Vaasan yliopisto
UNIVERSITY OF VAASA

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The Role of circular economy practices in supply chain management in supporting decarbonization

Study on energy-based companies

School of Innovation and Technology
Industrial Engineering & Management
Master of Science in Economics and Business Administration

Vaasa 2026

UNIVERSITY OF VAASA
School of Innovation and Technology
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Title of the thesis: The Role of circular economy practices in supply chain management in supporting decarbonization: Study on energy-based companies
Degree: Master of Science in Economics and Business Administration
Degree Programme: Industrial Engineering and Management
Supervisor: Ines Simoes de Brito Peixoto
Year: 2026 **Pages:** 90

ABSTRACT:

The study explores the role of practises of circular economy (CE) in relation with supply chain management (SCM) in contributing decarbonisation in energy-based companies. The key motivation for the research is the increasing pressure to minimise the greenhouse gas emission in energy sector, specially related to indirect supply chain emissions (scope 3), and contribute to environmental and sustainability goals. The practises related to decarbonization in the energy industry is more focused on efficiencies in the operations and the technological innovations, the contribution through circular economy initiatives related to the supply chain remains underexplored.

The study is incorporated with theories related to CE, sustainable SCM and decarbonization. The main terminologies consist of sustainable procurement, circular supply chains, lifecycle management, resource efficiency, and closed loop systems. The study explores how these strategies are integrated in SCM initiatives to reduce the greenhouse emission and contribute to the sustainability goals and objectives.

A qualitative multiple case study method has been identified in relation with secondary data from ESG, annual reports, sustainability disclosures, and policy related documents from selected European energy organisations namely, Fortum Oyj, Pohjolan Voima Oyj, Statkraft, and Enel Group. The analysis of data is done through thematic and content analysis to explore the recurring patterns and interrelationships in connection with CE and SC decarbonization tactics.

The findings reflects that in order to minimize the reduction of the carbon generation across the SC operation, supplier management, sustainable procurement, efficiency of the resources, lifecycle management, and closed loop material processes acts as a crucial role .The cross company analysis reflects that the selected European and Nordic companies integrate CE practices in to their SC decision making to enhance the sustainability across companies to contribute to long term sustainability efforts to achieve decarbonization goals.

The conclusion of the study demonstrates that the integration of CE strategies into the SCM practices is a significant factor for achieving the systemic decarbonization outcomes in energy sector. The study assists both theoretically and practically by improving the understanding of how Supply Chain tactics can support the transition of sustainability and assist managers to inline circular economy initiatives with Supply Chain Management to achieve decarbonization.

KEYWORDS: Circular Economy, Supply Chain Management, Sustainability, Decarbonization, Energy, Carbon Emission

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Abbreviations

CE- Circular Economy

SCM- Supply Chain Management

EU - European Union

TBL - Triple Bottom Line

CO_2 - Carbon Dioxide

PVO - Pohjolan Voima Oyj

1 Introduction

Climate change has become an extensive global challenge, and energy industry is one of the main players which aim to achieve international decarbonization goals. Production of the energy and related industries have contributed a significant amount of greenhouse gas emission globally (IEA, 2023). With the introduction of renewal energy sources, industries have able to mitigate the greenhouse gas emissions in considerable way but research continuously reflects on indirect supply chain emissions which is identified as scope 3 emission, most of the time exceed direct emission in the carbon intensive sector (Huang et al., 2009). It requires to have innovative procedures beyond the traditional way to control the emission.

The Circular Economy (CE) has become a new norm and consider as a strategic sustainability terminology which has provided the solution for traditional take-make-dispose approach while CE works on resource efficiency, remanufacturing, reuse and extension of lifecycle of the products (Kirchherr et al., 2023a). In the case of supply chain management perspective, CE plays a pivotal role in green supply chain management which take into the consideration of sourcing, logistics and reverse engineering practises (Hariyani et al., 2024).

The supply chain management and the circular economy principles cannot be kept apart as they are linked with each other while their execution depends on the relationship between, sourcing or purchasing, production, logistics and end of life activities. The purpose of integrate the closed loop system is to minimise the additional resource extraction, energy usage, and generation of waste. These modifications assist directly to the decarbonisation as the result is the decline of emissions across the value chain, specially the indirect emission which has the minimum attention yet generated largest amount of emission in the energy sector (Kirchherr et al., 2023b, Farooque et al., 2019).

Even though the priorities are given to circular economy practices and sustainable supply chain, the application of these terminologies in the energy industry remains underdeveloped, when it comes to addressing scope 3 emissions. Since the energy sector is operated in complicated, asset intensive, and globally connected supply chain networks, as the indirect emission from the activities such as logistics, procurement, and development of the infrastructure impact directly to the carbon footprint overall. Scope 3 emission, which is the most complicated element of corporate greenhouse emission contribute mainly for carbon footprint and offering major challengers for decarbonisation goals in the industries specially related to the energy (Stenzel & Waichman, 2023).

