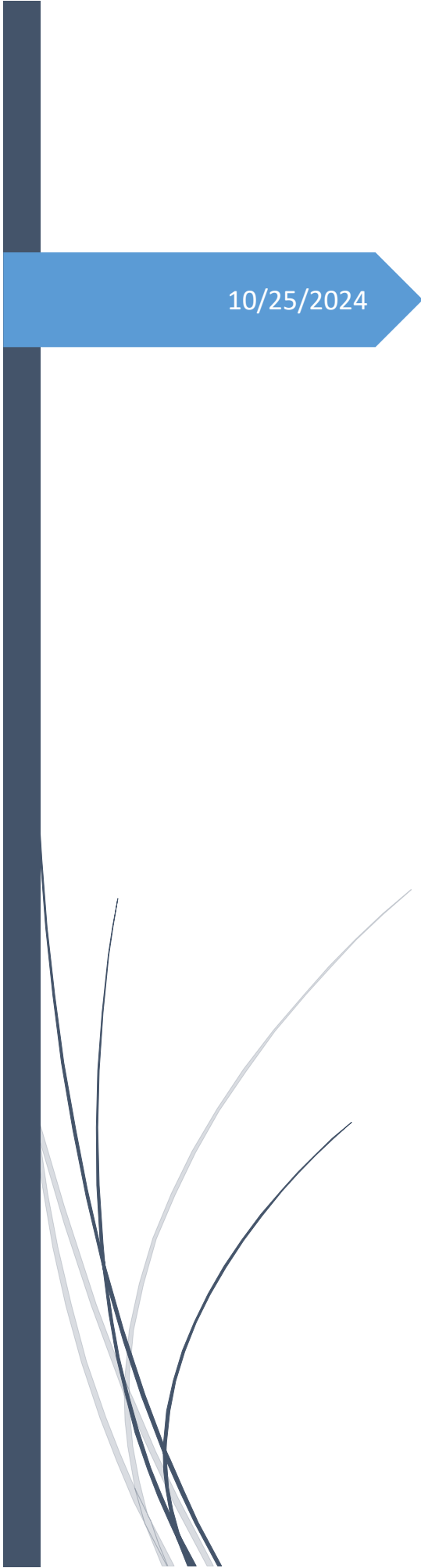




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Going around in circles

A study on the limitations of circular economy models implementation in Manufacturing Small Medium Enterprises (SME's). Challenges, Opportunities, and Limitations within the current Supply Chains.

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I. Introduction

1.1 Background

The roots of the Circular Economy (CE) are grounded in mid-20th-century ideas of sustainability and resource efficiency. Economist Kenneth Boulding pioneered the notion of finite resources, promoting a shift from a linear "take-make-dispose" model to a regenerative, closed-loop system (Boulding, 1966). Later, Walter R. Stahel and Geneviève Reday-Mulvey further developed these ideas, advocating for resource efficiency in an industrial context, and their work laid a foundation for CE as we understand it today (Stahel, 1982).

In the 21st century, the concept has generated growing attention as a response to the environmental challenges posed by linear economic models. International bodies, governments, and businesses have embraced Circular Economy principles, leading to the development of policies, initiatives, and frameworks to promote sustainable production and consumption.

1.2 Rationale for the Study

The present study has been conducted starting from the hypothesis that circular economy and its current practices can only be effective in a limited capacity within the current market conditions.

The transition to a circular economy within a company faces numerous barriers, categorized primarily as human, financial, and technical. These limitations are inherent to any significant structural or organizational shift. Human barriers include resistance to change and a lack of necessary skills among employees, which can hinder the adoption of circular practices (Kirchherr et al., 2018). Financial constraints often involve high upfront costs for circular infrastructure, such as new technology for recycling and refurbishment, and challenges in aligning profitability with sustainability goals (Geissdoerfer et al., 2017). Lastly, technical barriers encompass limited access to efficient recycling technologies and insufficient supply chain coordination, both critical for closed-loop systems (Lieder & Rashid, 2016).

1.3 Research Aim

The overarching purpose of the study is to investigate the limitations to achieving a fully circular economy model within manufacturing SME's (small-medium enterprises) and provide insight to leadership teams interested in employing CE models in their business.

This aim will be achieved by the research methods employed during the research and by data analysis of the specific objectives in the following paragraph.

1.4 Research Objectives

To fulfil the research aim, the following specific objectives have been identified:

- Analyse the CE models applicable to the target industry
- Analyse the implementation of CE models in the manufacturing world
- Compare the two case studies and against the theoretical framework set out in the literature

- Evaluate the impact for CE on environmental and economic factors
- Observe and highlight the challenges, barriers, limitations and cultural differences identified
- Map out recommendations for achieving a higher level of sustainable processes that can lead to a future circular economy model for the business.

1.5 Scope and Delimitations

The dissertation is a limited study performed on a SME Company being part of the supply chain for the Energy Sector, evaluating 2 case studies of supplied equipment from the SME.

The delimitations help in refining the study's scope and enhance its relevance by ensuring that the research remains focused on specific objectives without diverging into unrelated areas (Robson, 2011).

1.6 Methodology

To achieve the aim and to accomplish the objectives set out in the introduction of the study, two methods of research have been employed:

- A literature review of a wide range of sources shall be used such as scientific articles, case studies, journals, and books. This will cover the concept of Circular Economy with its historical evolution and core principles, the environmental and economic implications, the practices employed in manufacturing industries, challenges, barriers, policies, initiatives and other facets of the subject matter.
- Presentation of two case studies where circular economy principles were employed or omitted – with various degrees of success.

1.7 Significance of the Study

A circular economy future appears inevitable, and any business set on surviving or even prospering in the up-and-coming environmental framework must embrace it. This study does not set out to be a pioneer in the field of sustainability or to be a 'vox clamantis' against the current shortfalls and perceived greenwashing prevalent in the business world.

The significance of this study sits with the research and the observations made based on literary and case study reviews, which can be a useful guide to manufacturing SME's. SME's are the primary focus and benefactor of the study, but it can benefit the entire supply chain involved in the manufacturing industry, from raw material manufacturers to end clients.

1.8 Research ethics

Two considerations have been taken concerning ethics in research.

- Due to confidentiality requirements and signed non-disclosures agreements between the parties, the case studies details concerning client companies have been altered.
- To avoid plagiarism, any citations and quotations of previous work has been properly referenced in-text and in the bibliography section.

II. Literature Review

2.1 The Concept of Circular Economy

The circular economy (CE) is an economic system aimed at reducing waste and making the most of resources. In contrast to the traditional linear economy, which functions on a take-make-dispose model, the circular economy pursues to close resource loops by sustaining the utility of products, materials, and resources for as long as possible. Over the last few years, this notion has gained standing as environmental challenges such as resource scarcity, climate change, and pollution have pressed industries, policymakers, and academics to explore sustainable alternatives to the linear economic model. This section explores the historical evolution of the circular economy concept and examines its core principles.

2.1.1 Historical Evolution

The circular economy is rooted in ideas that stretch back several decades, although the term itself only became widespread in the late 20th century. The historical evolution of CE can be traced through several intellectual traditions and movements that laid the groundwork for this paradigm shift.

Early Environmentalism and Industrial Ecology (1960s-1980s)

The origins of circular economy thinking can be linked to the early environmental movement of the 1960s and 1970s. Pioneers such as Rachel Carson, with her seminal work *Silent Spring* (1962), raised awareness of environmental degradation caused by industrial activity. This era marked the rise of environmentalism and a growing recognition of the need for sustainable development.

Industrial ecology, which emerged in the 1970s, became one of the key precursors to circular economy thinking. Industrial ecology viewed industry as a subsystem of the biosphere and advocated for the optimization of resource flows within industrial systems in ways that mimicked natural ecosystems. According to this perspective, industries should minimize waste by transforming it into inputs for other processes, analogous to nutrient cycles in nature (Graedel & Allenby, 1995).

The Emergence of the Circular Economy Term (1980s-1990s)

The concept of circular economy began to take shape in academic literature in the 1980s, drawing on ideas from industrial ecology, cradle-to-cradle design, and regenerative economics. Two German scholars, Walter Stahel and Genevieve Reday, played an influential role in developing early CE thinking. In their report *Jobs for Tomorrow: The Potential for Substituting Manpower for Energy* (1981), they proposed extending product lifecycles through maintenance,

repair, and reuse. Stahel further developed the idea of a “closed-loop economy” in which materials are continually cycled through the production system, minimizing waste (Stahel, 1982).

