial challenges to the wider adoption of RL in the sector. In many instances, waste management activities operate in isolation from core supply chain functions, reducing opportunities for efficiency gains and integrated planning. The findings echo earlier research suggesting that the lack of reverse logistics specific knowledge and leadership attention significantly limits its implementation (Hamilton and Finley, 2019; Pokharel and Mutha, 2009). These findings directly address **RQ5 - "What barriers would companies face while implementing Reverse Logistics and how to overcome them?"**, highlighting the key barriers companies face when implementing reverse logistics in the oil and gas sector. By identifying technological limitations, infrastructure constraints, fragmented stakeholder coordination, and insufficient awareness, the study provides a clear understanding of the challenges that hinder RL adoption. At the same time, the results respond to **RG5**, by showing how Industry 4.0

technologies such as IoT tools, software systems, and automation can help address these barriers, and to **RG6**, by contributing empirical evidence from multiple case studies and interviews that enrich understanding of RL implementation in practice.

The integration of Industry 4.0 technologies emerged as a pivotal factor in advancing RL efficiency. Digital tools such as real-time tracking systems, predictive analytics, and automation platforms have the potential to transform waste management operations by enhancing data visibility, forecasting capabilities, and operational responsiveness (CUNHA and LIMA, 2023; Novita Sari., Achmad Hizazi., 2021). Case companies that adopted such technologies reported higher operational accuracy and improved compliance reporting. Nonetheless, the adoption rate of these solutions remains uneven, particularly in regions where infrastructure and technical expertise are limited. These observations help to answer **RQ6 - "What is the role and significance of technology and software` in enhancing Reverse Logistics/Waste Management within the oil and gas industry's Supply Chain Management?"**, highlighting that technology and software play a key role in improving reverse logistics. At the same time, the findings also address **RG7**, by demonstrating how RL networks in oil and gas can be designed with technology as a structural component, and **RG8**, by offering a more comprehensive perspective that considers multiple variables, including infrastructure readiness, digital capacity, and stakeholder coordination, in assessing the effectiveness of technology-enabled RL. However, the uneven adoption shows that companies need to invest in infrastructure and technical skills to fully benefit from these technologies.

From a methodological perspective, the use of a grounded theory approach for data analysis allowed for the generation of context-specific insights that reflect the lived experiences of industry professionals. This empirical grounding enabled the development of a practical conceptual framework for RL in the oil and gas sector, one that incorporates process design, stakeholder collaboration, outsourcing strategy, and technology adoption as mutually reinforcing components. By drawing on qualitative data from multiple geographic and operational contexts, the research contributes to a more nuanced understanding of RL's application in complex industrial environments.

Importantly, the comparative analysis between companies operating in developed and developing countries underscored the influence of regulatory environments, resource availability, and organizational maturity on RL implementation. While firms in advanced economies often benefit from established waste management infrastructures and supportive policy frameworks, those in emerging markets face additional constraints that require adaptive and often more resourceful solutions. These differences highlight the necessity of tailoring RL strategies to the local operational context, an approach that is supported by both academic literature and practical experience (Gentles et al., 2015; Hamilton and Finley, 2019).

In conclusion, this research reaffirms that reverse logistics, when strategically integrated into the oil and gas supply chain, can serve as a catalyst for both operational excellence and environmental stewardship. The findings advocate for a holistic approach that combines internal capability building with external partnerships, leverages technological innovations, and aligns RL objectives with broader corporate sustainability goals. By addressing the identified barriers and fostering stronger collaboration among stakeholders, oil and gas companies can enhance the efficiency, compliance, and resilience of their waste management operations. This thesis therefore offers both a theoretical contribution to the understanding of RL in oil and gas industry and practical guidance for its implementation. Its insights also hold potential to inform policy, corporate strategy, and future research.

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Acknowledgement

To enhance the clarity and consistency of academic writing, this thesis employed OpenAI's ChatGPT (different language models: GPT4-GPT5) as a linguistic support tool. The AI system was used strictly for improving grammar, rephrasing technical explanations, and validating the logic and structure of written sections. No analytical tasks, data interpretation, or original content generation were conducted by the AI. The researcher maintained full control and authorship over the theoretical development, methodological design, data analysis, and final conclusions.

Appendix A: Semi-Structured Interview Questions

This appendix provides the full list of 9 questions used during the semi-structured interviews with managers and specialists across the case study companies: BP, ExxonMobil, Shell, TotalEnergies, Equinor, SOCAR, and AA Services.

1. What is the awareness level among internal and external stakeholders in your company about the significance of efficient waste management?

2. Could you describe your company's overall process for managing waste, from collection to final disposal or recycling?

3. Which types of waste account for the majority of the waste generated in your operations?

4. How do you handle the transportation of waste materials in your operations?

5. What key performance indicators do you utilize to measure the effectiveness of your waste management efforts?

6. What are the most significant challenges your company encounters in implementing reverse logistics and waste management for waste materials?

7. From an economic standpoint which waste management method is considered the most cost-effective?

8. How do you propose minimizing the amount of waste sent for disposal to landfills?

9. What areas do you believe could be enhanced in the company's waste management strategies?