However, the current research studies have been more focus on operational decarbonisation where the attention is towards scope 1 and 2 emissions while the role in the case of supply chain towards emission reduction in scope 3 has less attention comparatively which is highly important in order to minimise the indirect emission (Borchardt et al., 2025). Further, even though the circular economy terminologies are extensively identified the ways to enhance the resource efficiency and enable to create closed loop supply chains, their implementation towards supply chain as a mechanism to minimizing the scope 3 emission still to be extensively explored (Kazakova & Lee, 2025).

Hence, there is a significant need to explore how the circular economy practises in supply chain can increasingly contribute to decarbonisation efforts in energy-based companies.

1.1 Background of the study

Climate change has become one of a challenging global effect to the world, requires basic changes to the industries on their production, consumption and manage resources. The reason why the energy sector is the main contributor because it contributes the most impact of releasing greenhouse gas to the environment. As countries focus on achieving carbon neutrality and aim for sustainable goals and international global climate commitments, the companies under energy sector have an immense pressure to implement the decarbonization strategies to their company, especially for the supply chain management practises (Dongo & Relvas, 2025). While most of the companies try to achieve the operational excellence and improving the usage of renewal sources to their production to generate the energy, considerable portion of the emission is generated through supply chain activities including raw material generation, equipment manufacturing, logistics activities, development of the supply chain infrastructure (Seuring & Müller, 2008). This indirect emission reflects the importance of aim on sustainability obstacles beyond the individual company level.

Integrating of the circular economy strategies to the supply chain management is a smart move to achieve the sustainability goals and decarbonisation goals. Supply chain links to production and distribution in multiple ways, making them a vital point for implement the improvements for the environment. Sustainable supply chain management links the environmental consideration with the activities in relation to logistics, procurement, sourcing and supplier collaborations (Velenturf & Purnell, 2021). But in the case of circular supply chain, it works in a closed loop system and help materials and resources to move within the economy but not to waste or dispose (Farooque et al., 2019).

This terminology is extremely relevant for energy-based companies since they are operating in a complex supply chain network which involves large scale infrastructure, high tech equipment, and long asset lifecycles. Introducing circular practises help them to sustainable in their sourcing, lifecycle management to achieve the long-term decarbonisation goals for the companies (Farooque et al., 2019). Even though the previous research studies have been explored on sustainable supply chain and circular principles separately, energy sector focused empirical research related to these perspectives have been limited, especially in relation with decarbonization strategies (Seuring & Müller, 2008).Further, the contribution on circular supply chain practises in relation to scope 3 emissions remains partly explored in the current literature(Hettler & Graf-Vlachy, 2024).

Therefore, this research study finds the role of circular economy practises within the supply chain management in assisting decarbonization strategies in selected energy companies.

1.2 Research questions and objectives

Following to the research background, it is important to clearly articulate the research questions and the objectives for a better understanding and direction of the research. While the prior researchers highlight the possible circular economy practises to enhance the resource efficiency and minimise the impact to the environment, there are yet to be clearly indicate on how these terminologies are incorporated into the supply chain management process to assist decarbonisation strategies and in relation with energy-based companies in the Europe and Nordic regions (Bressanelli & Saccani, 2025). Since the energy-based companies are operated in a complex supply chain operations in their networks, it is important to make sure that the environmental concerns are tracked and minimised across the value chain (Geissdoerfer et al., 2017a). Thus, the importance of incorporate the circular economy strategies to their network is paramount and supporting the industries to transform into a sustainable future.

Based on the research context, the main research question of the study is:
How are circular economy principles integrated into supply chain management practices to support decarbonization in energy-based companies?

To address this question, the study has defined several research objectives. First, study seeks to identify how the CE practises are reflected in their sustainability strategies of the selected energy-based companies. Second, to explore key supply chain management practises, such as sustainable procurement, life cycle management, and supplier collaboration that assist to environmental performances. Finally, research seeks to analyse how these steps support broader decarbonisation strategies and sustainability commitments.

1.3 Conceptual Framework

The conceptual framework of this study is linked through circular economy practises, supply chain management, and decarbonisations initiatives. The framework assumes that the circular economy practises incorporated in supply chain management direct to decarbonisation performance in energy-based companies. Circular economy models replaced the traditional linear economy model where the resources are linked to a regenerative system where the materials are used in a closed system and use for long as possible through reuse, recycle, remanufacture, and life cycle extension. When these terminologies are applied in an organisation's supply chain processes, it can reduce the waste, minimise the resource consumption and enhance the environmental efficiency across the company value chain (Geissdoerfer et al., 2017a).

Supply chain management act as a key player for circular economy since it is incorporated with procurement, production, logistics, and vendor management. Research work on circular economy activities reflects link into sustainability to that process can assist on more effective use of materials while reduce the environmental issues in relation with production and distribution in the supply chain network (Farooque et al., 2019). In the context of energy sector, since all the activities related to emission is linked through the supply chain processes, it is important to consider on these activities as the small contribution to reduce the greenhouse emission through circular economy practises can lead to bigger impact to the bottom line of the energy based companies in terms of achieving targeted decarbonisations goals and objectives (Hariyani et al., 2024).