During the 1990s, Michael Braungart and William McDonough introduced the concept of cradle-to-cradle design in their book *Cradle to Cradle: Remaking the Way We Make Things* (2002). This approach highlighted designing goods with the intention that every element could be reused or returned to nature without causing harm, therefore eliminating the concept of waste. Their concepts deeply influenced the future circular economy discussion.

Spread of the Circular Economy (2000s-Present)

The term circular economy gained mainstream credit in the early 21st century, largely due to efforts by groups like the Ellen MacArthur Foundation. Established in 2010, the Foundation has been influential in promoting CE principles globally and working with governments and businesses to implement circular practices. The European Union also adopted circular economy frameworks as part of its environmental and industrial policies, culminating in the Circular Economy Action Plan of 2015.

Today, the circular economy idea continues to advance as new frameworks and strategies are established. It is now recognized as a key approach to achieving the Sustainable Development Goals (SDGs) and addressing global environmental issues.

2.1.2 Core Principles of Circular Economy

The circular economy rests on several key principles that differentiate it from the linear economic model. These principles form the backbone of strategies for transforming the way industries, consumers, and policymakers approach resource use.

Design Out Waste and Pollution

One of the fundamental principles of the circular economy is the goal of eliminating waste and pollution from the beginning of the design process. This requires designing products and systems that do not generate waste as a by-product of production or consumption. By using eco-design and sustainable materials, companies can manufacture products that are easily disassembled, repaired, or recycled, ensuring that components do not end up as waste (Ellen MacArthur Foundation, 2015).

Keep Products and Materials in Use

A core strategy of the circular economy is to extend the lifecycle of products and materials, ensuring they are kept in use for as long as possible. This principle is underpinned by practices such as repairing, refurbishing, remanufacturing, and recycling. The circular economy emphasizes creating closed-loop systems where materials are continually circulated in the economy rather than being discarded (Stahel, 2016).

Regenerate Natural Systems

The circular economy goes beyond simply reducing harm to the environment; it seeks to regenerate and restore natural systems. This principle draws on ideas from regenerative design, which focuses on creating systems that restore ecosystems and enhance biodiversity. In the CE model, organic waste is returned to the soil through composting and other processes, closing the loop between human activities and natural cycles (Braungart & McDonough, 2002).

Rethink Ownership and Business Models

The circular economy encourages a shift away from traditional ownership models toward models based on leasing, sharing, or servitisation. For instance, consumers may lease goods instead of owning them, allowing manufacturers to retain the obligation for maintaining, upgrading, and ultimately recycling those products. This approach promotes innovation in business models that line up with circular economy principles and reduce overall consumption of virgin resources. (Bocken et al., 2016).

2.2 Environmental and Economic Implications of the Circular Economy

2.2.1 Environmental Implications of the Circular Economy

Reduction of Resource Extraction and Environmental Degradation

One of the most cited environmental benefits of the circular economy is its potential to drastically reduce the need for virgin material extraction. By closing resource loops through reuse, remanufacturing, and recycling, CE can lower the demand for raw materials and alleviate the pressures placed on natural ecosystems. According to Allwood (2014), the circular economy could decrease the environmental impacts of mining, agriculture, and forestry, which are major contributors to biodiversity loss and ecosystem degradation. This shift could potentially conserve natural resources, reduce deforestation, and protect habitats.

Additionally, life cycle analysis (LCA) studies on circular practices support these claims. For example, a study by Niero and Olsen (2016) on circular product design in the electronics sector showed that remanufactured products significantly reduced material and energy usage compared to newly manufactured items. This, in turn, minimized environmental footprints, including reductions in greenhouse gas emissions and energy consumption. Such findings underscore the potential of CE to mitigate climate change and other environmental impacts tied to resource-intensive industries.

Waste Minimization and Pollution Prevention

A core environmental principle of the circular economy is the reduction of waste. In the linear economy, waste is a natural by-product of manufacture and consumption, regularly causing landfill accumulation, pollution, and toxic emissions. CE, by contrast, aims to transform waste into valuable resources, thus eliminating the concept of waste altogether (Ghisellini et al.,

2016). For example, closed-loop recycling in industries such as aluminium or paper production can prevent the release of harmful chemicals and pollutants into the air and water systems.

Moreover, CE practices such as composting and biomass recovery have the potential to significantly reduce organic waste. A study by de Jesus and Mendonça (2018) found that the use of organic waste for energy generation and soil restoration contributes to both lower waste volumes and a decrease in methane emissions from landfills. In cities, initiatives such as zero-waste policies and urban farming programs demonstrate how circular strategies can address issues like air pollution and food waste, promoting cleaner urban environments (Prendeville et al., 2017).

2.2.2 Economic Implications of the Circular Economy

Cost Savings and Efficiency Gains

One of the often discussed economic implications of the circular economy is its potential for cost savings and enhanced resource efficiency. By reducing dependence on virgin materials and decreasing waste disposal costs, businesses can lower their overall operating expenses. Stahel (2016) points out that remanufacturing and repair practices can extend the lifespan of products, thereby decreasing the need for frequent production cycles. These efficacy gains not only reduce input costs but also enable firms to generate value from secondary materials, thus creating new revenue streams.

Moreover, energy efficiency gains are frequently cited as an economic benefit of the circular economy. A study by the Ellen MacArthur Foundation (2015) estimates that adopting CE principles could save the European economy over €600 billion annually by reducing material and energy costs. These savings stem from designing products for durability, which reduces the frequency of replacements and lowers energy consumption throughout supply chains.

Job Creation and Economic Growth

The circular economy also holds the potential for job creation, especially in sectors such as repair, recycling, and remanufacturing. According to Ghisellini et al. (2016), circular business models, which rely on extended product lifecycles and increased services, could create more jobs compared to traditional manufacturing models. Activities such as refurbishing used products, managing waste streams, and innovating circular designs would require skilled labour, potentially boosting employment in both developed and developing economies.

Furthermore, CE is viewed as a key strategy for fostering green economic growth. The European Commission (2015) has argued that transitioning to a circular economy can spur innovation in new technologies and business models, contributing to sustainable economic growth. The shift to CE is expected to motivate investment in new industries, infrastructure, and technologies that support resource optimization, eco-design, and renewable energy, therefore generating new economic opportunities.

2.3 Circular Economy Practises in the Manufacturing Industries

The transition from a linear economy (take, make, dispose) to a circular economy (CE) is gaining momentum across various industries, with the manufacturing sector playing a pivotal role. In the manufacturing industry, CE principles are applied to improve resource efficiency, reduce waste, and encourage the reuse and recycling of materials. Manufacturing is highly resource-intensive, and circular economy practices offer potential solutions to both environmental and economic challenges. This literature review examines the state of circular economy practices in manufacturing industries, highlighting key strategies such as product design, remanufacturing, recycling, and supply chain innovations. Additionally, the review explores the challenges and opportunities associated with implementing CE in this sector.

Sustainable Product Design

The design phase is crucial for enabling circular economy practices in manufacturing, as it determines the materials used, the potential for disassembly, and the end-of-life options for products. Eco-design and design for disassembly (DfD) are key approaches that allow manufacturers to extend product lifecycles and facilitate material recovery at the end of a product's use.

Eco-design focuses on minimizing the environmental impact of products by using sustainable materials, reducing energy consumption, and designing for recyclability. According to Moreno et al. (2016), incorporating eco-design principles into manufacturing can significantly reduce waste, energy usage, and emissions, as well as improve the efficiency of materials. For instance, companies in the electronics and automotive sectors have increasingly adopted modular design, which enables easy repair and component replacement, thus extending the product's lifespan and reducing the need for new materials (Bocken et al., 2016).

Design for disassembly emphasizes creating products that can be easily disassembled for maintenance, repair, or recycling. This approach is especially prominent in industries like electronics and appliances, where the rapid pace of technological change leads to frequent product replacements. As stated by Bakker et al. (2019), DfD helps manufacturers reduce the costs of recovering and reusing components, while simultaneously cutting down on the environmental impact of disposal.

Remanufacturing and Refurbishing

Remanufacturing is a key circular economy practice in which used products are restored to their original condition or better. In the manufacturing sector, remanufacturing has been widely implemented in industries such as automotive, aerospace, and heavy machinery. By reusing valuable components, remanufacturing conserves resources, reduces energy consumption, and limits the generation of waste (Sundin & Lee, 2012).

The automotive industry has been a leader in implementing remanufacturing practices. According to a study by Ijomah et al. (2018), remanufacturing car parts, such as engines and gearboxes, can reduce material input by up to 80%, with significant savings in energy and CO₂ emissions. The aerospace industry has similarly embraced remanufacturing to reduce costs and

environmental impact, especially for high-value components such as jet engines (Nasr et al., 2018).

Refurbishing, a related concept, involves the restoration of products to a working condition, often with a focus on extending their useful life. While refurbishment may not fully restore the product to “like-new” status, it still offers considerable environmental benefits by delaying product disposal and reducing demand for new products (Gray & Charter, 2007). In industries like electronics, refurbishment allows for the recovery of valuable materials like rare earth metals, further enhancing resource efficiency.

Recycling and Material Recovery

Recycling is a core component of the circular economy, aiming to recover valuable materials from end-of-life products for reuse in new manufacturing processes. In manufacturing, recycling can be either closed-loop, where materials are recycled into products of the same type, or open-loop, where materials are recycled into different products.

In industries such as metals, plastics, and textiles, recycling has become a cornerstone of sustainable manufacturing. For example, the steel industry has adopted closed-loop recycling, where scrap steel is recycled back into high-quality steel products with minimal loss of material quality (World Steel Association, 2020). Similarly, the plastics industry has seen growth in recycling technologies that allow for the recovery of plastic waste into new products, though challenges remain in achieving high-quality material recovery due to contamination and degradation (Hopewell et al., 2009).

However, recycling in the manufacturing sector is not without challenges. One major issue is the down-cycling of materials, where recycled materials lose quality or functionality, limiting their reuse in high-value applications (McDonough & Braungart, 2002). Furthermore, the energy requirements for some recycling processes can offset the environmental gains achieved through material recovery. Despite these challenges, innovations in recycling technologies, such as chemical recycling for plastics and advanced sorting systems for metals, offer promising solutions for improving material recovery (Yuan et al., 2006).

Circular Supply Chain Management

A critical aspect of implementing circular economy practices in manufacturing is circular supply chain management (CSCM), which involves redesigning supply chains to support the reuse, remanufacture, and recycling of materials. Circular supply chains are characterized by reverse logistics, where products or materials are returned to the manufacturer for recovery, repair, or recycling (Govindan & Hasanagic, 2018).

Incorporating reverse logistics into supply chain operations has been shown to offer significant environmental and economic benefits, particularly in reducing waste and raw material consumption. For example, companies in the consumer electronics industry have developed take-back schemes and closed-loop supply chains to recover valuable components from used devices (Genovese et al., 2017). This not only reduces the environmental impact of e-waste but also allows manufacturers to reduce costs by reusing materials in new products.

Moreover, circular supply chains emphasize partnerships between suppliers, manufacturers, and recyclers to optimize the flow of materials and minimize waste throughout the supply chain. According to Batista et al. (2018), effective collaboration within supply chains can lead to substantial resource efficiency gains and cost savings. However, challenges such as coordination among multiple stakeholders, high upfront costs, and regulatory barriers can hinder the implementation of CSCM in some industries (Kirchherr et al., 2017).

2.4 Circular Economy Policies and Initiatives

In recent years, governments, international organizations, and private sector stakeholders have developed various policies and initiatives to facilitate the transition to a circular economy. These initiatives aim to support the adoption of circular principles across industries and regions, while fostering economic growth and reducing environmental impacts. This literature review examines the evolution of circular economy policies and initiatives globally, focusing on key policy frameworks, regulatory mechanisms, and cross-sectoral collaborations that have shaped the transition to a circular economy.

European Union's Circular Economy Action Plan (CEAP)

The European Union (EU) has been a global leader in advancing circular economy policies through its Circular Economy Action Plan (CEAP). Introduced in 2015 and updated in 2020, CEAP is a cornerstone of the EU's Green Deal, which aims to make Europe climate-neutral by 2050 (European Commission, 2020). CEAP sets out a comprehensive framework for promoting resource efficiency, waste reduction, and sustainable product design. It includes specific legislative measures targeting sectors such as packaging, electronics, textiles, and construction, as well as initiatives to encourage the reuse and recycling of materials (European Commission, 2020).

A key component of CEAP is the Circular Economy Package, which introduced several waste management directives and ambitious recycling targets for EU member states. For instance, the directive mandates that by 2030, at least 70% of packaging waste must be recycled, and municipal waste disposal should be reduced to a maximum of 10% (European Parliament, 2018). The EU has also implemented the Ecodesign Directive, which requires manufacturers to design products that are more durable, repairable, and recyclable (Stahel, 2016). These policies aim to reduce the environmental impact of products throughout their lifecycle, while supporting the growth of circular business models.

CEAP has been widely regarded as a transformative policy framework, encouraging both public and private sector stakeholders to invest in circular practices. However, challenges remain in achieving consistent implementation across EU member states, particularly due to variations in waste management infrastructure and economic development (Kirchherr et al., 2017).

China's Circular Economy Promotion Law

China, the world's largest manufacturing economy, has also embraced circular economy principles as a strategy for achieving sustainable industrialization and addressing environmental degradation. In 2008, China passed the Circular Economy Promotion Law (CEPL), one of the first national laws aimed at promoting circular practices across industries. The law focuses on reducing resource consumption, improving recycling rates, and minimizing pollution (Su et al., 2013).

The CEPL outlines several measures for resource efficiency and waste reduction, including incentives for companies to adopt clean production technologies and penalties for those that exceed resource use limits or fail to manage waste properly. Moreover, the law encourages industrial symbiosis, where companies collaborate to use each other's waste streams as inputs, reducing resource consumption and waste generation. One successful example of industrial symbiosis is the Guangdong eco-industrial park, where multiple companies share resources such as energy, water, and raw materials (Yuan et al., 2006).

Despite the ambitious goals of CEPL, its implementation has faced challenges, particularly in monitoring and enforcement. A lack of robust regulatory oversight and limited coordination among different government agencies have hindered progress in some areas (Mathews & Tan, 2011). Nevertheless, China's circular economy policies have made significant contributions to reducing resource use in key industries such as steel, cement, and paper (Zhu et al., 2010).

Japan's Sound Material-Cycle Society

Japan has a long history of policies aimed at achieving resource efficiency and waste reduction, dating back to the Basic Law for Establishing a Sound Material-Cycle Society introduced in 2000. This law serves as the foundation for Japan's circular economy policies, with a focus on minimizing waste, promoting recycling, and optimizing resource use throughout the supply chain (Hotta & Aoki-Suzuki, 2014).

Key elements of Japan's circular economy framework include the 3R (Reduce, Reuse, Recycle) strategy and the Extended Producer Responsibility (EPR) system, which requires manufacturers to take responsibility for the entire lifecycle of their products, including recycling and disposal (Hotta et al., 2008). Japan has also implemented sector-specific laws, such as the Home Appliance Recycling Law and the End-of-Life Vehicle Recycling Law, which mandate the recycling of products like electronics and vehicles.

Japan's circular economy policies have been successful in achieving high recycling rates, particularly for materials such as metals and plastics. However, challenges remain in reducing overall waste generation and shifting consumption patterns toward more sustainable practices (Moriguchi, 2007). Additionally, while Japan has made significant progress in domestic circular economy initiatives, the country faces challenges related to managing waste exports and ensuring that materials are properly recycled abroad (Hotta & Aoki-Suzuki, 2014).

United Nations and the Sustainable Development Goals (SDGs)

The United Nations (UN) has played a central role in promoting circular economy principles through the framework of the Sustainable Development Goals (SDGs). Specifically, SDG 12, which calls for responsible consumption and production, directly aligns with circular economy principles (Schroeder et al., 2019). The UN's advocacy for sustainable production systems has encouraged countries around the world to develop national policies aimed at reducing waste and promoting resource efficiency.

Several UN initiatives, such as the Partnership for Action on Green Economy (PAGE) and the Global Compact, provide platforms for collaboration between governments, businesses, and civil society to advance circular economy practices. PAGE supports countries in developing circular economy roadmaps, while the Global Compact promotes corporate sustainability through voluntary commitments to sustainable production (United Nations, 2020).