1.4 Identification of key concept of the research

In any research defining key concepts is important for clarity and proper understanding. This section introduces the key terminologies which lay the foundation to the study.

Circular Economy (CE) is an economic framework focusses on keep the materials, products, and resources in the circulation for as long as possible by minimising the waste and regenerating the natural systems. Rather than follow the liner economy model, take-make-dispose, CE enables to support closed and regenerative system and use recycle, reuse and remanufacturing concepts (Korhonen et al., 2018). It allows companies to minimise the waste and improve the resource efficiency while minimising the environmental impacts.

Circular Supply Chain (CSS) converts CE terminologies into an operational structure of supply chain management. In circular supply chain, the materials, and the products flow beyond the end users and back to the flow from product take-back, reverse logistics, reverse engineering, and recycling initiatives. This reverse flow allows supply chain to reuse the materials and minimise the waste and generate value from the post use materials, maintaining closed loop system leads to sustainability and operational excellence (Angelis et al., 2017).

Supply Chain Management (SCM) engages in coordination of activities related in producing and delivering goods and services. It consists of operations, sourcing, logistics and distribution. Within the territory of circular practises, SCM involves in product returns, material tracking in closed loop systems, vendor collaboration, and reverse logistics enabling the circularity practises (Manavalan & Jayakrishna, 2019). Incorporating CE practises to SCM is essential for achieving sustainable manufacturing and better consumption patterns.

Sustainability is defined as per this research as a triple bottom line (TBL), balancing environmental integrity, social and economic concerns. In the context of CE and SCM, it allows systems to be defined to minimise the carbon emissions, extend the product life cycle and ensure equal use of resources while creating values for the businesses and to the society (Hariyani et al., 2024).

Decarbonisation refers to a strategic concept where to minimise the greenhouse emission in the business and the supply chains mitigate the climate change. In the context of energy-based companies, most of the emission happens through supply chain activities as scope 3 emissions and in the activities related to procurement, sourcing, logistics, transportation, and life cycle management in assets. Establishing the CE practises to the

SCM leads to decarbonisation and improve the life cycle of the products, reduce waste and utilise the resources efficiently (Papadis & Tsatsaronis, 2020).

All these concepts and theories lay the foundation to the study. The integration of CE and SCM is the key mechanism through which energy-based organisations can reduce the emission of scope 3 and achieve sustainability initiatives.

1.5 Research methodology and data collection

This study uses qualitative analysis how circular economy practises in supply chain management support for decarbonisation initiatives in energy-based companies. Qualitative analysis is ideal because the objective is to identify organisational strategies and sustainable initiatives rather than to explore on numerical figures such as measuring carbon footprint. In accordance with Hollweck (2016) qualitative approach is useful to understand and interpret the complex organisational procedures assist with textual data.

The selected companies demonstrated the sustainability and circular economy initiatives publicly to achieve the decarbonisation targets. The companies selected for the studies are Fortum Oyj, Pohjolan Voima Oyj, Statkraft and Enel group. The reason for select these companies based on their operations in the energy sector and publish the data related to sustainability, environmental, and ESG which provide related insights to the research study and identify their supply chain strategies for decarbonisation.

Data for the study are gathered from the secondary data sources such as sustainability reports, ESG reports, annual reports and relevant industry and policy documents. These sources consist of importance information related to strategic environmental details, supply chain initiatives, and strategies related to resources to drive circular economy initiation to their organisation. To analyse and interpret the collect data, thematic content analysis method is used which consist of systematic identification of recurring themes and patterns within the report. This terminology allows to identify how the circular economy practises are incorporated with their supply chain strategies to obtain the decarbonisation goals (Farooque et al., 2019).

1.6 Limitations and the validity of the research

Since this study seeks to provide comprehensive analysis of circular economy practises in supply chain management, several limitations are taken into the consideration. First the analysis is based on energy-based companies which are limited to Europe and Nordic regions including Fortum Oyj, Pohjolan Voima Oyj, Statkraft and Enel group. Selected companies are renowned for their sustainability and decarbonisation efforts. But their locations, regulatory environment and the structure of the organisations are differed from the companies operated in other regions of the world (Islam et al., 2025a). Therefore, the findings of this study may not fully incorporate in general way to the energy firms which are operated in different regions with various economies, technical and regulatory conditions.

Finally, the study is using qualitative thematic and content analysis to interpret the collected data. Even though the systematic coding procedures are implemented, qualitative analysis itself comes with the own judgments from the researchers end. According to the Ahmed et al. (2025) qualitative study comes with some sort of subjective interpretation despite of having methodological rigor. Hence, the results of this study should be analysed in the perspective of emerging patterns rather than definitive conclusions related to all the circular supply chain practises in the case of energy-based industries.

1.7 Research structure

This thesis study has been articulated into several chapters for reader to properly understand the step-by-step research work done for this specific topic. The first chapter reflects the background of the research, defining the importance of the decarbonisation initiatives in the energy sector and contribution in circular economy activities in their supply chain to contribute to the decarbonisation and sustainability targets. It also highlights the research problem, research questions and objectives, conceptual framework, limitations and validity, and research method and data collection.

The second chapter highlights the literature review which introduces and explore the current literature work done for the circular economy related to supply chain to achieve decarbonisation initiatives specially principles of circular economy, sustainable supply chain management, and strategic decarbonisation efforts. This chapter explore the theoretical aspects related to the topic and identify the key terminologies and concepts in relation with the selected topic (Geissdoerfer et al., 2017a). It also explains how circular economy practises can help to utilise the sustainable resources and minimise the carbon emission in the processes in supply chains.

The third chapter describes the research methodology and data collection process used in the study. It explains the qualitative research design and the secondary data collection from the sources such as sustainability reports, ESG reports, energy policies and closures and annual report from the selected energy-based companies and the thematic content analysis method to interpret the data collected. Since the qualitative data approach is ideal to identify the complex organisational strategies and to analyse the patterns and themes related to the research study from the reports (Hollweck, 2016).

The fourth chapter presents the analysis and the findings of the selected companies in relation to the research topic including four companies. This chapter analyses the sustainability, ESG and annual reports to review the selected company's circular supply chain practises, decarbonisation efforts.

Finally, the chapter five and six is all about discuss the major findings, present the conclusion, and provide recommendations for executives and future research opportunities.

2 Literature Review

2.1 Circular economy and sustainability

Circular economy has been considered as an alternative approach to the conventional linear "take-make-dispose" model which happened to be ruled the global production and consumption processes (Kirchherr, 2023,p.6). Kirchherr (2023) describes the importance of the circular economy system which focus on maintain the product's value, resources and the materials as longer as possible while keeping its value to minimise the generation of waste. (Geissdoerfer et al. (2017a) argues further on the circular economy systems which can be identified as à shift of a system towards a regenerative process that combines economic growth from consumption of resources. These studies offer unique and solid conceptual and theoretical foundation, aim on industrial systems but consist of limited applications specially for sector related contexts such as energy-based supply chains.

Circular economy is featured by a regenerative system to focus on enhancing the life cycle of the materials and the products from closed loop systems. Ghisellini et al. (2016) argues that the circular processes demand constant use of resources to keep the value of the products while minimising the waste as much as possible through recycling, reusing, remanufacturing and repair strategies. These initiatives shift from conventional production systems to life cycle focused thinking, where efficiency of the resources and the recovery of the materials are paramount and considered as a central principle of the supply chain processes. However, current research studies aim on conceptual arguments, and limited empirical exploration in to how these initiatives are embedded in to complex industrial sectors such as energy.

Kirchherr et al. (2023b, p.10) offers a widely acceptable definition for CE as an "economic system that replaces end-of-life disposal with strategies aimed at reducing, reusing, recycling, and recovering materials throughout production and consumption". Therefore, the circular economy operates at different levels such as organizational, product, industrial and regional or national level (Hummen & Sudheshwar, 2023a). This defines that the products are designed for longevity, align with reverse logistics systems, and collaborate with cross industries in a close resource loop.

A critical characteristic of the CE is the closed material loop where the materials are circulated in an economy and rather than discarded after a single use. Closed loop systems are highly important for industries which are highly intense, such as automotive, electronics, and energy infrastructure (Hummen & Sudheshwar, 2023b). These systems reduce reliance on virgin materials and utilize the resources to mitigate the environmental impact and direct sustainable resource management.

Circular economy also highlights the decoupling economic growth from resource consumption, where the economies can broaden without steadily improving the pressure towards the environment (Geissdoerfer et al., 2017b). To achieve decoupling requires product innovation and design, improved production processes, and cooperative business models. Organizations can be moved from selling products to offer a service, namely the product as a service model, which can promote the efficiency of the resources and improve the product life cycles (Kjær et al., 2018).

Governments and internal organizations identify the importance of recognizing the CE in advancing sustainability activities and climate objectives. For example, the European Union Circular Economy action plan encourages companies to implement CE plans to minimize the waste, improve the recycling rates, and optimize resource allocation. At the same time global companies including United Nations promotes the CE as a direction to obtain several sustainable development goal (SDG), specially SGD 12 on responsible production and consumption (Dragomir & Dumitru, 2024).

Figure 1 reflects the main principle of CE, inclusive reduction, reuse, recycling, and recovery tactics in life cycles of the products. It gives visual representation of how circulation of the materials is done in the closed loop system than discarded (Farooque et al., 2019).