National Circular Economy Roadmaps

Many countries have developed national circular economy strategies and roadmaps to guide the transition to a more sustainable economy. For example, Finland was one of the first countries to adopt a comprehensive Circular Economy Roadmap in 2016. The roadmap outlines key actions for reducing waste, promoting recycling, and fostering innovation in circular business models (Sitra, 2016). Finland's strategy emphasizes the role of education and research in supporting the circular economy, with initiatives such as the Circular Economy Lab, which fosters collaboration between businesses, researchers, and policymakers (Sitra, 2016).

Other countries, such as the Netherlands and France, have also adopted ambitious circular economy strategies. The Netherlands aims to achieve a fully circular economy by 2050, with interim goals such as halving resource consumption by 2030 (Rli, 2016). France's Anti-Waste and Circular Economy Law, passed in 2020, includes measures to combat plastic pollution, promote eco-design, and strengthen recycling systems (French Ministry for Ecological Transition, 2020).

These national roadmaps serve as valuable tools for coordinating circular economy efforts across different sectors and regions. However, the success of these strategies depends on effective implementation, cross-sectoral collaboration, and sufficient investment in circular economy infrastructure (Kirchherr et al., 2018).

2.5 Challenges and Barriers to Circular Economy Implementation

Potential Environmental Trade-offs

While the circular economy promises numerous environmental benefits, some studies point to potential trade-offs that may emerge. In particular, the environmental impacts of recycling and remanufacturing processes have been scrutinized. For example, down-cycling, a process in which recycled materials lose their quality and functionality, may not yield the same

environmental benefits as upcycling (McDonough & Braungart, 2002). Down-cycling could still require energy-intensive processing, potentially offsetting some of the environmental gains achieved through resource conservation.

Additionally, critics argue that without careful design, CE systems may contribute to rebound effects, where efficiency improvements lead to increased consumption. Zink and Geyer (2017) caution that increased product lifespans and resource efficiency in circular models might encourage more frequent use, negating environmental benefits. Therefore, ensuring that CE practices lead to real net reductions in environmental impacts requires a holistic approach that considers potential unintended consequences.

Regulatory and Policy Challenges

Government regulations and policies play a critical role in enabling or hindering the adoption of circular economy practices in manufacturing. While some governments have implemented supportive policies, such as extended producer responsibility (EPR) laws and incentives for recycling, inconsistencies in regulations across countries and regions create challenges for companies operating in global markets (Ghisellini et al., 2016). Additionally, the lack of standardized metrics and definitions for circular economy practices can make it difficult for manufacturers to assess their progress and comply with environmental standards.

Economic Challenges and Barriers

Despite its promising economic potential, the circular economy faces several barriers to widespread adoption. One major challenge is the high upfront costs associated with transitioning to circular practices. For many businesses, especially small and medium enterprises (SMEs), the costs of redesigning products, adopting new technologies, and establishing reverse logistics systems can be prohibitive (Kirchherr et al., 2017). For instance, redesigning products to be modular and repairable may require significant investments in research and development, while circular supply chains demand new infrastructure for material recovery and recycling.

Moreover, there are concerns about the economic viability of certain circular models in the short term. Kirchherr et al. (2017) note that business models based on leasing or product-as-a-service concepts may face difficulties in gaining consumer acceptance, particularly in industries where ownership is highly valued. Additionally, establishing circular systems in industries such as construction or electronics may be challenging due to complex supply chains and regulatory hurdles, which can further hinder economic benefits.

Inequalities and Global Implications

The global nature of supply chains raises questions about the distributional effects of the circular economy. Critics argue that while CE may benefit developed economies, the economic gains from circular practices may not be equally distributed across regions (Schroeder et al., 2018). For instance, developing countries that depend heavily on extractive industries for their economic growth may face significant economic disruption as global demand for raw materials decreases under circular models.

Also, there is concern that the benefits of the circular economy may be captured primarily by large multinational corporations, leaving SMEs and informal sector workers—especially in

developing countries—disadvantaged (Hobson & Lynch, 2016). These distributional issues highlight the need for inclusive policies that ensure that the economic gains from circular models are shared equitably across sectors and regions.

Consumer Behaviour and Cultural Barriers

In addition to regulatory and economic challenges, circular economy policies must address consumer behaviours and cultural barriers. Achieving a circular economy requires a fundamental shift in consumption patterns, with consumers opting for more sustainable products and services. However, ingrained habits, such as the preference for new products over refurbished or recycled items, can slow progress (Kirchherr et al., 2018). Public awareness campaigns and educational initiatives are essential for fostering a cultural shift toward circular consumption (Ellen MacArthur Foundation, 2015).

2.6 Link to the Theoretical Framework of the Study

III. Theoretical Framework for the Case Studies

3.1 Systems Thinking and Circular Economy

Systems thinking is a conceptual framework for understanding and managing complex, interconnected systems. It emphasizes the importance of looking at systems as wholes rather than analysing them in isolation, recognizing that the components within a system influence each other and that change in one part of the system can have ripple effects throughout the whole (Meadows, 2008). This approach is especially relevant for sustainability issues, where environmental, social, and economic systems are deeply interdependent.

Key elements of systems thinking include:

1. **Interconnectedness:** Understanding how different parts of a system are connected and how changes in one area affect the rest of the system (Senge, 1990).
2. **Feedback loops:** Identifying reinforcing and balancing feedback mechanisms that either amplify or stabilize behaviours within a system (Sterman, 2000).
3. **Holistic perspective:** Recognizing that sustainable solutions require addressing the system as a whole rather than focusing on individual components (Meadows, 2008).
4. **Dynamic behaviours:** Acknowledging that systems are not static but evolve over time, and that this evolution can lead to unintended consequences if feedback loops are ignored (Sterman, 2000).

In the context of circular economy implementation, systems thinking is essential because it helps manufacturers and policymakers understand the interconnectedness of production processes, supply chains, resource flows, and environmental impacts. By applying systems thinking principles, organizations can move away from linear production models toward circular practices that enhance resource efficiency and reduce waste.

The principles of the circular economy are inherently aligned with systems thinking. The circular economy seeks to create closed-loop systems that mimic natural ecosystems, where waste from one process becomes an input for another. This requires a shift from linear thinking—where products are designed for single-use and disposal—to circular thinking, where products are designed for longevity, reparability, and recyclability (Stahel, 2016). Systems thinking provides the theoretical foundation for this shift by emphasizing the interconnectedness of resource flows and the importance of feedback loops in maintaining system balance.

According to Meadows (2008), systems thinking allows for the identification of leverage points—places within a system where small changes can lead to significant improvements. In the case of the manufacturing industry, leverage points might include changes in product design, material selection, or supply chain collaboration that enable the transition to circular practices.

The implementation of circular economy practices in the manufacturing sector requires a fundamental rethinking of how products are designed, produced, and managed throughout their lifecycle. By applying systems thinking, manufacturers can identify opportunities for reducing resource consumption, extending product lifecycles, and closing material loops. The following sections will explore key areas where systems thinking can facilitate the integration of circular economy practices in manufacturing.

3.2 Life Cycle Assessment (LCA)

A critical tool in assessing the environmental performance of circular systems is the Life Cycle Assessment (LCA), a standardized methodology for quantifying environmental impacts across the entire life cycle of a product or service, from raw material extraction to disposal. This review explores the role of LCA in the circular economy, focusing on its potential to guide sustainable decision-making in product design, material flow, and waste management.

Life Cycle Assessment Overview

LCA is a comprehensive methodology standardized by ISO 14040/14044, used to assess the environmental aspects of a product or service across its life cycle (ISO, 2006). The typical stages in an LCA include:

1. Goal and scope definition – determining the purpose of the study, boundaries of the system, and functional units.
2. Life Cycle Inventory (LCI) – gathering data on all material and energy inputs and outputs across each stage.
3. Life Cycle Impact Assessment (LCIA) – evaluating the potential environmental impacts.
4. Interpretation – analysing the results to identify areas for improvement (Baumann & Tillman, 2004).

LCA has become increasingly essential in guiding environmental policies and corporate sustainability strategies, especially in circular economy initiatives, where the goal is to minimize resource extraction and waste.

LCA in Circular Economy

The integration of LCA within a circular economy framework is critical in evaluating the environmental sustainability of circular strategies, such as recycling, remanufacturing, and extended product life. LCA helps measure whether these strategies reduce overall environmental burdens or merely shift impacts from one stage of the product life cycle to another (Huysman et al., 2017).