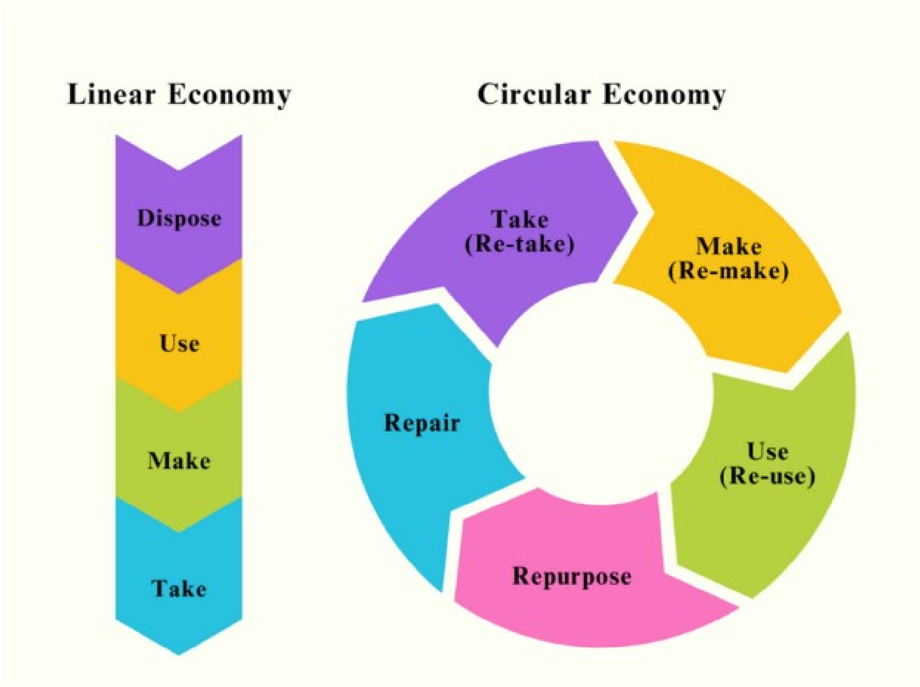

Figure 1. Linear and Circular Economy models

2.1.1 Circular Economy Principles

Circular economy principles focus on strategically eliminate the waste, material circulation and regenerate natural systems. Morseletto (2020) explains that these terminologies are developed through life cycle-based approaches which highlight the waste minimization and efficiency of the resources. At the same time Hunger et al. (2024) identify the 9R framework which is an expansion to the conventional 3R model such as reduce, reused and recycle, to incorporate with the strategies such as repair, refurbish, remanufacturing, and repurpose. These initiatives offer a strategic framework for integration of circularity in industrial sectors, even though their applications are unchanged in different sectors, and simply to achieve the decarbonization goals by minimizing the carbon emission across the value chain.

While most of the industrial sectors likely to adopt the circular practices such as 9R framework to contribute to a decarbonization targets, Velenturf & Purnell (2021,p.1443) argues that only aiming to reducing the emission can direct to “pseudo circular” practices, thermal waste to energy, which can direct to destroy the recyclable materials due to the release of the embodied carbon. Instead of that authors highlight “circular by design” framework which can optimize the overall value of the economic and material of the products lead to minimize the greenhouse gas emissions by up to 63% by the year 2050 through reuse, remanufacturing, and digital service models. By incorporating these principles into procurement and governance, supply chain management can contribute as a basic tool to assist decarbonization and in line with focus of industrial progress to achieve ecological stability in long run.

De Oliveira & Oliveira (2023) describes critical operational principles, saving natural capital from finite control of stock, resource optimization by circulating materials with the maximum utility, and enhancing process effectiveness by removing negative externalities. The main idea is to bridge the gap between strategies related to circularity and environmental performance through circular economic indicators.

Further, Anupama Sen (2021) explains that the existing decarbonization initiatives basically focus on energy efficiency and potential renewable energy which is clearly failed to provide solutions to the considerable portion of emissions created from the global supply chain operations. Below are the major insights relevance to supply chain decarbonization through circular economy principles:

In case of emission reduction for life cycles, circular economy focuses on reducing carbon emission in the value chain of the supply chain. This consists of longevity designing, replacing high emission resources with low emission ones, incorporate remanufacturing to minimize requirement for primary energy use and extra material production.

Renewal supply chain optimization – transform into renewable energy requires excess amount of minerals and metals, for instance, up to ten times excess metals than energy of fossil fuels. It minimizes the requirement for new resources and lowers the potential greenhouse emissions by incorporate circularity into the decommissioning phase by recycling wind and solar elements.

CE strategies have become supply chain and business models more innovative and competitive and make impressions on sharing platforms, industrial symbiosis network and product as a service, where the waste and by products of a one company become a input to another company, further reflect the closed loop nature of the process to become sustainable for the future (Benjamin T. Hazen et al., 2020).

2.1.2 Sustainable development and Circular Economy

The circular economy is well aligned with Triple Bottom Line (TBL) concept, which analyse and evaluate the performance in economic, environmental, and social dimensions (Jeurissen, 2000).

Economic dimension: From the circular business model, it creates new revenue generation and cost saving opportunities. Companies can do the recycling and identify models with service based and these waste streams can be monetised. With the adoption of CE practises, the additional raw materials need for the processes can be minimised due to the regeneration the material through circular economy and obtain the resilience on price of the resources needed against the high market price volatility in the raw materials (Islam et al., 2025b).

Environmental dimension: CE leads to reduce the greenhouse emission, minimise the waste generation and save the resources. Observation of the life cycle management on automotives shows that the remanufacturing of the components causes of reducing 60% of the CO_2 emissions compared with the manufacturing new parts, reflecting the benefit to the environment from the CE initiatives (Geissdoerfer et al., 2017b).

Social Dimension: CE practises allow to creation of the employment and development of the regions. The implementations of recycling, remanufacturing, and repair industries have provided more employment opportunities for the skilled workers, allow economies to develop locally and internationally while promoting sustainable consumption patterns (Valencia, 2023).

As a result, CE has become a strategic tool for the industries to achieve sustainability goals and targets. As per the figure 2, Policies and procedures related to CE not only promoting the sustainability but also the employment opportunities, innovations, and economic resilience, becoming a multi faced framework for achieving the sustainability (Falah et al., 2025).

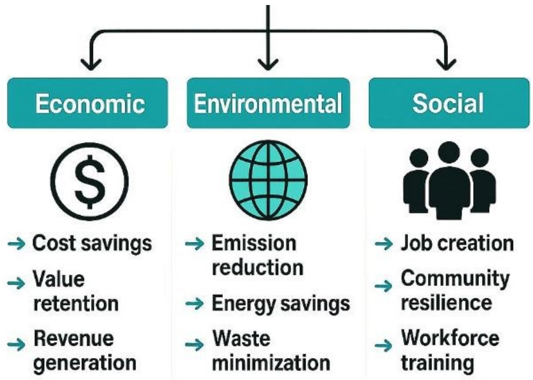

Figure 2. Triple Bottom Line (Sikder et al., 2025)

2.2 Circular Supply Chain Management

2.2.1 Traditional Supply chains and linear flow of resources

Since the traditional supply chain model operates in a take-make-dispose practise, where the material flow from source through production, distribution, consumption and disposal, Velenturf & Purnell (2021) explain as this model is extremely intensive of resource usage and not environmentally sustainable due to its dependency on finite resources and generation of high waste. Seuring & Müller (2008) argues that the supply chain is directly impacted to the environmental impacts from production, procurement, logistics transactions, which reflects the need of high attention for sustainable and circular alternatives.

But the linear model has been criticised with the time due to the inefficiency of resource and material utilisation and the bad impact to the environmental direct to unsustainability. Huge amount of waste dispose during the various phase of the supply chain specially in the post consumption stage, where the materials are discarded without estimate their remaining values (Geissdoerfer et al., 2017a). For example, the global electronics industry has created over 50 million tonnes of e waste annually, with the small amount of recycling (Ádám et al., 2021). In similar way, energy and construction industries tend to make considerable amount of waste due to the limited number of frameworks and mechanisms for material recycling and reuse (Rajesh et al., 2022).

With addition to the waste disposal, linear economy generates significant greenhouse gas emission and environmental degradation. Since the high energy needed for extraction of resources, manufacturing, and for the logistics activities, most of the fossil fuels are used to which happen to increase the greenhouse gas emission (Calzolari et al., 2021). These challenges related to the environmental has become a limitation of implement the linear model into the supply chain processes to incorporate long term sustainability.

To address these issues, scholars increasingly promote the necessity of transform towards to the circular supply chains (CSCs). Circular supply chain generates to design the traditional linear flow in to closed loop systems, where the materials and resources are cycling back to the closed loop system through reuse, recycle, and remanufacturing. This shift not only reduce environmental impacts but also enhance the resource efficiency and direct to economic resilience (Roy et al., 2022).

2.2.2 Concepts of circular supply chain

Circular supply chain management incorporates principles of circular economy in to supply chain activities by applying both forward and reverse flow of materials. Katsanakis et al. (2023) describes circular supply chain as a system that recover the resource through initiatives such as remanufacturing, reverse logistics, recycling, and product take back systems. These strategies assist dependency on the virgin material requirement while enhancing the efficiency of the resources in various phases in supply chain. But the integration of circular supply chain strategies is often considered as a challenge due to the proper coordination among stakeholders.

One another practise in the product take back programme where the consumers are getting back the used products through incentives such as discounts or deposit refund processes. These programmes are often conducted in automotive and electronics industries to enhance the material recovery rates (Kirchherr et al., 2023b).