Material flow and resource efficiency are core elements of CE. LCA facilitates the quantification of resource use efficiency and environmental impacts in different circular economy strategies (Haupt & Zschokke, 2017). For instance, LCA can be used to compare the

environmental trade-offs between using virgin materials and recycled materials. A study by *Zhao et al. (2018)* found that while recycling significantly reduces resource extraction and energy consumption, it may also lead to higher impacts in other categories, such as water use and toxicity due to additional processing.

Product life extension strategies, such as reuse, remanufacturing, and refurbishment, are central to CE. LCA allows for assessing the environmental benefits of extending product life versus producing new products. Studies show that remanufacturing can significantly reduce energy consumption and greenhouse gas emissions, especially in sectors like electronics and automotive manufacturing (Gutowski et al., 2011). However, LCA results indicate that the benefits depend on factors such as the energy mix, transportation distances, and remanufacturing processes.

Waste management and the reduction of landfill disposal are crucial in CE. LCA helps evaluate the environmental impacts of various waste management strategies, including recycling, composting, and incineration with energy recovery (Finnveden et al., 2013). In a comparative LCA study, *Turner et al. (2015)* showed that incineration with energy recovery, despite generating emissions, can offset the need for fossil fuel energy and reduce landfill waste. This highlights the importance of considering system-wide impacts when designing waste management strategies in CE.

LCA plays a critical role in evaluating and guiding the environmental sustainability of circular economy strategies. It provides a scientific basis for assessing the trade-offs between different circular approaches, such as recycling, remanufacturing, and waste management. However, several challenges, including impact allocation and the dynamic nature of circular systems, need to be addressed to fully realize LCA's potential in supporting the transition to a circular economy. Future research should focus on advancing dynamic LCA models and integrating social and economic dimensions into sustainability assessments to provide a more comprehensive evaluation of circular economy strategies.

3.3 Industrial Ecology

Key Concepts of Industrial Ecology in Circular Economy

Several key concepts of industrial ecology align with and reinforce the goals of the circular economy. These include industrial symbiosis, material flow analysis, and eco-efficiency.

1. **Industrial Symbiosis:** One of the most well-known applications of IE is the concept of industrial symbiosis, which refers to the collaboration between different industries to exchange by-products, energy, and materials in a way that benefits all participants and reduces waste. The Kalundborg industrial symbiosis in Denmark is a well-documented

example, where companies from different sectors (e.g., energy, chemicals, cement, and pharmaceuticals) share resources, leading to significant reductions in waste and resource consumption (Chertow, 2000). In the context of circular economy, industrial symbiosis can be seen as a practical implementation of circular principles by fostering inter-firm collaborations that enhance resource efficiency and close material loops.

2. **Material Flow Analysis (MFA):** MFA is a key tool in industrial ecology, used to analyse the flows of materials and energy through industrial systems. This methodology allows for the identification of inefficiencies, hotspots of waste generation, and opportunities for resource recovery (Brunner & Rechberger, 2004). In circular economy strategies, MFA provides the data needed to understand material cycles and design interventions that enhance circularity, such as recycling, remanufacturing, and reuse. Studies have shown that MFA can support decision-making in sectors like construction, where circular economy strategies, such as material reuse, could significantly reduce environmental impacts (Haas et al., 2015).
3. **Eco-Efficiency:** Eco-efficiency, a concept developed by the World Business Council for Sustainable Development (WBCSD), aims to deliver goods and services at lower environmental costs. It emphasizes reducing resource use, waste generation, and emissions while maintaining or increasing economic value (DeSimone & Popoff, 1997). In the industrial ecology framework, eco-efficiency is a central concept that complements circular economy strategies by encouraging industries to decouple economic growth from environmental degradation. By improving resource productivity and minimizing waste, businesses can create more sustainable products and services that align with the circular economy's goals of closed-loop systems and reduced environmental impact.

Industrial Ecology and Circular Economy: Synergies and Applications

The synergy between industrial ecology and the circular economy is evident in various sectors and regions, where IE concepts have been applied to design more sustainable industrial systems.

Urban Metabolism: One of the emerging areas where industrial ecology can support circular economy strategies is in the study of urban metabolism, which analyses the material and energy flows within cities (Kennedy et al., 2011). By applying industrial ecology principles to urban systems, policymakers can develop strategies that reduce resource use and waste generation in cities, creating more circular urban environments. For example, initiatives to promote building material reuse, energy recovery from waste, and water recycling are all influenced by the principles of urban metabolism and industrial ecology (Barles, 2010).

Waste Management and Resource Recovery: Industrial ecology has also been instrumental in the development of sustainable waste management systems that align with the goals of the circular economy. By focusing on the efficient use of resources and the recovery of valuable materials from waste, industrial ecology promotes the creation of circular systems where waste is minimized and reintroduced into production cycles. Life cycle assessment (LCA)

and MFA are often used together to optimize waste management strategies, such as recycling and energy recovery (Finnveden et al., 2009).

Bio-based Economy: Another area where IE and CE converge is in the development of bio-based economies, where biological resources are used in a circular manner to produce food, energy, and materials. Industrial ecology principles, such as nutrient cycling and industrial symbiosis, are applied to optimize resource use in agriculture and bioenergy production, reducing waste and enhancing sustainability (Mattila et al., 2012). This is especially important in sectors like agriculture and bioenergy, where circular economy approaches, such as composting and biogas production, help close nutrient loops and reduce reliance on synthetic fertilizers and fossil fuels.

Industrial ecology provides a robust theoretical framework for understanding and optimizing the material and energy flows in industrial systems, making it highly relevant to circular economy strategies. By applying concepts such as industrial symbiosis, material flow analysis, and eco-efficiency, industrial ecology can help design more sustainable systems that reduce resource use, minimize waste, and close material loops. However, challenges remain in scaling up IE practices to achieve the global systemic changes required for a circular economy. Future research should focus on integrating industrial ecology with broader circular economy initiatives, incorporating systemic and long-term thinking to create truly sustainable industrial systems.

3.4 Triple Bottom Line (TBL) Sustainability Framework

The Triple Bottom Line (TBL) sustainability framework, first introduced by John Elkington in 1994, expands the traditional bottom line of business success—profit—by including two additional dimensions: environmental and social impact (Elkington, 1997). This approach encourages organizations to measure and manage not only their financial outcomes but also their contributions to environmental stewardship and social well-being. In the context of the circular economy, which seeks to design out waste, keep materials in use, and regenerate natural systems, the TBL framework provides a holistic lens for evaluating sustainability.

The Triple Bottom Line: Economic, Environmental, and Social Dimensions

The Triple Bottom Line (TBL) framework emphasizes the interconnection of three sustainability pillars: the economic, environmental, and social dimensions.

1. Economic sustainability refers to the long-term financial viability of a company or system, which includes not only profit generation but also the efficient use of resources and the ability to create value for stakeholders (Elkington, 1997).

2. Environmental sustainability focuses on minimizing environmental harm by reducing resource extraction, energy use, waste, and pollution, thereby preserving ecosystems and biodiversity (Bansal, 2005).
3. Social sustainability addresses the equitable treatment of people, including fair labour practices, community development, and ensuring human rights and well-being across the value chain (Spangenberg, 2005).

Economic Sustainability in Circular Economy

The economic dimension of TBL in circular economy focuses on creating business models that generate profit while minimizing resource use and waste generation. Circular economy strategies such as product-service systems (PSS), remanufacturing, and recycling offer opportunities for businesses to reduce costs, increase resource efficiency, and tap into new revenue streams (Stahel, 2016). For instance, in the remanufacturing sector, companies can extend the life of products by repairing or refurbishing them, which can lead to significant cost savings and lower raw material consumption. A study by *Lieder and Rashid (2016)* highlighted that companies adopting remanufacturing practices could achieve up to a 50% reduction in material costs, demonstrating the economic potential of circular business models.

Moreover, the circular economy offers new opportunities for innovation and growth. Circular supply chains, which prioritize recycled and renewable materials, can reduce dependence on volatile raw material markets and create competitive advantages for businesses (Lewandowski, 2016). Circular business models that focus on long-term value creation can also help companies build resilience to resource shortages and market fluctuations, ensuring long-term profitability.