Recycling and remanufacturing are also integral part to circular supply chains. Remanufacturing involves restoring the used product to almost new like products while recycling allows materials to prevent as a waste product. Both operations allow products and materials to reduce resource extraction and impacts to the environments (Ghisellini et al., 2016). In addition, the sustainability procurement practises are vital in CSCM practises where the companies tend to select the suppliers for the materials who are align and follow the sustainability practises to obtain environmental performance such as resource efficiency, reduction of emission, and compliance with company's sustainable initiatives. That make sure the sustainability practises are embraced into their own supply chain processes (Samantha Reynolds, 2024).

It is important to have high level of collaboration among stakeholders and information sharing for to successfully integrate the CSCs among various supply chain partners. The technological innovations such as Internet of thing (IoT), block chain and digital twins improve the transparency, coordination, and traceability in supply chain processes. These steps help to improve the real time data monitoring and help for managers to obtain data driven decision making in their supply chain processes and enhance the efficiency in circular supply chains (Zighan & Ruel, 2025).

2.3 Drivers and Barriers to Circular Supply Chain

2.3.1 Internal Drivers

Internal organisational factors play a major role when implementing a circular supply chain adoption and practises. One of the major factors is how the top management involvement in implementing resource allocation, prioritization of the strategies, and organisational culture since they have the leadership power which be influenced to make this strategic development within the company (Govindan & Hasanagic, 2018). Companies which the leadership are committed to sustainability more like to invest more on circular supply chains and integrate them in to long term strategic goals of the company.

One other factor is the organisational culture, especially the way sustainability is applied into their values and process of decision making. Organisations which are commit to integrate environmental responsibility and innovation is more like to implement the circular practises (Kirchherr et al., 2023b). Technological innovations are also playing a significant role, where the advanced tools such as smart inventory management, data analytics and product lifecycle management (PLM) system enable company to utilize the resource while enhancing the supply chain efficiency (Farooque et al., 2019). These technologies allow firms to offer better transparency on usage of the products, material flow, and generation of waste there by offering leads for circular practices. Further, companies need align the strategic objectives against the sustainability goals which assist to adapt circular supply chains. It is like to implement circular business models to their supply chain for the companies sees the economic benefit of efficiency of the resources and waste reduction (Laukkanen et al., 2026).

2.3.2 External Drivers

External factors also mainly influence to the circular supply chain practises. One of the keys is the involvement of the government towards circular practises and how they impose environmental policies and waste management initiatives. For an instance, European union imposes the regulations to enhance recycling rates, and minimising landfill waste, to encourage firms to adopt the circular initiatives (*European Environment Agency*, 2024). And the demand of the market and the awareness of the consumers are also equally important. As the consumers are environmentally conscious, then they willing to buy the product which are sustainable and produced in ethical way. This behaviour of the customers can put pressure on organisations and their production processes to become sustainable and implement more circular practises to cooperate with market and achieve the competitive advantage (Geissdoerfer et al., 2017a).

Pressure of the stakeholders such as investors, NGOs and regularity bodies also push the boundaries of the companies to demonstrate sustainable practises even to apply and obtain the quality management certificates such as ISO 14001 which support environmental management systems (Gerged et al., 2024). The innovation on technological level is also providing companies on leverage on integrating recycling, remanufacturing and recovery of the resources to be sustainable (Latip et al., 2022).

2.3.3 Obstacles to Circular Supply Chain Implementation

Even though the CSS has potential benefits, there are also some barriers to implement in the organisations. One main challenge is the high initial investment cost due to reverse logistics systems, infrastructure related to the recycling plants, and for advanced technologies (Farooque et al., 2019). These costs potentially discourage the firms specially the small and medium size enterprises from incorporating circular terminologies. And inadequate infrastructure for recovery of the materials and recycling. Most of the regions find it difficult to implement circular systems due to the logistical constraints (Kannan Govindan, 2018).

And the complication of supply chain coordination generates some issues. CSCs requires the collaboration between internal and external stakeholders such as suppliers, manufacturers, logistic parties, and consumers. Most of the time coordination work among these parties aften see a challenge to implement circular practises (Tahiri et al., 2025).

Eventually, the lack of knowledge and capability gaps among parties related to circular practises often a challenge for the firms which the expertise requires to design and implement the business models in line with sustainability as well as the metrics required to track and measure the performances (Kirchherr et al., 2023b).

To get of rid barriers, require combination of technological design and innovation, policy and procedures, and capacity development initiatives to focus on enhancing the capabilities and capacities across the supply chain management processes.

2.4 Decarbonisation in Energy Supply Chain Management

Decarbonisation can be defined as a methodical systematic reduction of the emission of greenhouse gases throughout the economic systems from effectively enhancement of low carbon technologies (Intergovernmental Panel On Climate Change (Ipcc), 2023). Emissions can be categorised into 3 scopes namely scope 1, scope 2 and scope 3 in supply chain, where scope 3 is the indirect emission across the value chain and considered to be the largest portion compared to other two scopes and contribute to larger portion of total emission (Hertwich & Wood, 2018). Mohsin et al. (2025b) further figure out that the activities such as procurement, logistics, and distribution are the key factors which contribute to the scope 3 emissions, which create the supply chain as one of the most critical process to manage in order to achieve decarbonization goals.