Environmental Sustainability in Circular Economy

The environmental dimension of TBL is deeply embedded in the principles of the circular economy. By designing out waste and pollution, keeping products and materials in use for as long as possible, and regenerating natural systems, the circular economy seeks to minimize negative environmental impacts (Ellen MacArthur Foundation, 2013). LCA studies consistently demonstrate that circular strategies such as recycling, material recovery, and eco-design can reduce energy consumption, greenhouse gas emissions, and resource depletion (Ghisellini et al., 2016). For example, a study by *Mendoza et al. (2017)* revealed that recycling and reusing construction materials could lead to a 20-30% reduction in CO₂ emissions, highlighting the environmental benefits of circular practices.

Another important element of environmental sustainability in the circular economy is the focus on regenerating natural systems. Circular strategies such as biomimicry, regenerative agriculture, and industrial symbiosis help restore ecosystems and enhance biodiversity by reducing pollution, conserving resources, and closing nutrient cycles (Benyus, 2002). These practices not only minimize environmental harm but also create new opportunities for sustainable growth in sectors such as agriculture, energy, and manufacturing.

Social Sustainability in Circular Economy

The social dimension of TBL focuses on the impact of circular economy practices on people and communities. Social sustainability in CE involves creating equitable access to resources, improving working conditions, and promoting social inclusion through job creation and community engagement (Murray et al., 2017). For example, recycling programs in developing countries have the potential to create significant social benefits by providing employment opportunities for marginalized communities, improving waste management infrastructure, and reducing environmental health risks (Wilson et al., 2006).

Circular economy business models such as product-as-a-service can also promote social sustainability by shifting ownership models, reducing the need for resource-intensive production, and promoting collaborative consumption (Bocken et al., 2016). These models encourage consumers to rent, lease, or share products rather than purchasing them outright, which can lead to more equitable access to goods and services while reducing resource consumption.

However, achieving social sustainability in the circular economy requires addressing potential challenges such as labour displacement due to automation and technological advancements. As industries transition to more resource-efficient production methods, some traditional jobs may be at risk, particularly in sectors like manufacturing and mining. Policymakers and businesses must ensure that the transition to a circular economy includes strategies for re-skilling workers, promoting inclusive economic growth, and ensuring fair labour practices (Korhonen et al., 2018).

3.5 Greenwashing

Greenwashing, a term coined in the 1980s, refers to the practice of misleading consumers regarding the environmental benefits of a product or service (Delmas & Burbano, 2011). Greenwashing can take many forms, including exaggerated claims about environmental performance, selective disclosure of positive environmental attributes while hiding negative aspects, and the use of vague or misleading language (TerraChoice, 2010). In the context of the circular economy, greenwashing occurs when companies falsely claim that their products or processes align with circular principles without making substantive changes to reduce environmental impacts.

The rise of greenwashing is driven by several factors, including increased consumer demand for sustainable products and the pressure on companies to appear environmentally responsible. However, greenwashing undermines genuine sustainability efforts by creating confusion in the marketplace and enabling companies to avoid accountability for their environmental practices (de Freitas Netto et al., 2020).

Greenwashing in the Circular Economy: The Scope of the Problem

As businesses and policymakers increasingly embrace the circular economy, the prevalence of greenwashing in this space has grown. Kirchherr et al. (2018) argue that many companies misrepresent their circular practices by focusing on small, incremental changes rather than systemic shifts in production and consumption. For example, companies may advertise their products as “recyclable” without addressing the fact that existing recycling infrastructure is insufficient to handle the materials effectively (Zink & Geyer, 2017). In other cases, businesses may claim that they are embracing circularity by offering take-back schemes or recycling programs, but these initiatives are often poorly designed and fail to significantly reduce waste (García-Quevedo et al., 2020).

The impact of greenwashing on the circular economy is twofold. First, it undermines genuine circular efforts by allowing companies to gain competitive advantages without making meaningful environmental improvements. Second, it erodes consumer trust, as consumers who are misled by greenwashing claims may become sceptical of future sustainability efforts (Lyon & Montgomery, 2015). This scepticism can ultimately hinder the transition to a circular economy by reducing the willingness of consumers to engage with circular products and services.

Environmental and Economic Implications of Greenwashing in the Circular Economy

The environmental implications of greenwashing in the circular economy are significant. By allowing companies to misrepresent their sustainability efforts, greenwashing contributes to the persistence of unsustainable practices and undermines efforts to reduce waste, lower carbon emissions, and conserve resources (de Freitas Netto et al., 2020). In sectors such as fashion and electronics, where greenwashing is prevalent, the failure to genuinely implement circular practices results in continued environmental degradation, despite claims of progress.

Economically, greenwashing can distort markets by creating unfair competitive advantages for companies that engage in superficial sustainability practices. Genuine circular businesses may struggle to compete with companies that falsely claim circularity without incurring the costs associated with true circular practices (Lyon & Montgomery, 2015). This can hinder the development of a robust circular economy, as businesses that prioritize sustainability may be undercut by competitors engaging in greenwashing.

Impact on Consumer Trust and Corporate Accountability

Greenwashing also has significant implications for consumer trust. Research shows that consumers are increasingly aware of greenwashing practices, and this awareness can lead to scepticism about all sustainability claims, not just those that are false (Chen & Chang, 2013). This erosion of trust makes it more difficult for genuinely circular businesses to market their products and services effectively, as consumers may be hesitant to engage with circular offerings due to past experiences with greenwashing.

Furthermore, greenwashing undermines corporate accountability by allowing companies to avoid making substantive changes to their environmental practices. By focusing on marketing

rather than actual sustainability improvements, businesses can continue to engage in environmentally harmful practices while presenting themselves as circular economy leaders (TerraChoice, 2010). This lack of accountability hinders progress toward a truly circular economy and contributes to the persistence of linear economic models.

Greenwashing presents a significant barrier to the successful implementation of the circular economy. By allowing companies to mislead consumers and regulators about their environmental practices, greenwashing distorts the circular economy narrative and undermines genuine efforts to reduce resource consumption and waste (García-Quevedo et al., 2020).. The environmental and economic consequences of greenwashing are profound, as it disseminates unsustainable practices and corrodes consumer trust in circular solutions.

3.6 Introduction to the case studies and the company

The next 2 sections of the research present 2 mixed-method (qualitative and quantitative) case studies. One of the key strengths of the case study method is its flexibility. Case studies can be designed to align with either qualitative or quantitative research paradigms, depending on the research questions, objectives, and context. As Stake (1995) points out, case studies are often qualitative because they seek to understand complex, contextualized phenomena that cannot be easily quantified. However, as Gerring (2007) demonstrates, case studies can also be quantitative when they involve the measurement and analysis of numerical data.

Mixed-methods case studies offer an additional layer of flexibility by integrating qualitative and quantitative approaches. This combination allows researchers to address complex research questions from multiple angles, providing both depth and breadth in the analysis (Creswell & Plano Clark, 2017).

Limitations of Case Studies as Research Methods

Despite their flexibility, case studies also have limitations. One common critique is that case studies lack generalizability because they focus on a single case or a small number of cases (Yin, 2018). However, proponents argue that case studies are not intended to produce generalizable findings but rather to provide in-depth insights that can inform theory development (Stake, 1995). Additionally, the findings of quantitative case studies may be more generalizable if the sample size and design allow for broader inferences (Gerring, 2007).

Another limitation is the potential for researcher bias, particularly in qualitative case studies where the researcher's interpretations play a central role in the analysis. To mitigate this, case study researchers often use techniques such as triangulation—combining multiple data sources and perspectives—to enhance the validity of their findings (Merriam & Tisdell, 2015).

The two case studies will present and analyse the company's performance against the framework set out in section 3, and namely LCA, Industrial Ecology, TBL and Greenwashing.

The company, Prolift, is a British SME producing bespoke lifting and handling equipment for the energy sectors, with a 40 year track-record in the Oil&Gas sector, and a recent new market engagement—offshore wind renewables—has become a central strategy for the business aiming to enhance competitiveness, increase revenue streams, and diversify risks (Kotler et al., 2019). However, entering new markets requires more than simply extending existing products or services into a different region. It demands a nuanced understanding of market dynamics, consumer behaviour, cultural preferences, and local regulations (Johnson et al., 2021).

The concept of the circular economy (CE) is increasingly being integrated into industries such as offshore crane manufacturing and operation, where it focuses on maximizing resource efficiency, extending the lifecycle of materials and products, and minimizing waste (Geissdoerfer et al., 2017). Offshore cranes, critical components in the oil, gas, and renewable energy sectors, present unique challenges and opportunities for circular economy practices. The implementation of CE principles in this sector can help reduce environmental impacts, lower operational costs, and foster innovation in sustainable design and manufacturing processes.

IV. Case Study 1 – Overhead EOT Cranes for Jack Up Drilling Unit

4.1 Overview of the Project

The purpose of this specification is to define the requirements for 10 Service Cranes used for handling equipment in the BOP stack storage area on Jack Up drilling Units which will be operating in the offshore UK, Denmark and Netherlands water area in depths up to 122m.

General Requirements

Dalian requires the vendor (Prolift) to build 10 SWL 17.5 tonnes (35 tonnes) service cranes

complete, including the following main components.

- Structure, including crane bridge girders and long travel rack and rails.
- Motors (2 speed) and gearboxes for both long and cross travel.
- Electrical systems including all JBs, connections and catenary to rig supply.
- Radio Remote Control – Primary
- Pendant control with spring tension – Secondary
- Twin sheave block with Crosby Bow shackle.
- Small maintenance platforms

Structural design temperature is -20oC min to +45oC

Structural design life is 25 years.

Load bearing structure to be steel of minimum grade 50D or equivalent.

4.2 Empirical findings

The following data array presents various metric that will be used to compare the two case studies against each other and against the theoretical parameters listed in the previous section.

- The contract was signed in 2008 and commissioned on the Jack Up drilling Units in 2010
- The Value of the contract was 4 million £
- The costs including material costs, labour expenses, overhead, and indirect costs (NIST, 2023) represented 65% of the contract price
- The total tonnes of ferrous material used was 240t, approximately 1.8-1.9 tons of CO2
- The local (UK) content represented 25%, European content 45% and the balance of 30% was supplied from South-East Asia
- The manufacturing processes were 100% local to the UK

- The Service Cranes were shipped by sea to China, Dalian Shipbuilding
- The final destination was UK offshore
- Further to the original supply, Prolift was awarded to blanket orders to maintain and provide spare parts for the lifespan of the cranes. This included capital refurbishments for 2 cranes a year from 2019 to 2024 – which prolonged the life of the cranes by a further 10 years and brought in a further £500,000.00 to the company.

4.3 Circular Economy Practices

Design for Durability and Maintenance: One of the fundamental principles of the circular economy is designing products for extended life cycles. In the case of offshore cranes, this translates into engineering cranes with durable components that can withstand harsh marine environments. Materials such as high-strength steel and corrosion-resistant alloys are used to prolong the operational life of cranes, thus reducing the need for frequent replacements (Stahel, 2016). Additionally, incorporating modular designs enables easier repairs, upgrades, and maintenance, which minimizes downtime and ensures that key components can be replaced without discarding the entire crane (Korhonen et al., 2018).

Reuse and Remanufacturing: Offshore cranes are often subjected to high levels of wear and tear, but rather than discarding cranes at the end of their service life, circular economy practices encourage the reuse and remanufacturing of crane components. Companies in the offshore sector are increasingly investing in remanufacturing programs, where older cranes or crane parts are disassembled, repaired, and reassembled to meet current operational standards (Ghisellini et al., 2016). This not only reduces the demand for new materials but also lowers overall production costs and extends the operational life of cranes.

Recycling of Materials: At the end of their lifecycle, offshore cranes can be recycled to recover valuable materials such as steel, copper, and other metals. Advanced recycling technologies allow these materials to be processed and reintroduced into manufacturing supply chains, thereby reducing the need for virgin raw materials and lowering the environmental footprint of crane production (Kirchherr et al., 2018). For example, the use of high-quality recycled steel in the production of new cranes can lead to substantial reductions in greenhouse gas emissions associated with steel production.

Energy Efficiency and Resource Optimization: Offshore cranes consume significant amounts of energy, particularly in operations such as lifting and moving heavy loads. Circular economy practices in crane operation involve optimizing energy use through the development of more efficient hydraulic systems, electric motors, and regenerative braking technologies (Stahel, 2016). By improving the energy efficiency of cranes, companies can reduce both operational costs and the environmental impact associated with fuel consumption or electricity usage in offshore environments.

4.4 Identified Challenges and Barriers

While the benefits of adopting circular economy practices in offshore cranes are clear, several challenges persist. First, high upfront **costs** for designing durable, modular, and easily repairable cranes can deter companies from embracing these practices, especially in a highly competitive market (Kirchherr et al., 2018). Moreover, the lack of established reverse logistics systems for returning and remanufacturing offshore crane components complicates efforts to implement circular practices at scale.

Another challenge is related to the regulatory environment. The offshore industry is governed by stringent safety and operational standards, which may limit the extent to which reused or remanufactured parts can be deployed in critical operations without extensive certification processes (Ghisellini et al., 2016). Additionally, technological barriers in recycling certain materials, such as composite materials or advanced alloys used in crane manufacturing, limit the efficiency of material recovery and recycling efforts (Korhonen et al., 2018).

V. Case Study 2 – Offshore Wind Farm Foundation Cranes

5.1 Overview of the Project

EDF Energy Renewables (Company) is developing the Neart na Gaoithe (NnG) Offshore Wind Farm (OWF), a 450MW development located in the North Sea, off the Fife Coast, Scotland. The project is at advanced stage of development with construction phase currently scheduled to be completed by 2021.

The Foundations for Wind Turbine Generation (WTG) and Offshore Substation (OSS) shall be steel jackets supported on piles.

The Offshore Site is 15km east of Fife Ness and 29km from the East Lothian coastline and covers an area of 105km². Water depths across the Offshore Site generally range from 40 to 60m LAT.

Company has advised that it has obtained consent for use of 54 No. 8MW turbines in the OWF, subject to confirmation via the appeals process, and this is the base case for the concept phase engineering.

The 54 foundation cranes are required during operation and maintenance of the Wind Turbine Generator (WTG) to dynamically load and unload wind turbine parts and others equipment from the vessel positioned at the boat landing to and from the foundation platform. The foundation crane may be also used during installation and commissioning of the WTG.

In case of emergency evacuation, a static anchor point on the boom may be used to attach a rescue device for the transfer of injured personnel to a vessel.

The foundation crane consists of a hydraulic slewing mechanism, a crane hydraulic luffing boom and an electric crane hoist. Foundation crane shall be equipped also with an Emergency hand operated system and shall be movable manually in case needed.

On the crane boom a red painted hook-on point SWL 20kN as of EN 50308 shall be present, along with a yellow painted static anchor point for emergency descent with SWL 20kN as of EN50308. The crane design life is 25 years.

5.2 Empirical Findings

The following data array presents various metric that will be used to compare the two case studies against each other and against the theoretical parameters listed in the previous section.

- The contract was signed in 2020 and commissioned on the Offshore Steel Jackets in 2022
- The Value of the contract was 3.5 million £
- The costs including material costs, labour expenses, overhead, and indirect costs (NIST, 2023) represented 80% of the contract price
- The total tonnes of ferrous material used was 280t, approximately 1.8-1.9 tons of CO₂
- The local (UK) content represented 50%, European content 35% and the balance of 15% was supplied from South-East Asia

- The manufacturing processes were 100% local to the UK
- The Foundation Cranes were shipped by air to Indonesia, Karimun Shipbuilding
- The final destination was UK offshore
- in 2024, the Company has scrapped the 54 Foundation cranes, citing a specification update to which the Cranes were not compliant. Prolift had offered a quotation to carry out the modification work required offshore for an additional £250,000.00. The Company decided to scrap the cranes and reorder new cranes to the Value of 4.5 million £ and tonnage of 320t of new steel. In addition to this, the removal of the original cranes and the installation of the new cranes will be performed offshore with the CO2 expense of the Jack-Up Vessel.

5.3 Circular Economy Practices

In addition to the Circular Economy Practices presented in paragraph 4.3: design for durability and maintenance, reuse and remanufacturing, recycling of materials, energy efficiency and resource optimization, the Foundation Cranes also had **Digitalization and Predictive Maintenance**: The integration of digital technologies is a critical enabler of circular economy practices in offshore crane operations. Technologies such as the Internet of Things (IoT) and predictive maintenance systems allow operators to monitor the condition of cranes in real-time, reducing the likelihood of sudden failures and enabling timely interventions before major repairs are required (Porter & Heppelmann, 2014). By preventing premature breakdowns, predictive maintenance extends the lifespan of components and reduces the need for replacement parts, aligning with the principles of circularity.

5.4 Identified Challenges and Barriers

The offshore windfarm industry has seen significant growth as a renewable energy source, promising reduced emissions and a cleaner energy alternative. However, greenwashing—where companies exaggerate or misrepresent their environmental credentials—has increasingly come under scrutiny within this sector. Greenwashing in offshore wind can undermine genuine environmental efforts, erode public trust, and hinder the transition to truly sustainable energy solutions.

Forms of Greenwashing in Offshore Wind

Overstating Emission Reductions: Companies may claim that offshore windfarms are entirely carbon-neutral without accounting for the emissions associated with production, transportation, installation, and maintenance (Nyberg & Wright, 2016). The construction of wind turbines, especially offshore, involves significant carbon emissions from sourcing materials, transportation

to remote sea locations, and the use of fossil-fuel-powered machinery during installation (European Environment Agency, 2023).

Selective Reporting: Some offshore wind companies focus exclusively on the operational phase, where turbines produce no direct emissions, while omitting details about resource-intensive processes, such as the use of rare earth metals in turbine components and seabed disruption during installation (Ritchie & Roser, 2022). Selective reporting can create a misleading image of environmental responsibility.

Biodiversity and Marine Ecosystem Claims: Offshore wind projects often face criticism for their impact on marine ecosystems, yet companies sometimes emphasize minimal impacts or even claim positive effects without rigorous evidence. Greenwashing in this context might involve claims that turbine bases act as artificial reefs that enhance biodiversity, despite evidence of disruption to fish habitats and potential risks to marine mammals (Thomsen et al., 2021).

Implications of Greenwashing in Offshore Wind

Greenwashing in offshore wind farms can have substantial implications. First, it can mislead investors and policymakers, leading to suboptimal resource allocation and policy frameworks. Second, greenwashing risks reducing public trust, especially as communities become more aware of the complex trade-offs in renewable energy. Finally, it may delay the implementation of genuinely sustainable practices in offshore wind, as resources are diverted toward marketing rather than addressing actual environmental challenges (Nyberg & Wright, 2016).

VI Analysis and Discussion

6.1 Data Analysis against Theoretical Framework

	Case Study 1	Case Study 2 Original	Case Study 2 Final
Scope 3 Emissions			
Ferrous Steel Content (t)	240	280 [#]	600
Local Content	25%	50%	20%
European Content	45%	35%	20%
S.E Asia Content	30%	15%	60%
Total Shipping Distance (miles)	10314	14644	20501
Specification Compliant	Yes	No	yes
Scrap & remanufacture	No	Yes	Yes
Maintenance Contract	Yes	No	No

Note - By scrapping the original supply, the steel consumption has gone up by 114%, more than doubling the CO2 emissions caused by re-production activities.

Life cycle Assessment – Case Study 1 increased the Design Life from 25 years to 35 years, while Case Study 2 decreased the Design Life from 25 years to 2 years.

Industrial Ecology – Case Study 1 implemented waste reduction through the maintenance contract while Case Study 2 wasted 280t of steel and 14644 miles of air transport.

Triple Bottom Line – Case Study 1 is the more sustainable project from the economic, environmental and social aspect.

Greenwashing – Albeit serving the Oil&Gas industry, the cranes in case study 1 have consumed less energy and released less CO2 than the cranes in case study 2.

6.2 Overcoming Challenges and Barriers

The integration of circular economy practices in offshore cranes represents a promising approach to achieving sustainability and resource efficiency in the offshore sector. By designing for durability, enabling remanufacturing and recycling (Korhonen et al., 2018), and leveraging digital technologies for predictive maintenance, the offshore crane industry can significantly reduce its environmental footprint while enhancing operational efficiency. However, overcoming challenges related to high costs, regulatory constraints, and technological barriers (Ghisellini et al., 2016) will require continued innovation and collaboration across the industry.

6.3 Organizational Culture Impact on Circular Economy Implementation

The effectiveness of implementing circular economy (CE) practices varies significantly across companies, often due to differences in organizational culture. Company cultures play a pivotal role in shaping employee attitudes, decision-making processes, and openness to new sustainability practices. For instance, companies with a hierarchical, risk-averse culture may struggle to adopt circular practices because of rigid processes and resistance to change (Geissdoerfer et al., 2017). In contrast, organizations that foster innovation and sustainability-driven cultures are typically more adaptable and proactive in integrating circular economy principles, as employees are encouraged to experiment and embrace sustainability initiatives (Lacy et al., 2019).

Communication practices within company culture also affect CE implementation. In a culture that prioritizes transparency and collaboration, circular economy initiatives are more likely to gain widespread support. However, in companies where siloed departments operate with limited cross-functional communication, it becomes challenging to implement circular strategies that require integrated efforts across supply chains, product design, and waste management (Bocken et al., 2016).

A culture that prioritizes short-term financial goals can also hinder circular supply chain efforts. In such environments, financial constraints may prevent the investment in the necessary technologies, infrastructure, and training for CE practices (Lacy et al., 2019). Moreover, organizational culture affects the motivation to invest in sustainability. Companies with a strong corporate social responsibility (CSR) orientation may view circular economy practices as a valuable brand asset, aligning with their ethical and environmental goals. In contrast, companies focused purely on short-term financial gains may find it harder to justify the initial investment required for circular practices (Kirchherr et al., 2018).

6.4 Policy Implications and Recommendations

Circular economy policies and initiatives have gained significant momentum globally, with governments, international organizations, and the private sector playing key roles in advancing the transition to a more sustainable economy. Policy frameworks such as the EU's Circular Economy Action Plan, China's Circular Economy Promotion Law, and Japan's Sound Material-Cycle Society presented in section 2.4 have set ambitious goals for waste reduction, resource efficiency, and sustainable production. Despite challenges related to regulatory alignment, economic costs, and consumer behaviour, these policies represent critical steps toward a more circular and sustainable global economy. Continued collaboration between stakeholders and investment in circular infrastructure will be essential to overcoming these barriers and realizing the full potential of the circular economy.

Transitioning to a circular economy requires significant financial investments in infrastructure, technology, and business models. Many small and medium-sized enterprises

(SMEs) face challenges in adopting circular practices due to the high upfront costs associated with new production processes, reverse logistics, and recycling systems (Masi et al., 2018). Governments can play a critical role in addressing these economic barriers through incentives, subsidies, and public-private partnerships that support the circular transition (Ghisellini et al., 2016).

VII. Conclusion

7.1 Summary of Findings

The two case studies presented in this study have similarities when it comes to original steel content, contract values, distances travelled to the installation and final use locations, design life, energy efficiency and resource optimisation (local content).

The event that tips the balance away from the Offshore Wind Farm Project is the Company's decision to scrap the original Cranes instead of performing the modification required – and therefore increasing the resource extraction, energy use, waste, and pollution (Bansal, 2005).

This is an illustrative example of the challenges and limitations faced by an SME involved the current energy sectors supply chain (Bocken et al., 2016). Thus, a company's culture either disrupts or promotes CE practices in supply chains, underscoring the need for cultural alignment with sustainability goals to achieve circular supply chain transformations.

7.2 Contributions to Knowledge

This study contributes to the understanding of circular economy implementation within manufacturing SMEs by highlighting the unique challenges they face compared to larger organizations (Bocken et al., 2016). It provides a framework for identifying specific limitations in financial, technical, and supply chain domains, which are often overlooked in broader discussions on CE.

7.3 Implications for Practice

To mitigate these limitations and challenges, stakeholders in the supply chain should adopt transparent reporting practices that account for emissions across the entire lifecycle, from materials sourcing to decommissioning (Nyberg & Wright, 2016). Third-party certifications and regulatory oversight can provide accountability, ensuring that environmental claims are substantiated with evidence. Enhanced assessments and impact studies before project approval can help address Industrial Ecology concerns.

By confronting greenwashing, the energy industry can better fulfill its promise of sustainable energy, contributing genuinely to climate goals and maintaining public trust.

7.4 Suggestions for Future Research

While implementing circular economy models in manufacturing SMEs presents significant challenges, such as financial limitations, technical constraints, and linear supply chain structures, it also offers unique opportunities for cost savings, market differentiation, and green financing (Kirchherr et al., 2018). Overcoming these limitations will require coordinated efforts from governments, industry partners, and SMEs themselves. By fostering collaboration (Geissdoerfer et al., 2017), building capacity, and leveraging digital solutions, manufacturing SMEs can progress toward sustainable circular practices and contribute meaningfully to the broader transition to a circular economy.

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