Supply chain activities play a critical role in decarbonisation, in relation to scope 3 emissions, which defines as an indirect emission from all the activities related to the upstream and downstream. Most of the industries responsible for releasing scope 3 emissions which contribute for majority of the total emissions, reflects the importance of involvement of supply chain (Mohsin et al., 2025a). Circular economy activities can allow industries to support for decarbonisation as it minimises the need of energy intensive materials extractions and production process. For instance, aluminium and steel needs low energy compared to making them from virgin resources compare with them being recycled (Mulvaney et al., 2021).

In related to the energy sector, circular initiatives such as wind turbine component recycling, repurposing batteries and material optimisation use in solar panels can minimise lifecycle emission and enhance the performance for sustainability (Abdirahman et al., 2025). These activities highlight the potentiality of circular supply chain to contribute to the decarbonisation.

Apart from the categorisation of the emission, current studies reflects that the supply chain decarbonisation needs combinations of operational, technological, and material efficiency tactics. International Energy Agency (2019) highlights that there is not only solution for the decarbonization, but reduction of emissions also needs the involvement of the total value chain, consist of improvements for energy efficiency, efficiency of the materials, and less carbon production systems. Strategies for material efficiency such as reuse, recycling, and life extension of the products have been identified as important mechanism to minimise the greenhouse gas emission in entire supply chain process. At the same time, it is important to consider the emission in the full value chain, since the scope 3 emissions are most of the time larger than the direct emissions and need coordination in the supply chain network (Hertwich & Wood, 2018). OECD (2021) further reflecting that the decarbonisation in supply chain consist of measures like low carbon procurement, convert to renewal energy sources, and logistics activity optimization and circular economy strategies to minimise the demand for the materials and thereby reduce the release of emission. Even though the theoretical frameworks have been discussed, the practical implementations specially the complicated sectors such as energy remains underexplored in the current literatures.

2.5 Circular Economy in the Energy Sector

The energy industry is extremely energy and material intensive where most of the time depend on the material extraction for technologies such as solar panels, wind turbines, and energy storage systems (*World Energy Outlook 2023 – Analysis*, 2023). Velenturf and

Purnell (2021) highlights the strategies of circular economy such as recovery of materials, recycling, and extension of life cycle can considerably reduce the environmental impacts in energy systems. Circular economy initiatives in the energy sector can be identified through few main strategies, inclusive of narrowing, slowing, and closing resource loops. The main focus to narrowing down the resource loops is to enhance the material efficiency in the energy production systems, especially the material optimisation in critical inputs in solar panels and batteries. Slowing resource loops indicates the extension of the life cycle energy assets from maintenance refurbishment. Repair for wind turbines and the energy storages. Resource loop closure influence on recycling and the recovery of the materials in the end of the life cycle of products enabling to recover and reintroduce the valuable resources such as copper, aluminium and silicon back to the production cycle (Mendoza et al., 2022).

The environmental implications can be minimised from the circular economy practises by promoting material recovery systems, recycling, and modular designs. For example, the wind turbine blades can turn and recycled in to construction materials, and the solar panels can be converted to recover the important and valuable components such as aluminium and silicone materials (Internationale Agentur für Erneuerbare Energien & Methanol Institute, 2021).

There are several challengers which act as a barrier to implement the circular economy practises in the energy sector. Technical challengers can be considered as a main factor where the recycling of complex material components such as turbine blades and lithium-ion batteries and parts. At the same time, the expensive nature of the recycling process than the usage of virgin materials which cause the challenge for economical perspective. In addition to that the lack of the policies and procedures in the regions limit the standardisation of implementation of circular activities. Further, the lack of transparency among the stakeholders and the complexity of the processes of the supply chain creates challenges leads to poor implementation of the circular economy activities in energy supply chain (International Energy Agency, 2019b; Salehi et al., 2024).

Circular supply chain also allows energy companies to utilize operations related to logistics and reduce the release of greenhouse gas emission associated with distribution and transportation activities. CSCs can support to achieve both environmental and economic targets, by enhancing the efficiency of the resources and reducing the waste (Salehi et al., 2024). Further, the digital technologies contribute heavily to achieving circular economy initiatives in energy sector. IoT, block chain technology and data analytics allow to monitor the real time energy assets, assisting predictive maintenance and enhancing product life cycles (Ries et al., 2026).

Circular economy activities plays a pivotal role to reduce the scope 3 carbon emission in relation with decarbonisation by reducing the need of energy intensive raw material sourcing and production processes (Hertwich & Wood, 2018). However, it is stated on the environmental impact reduction in the conceptual level for circular economy activities but limited empirical research studies on how to integrate within energy supply chain and obtain the measurable impacts on reduction of emissions in the current literature (Kirchherr, 2023). This gap can be identified in the case of energy supply chain where the implementation of the supply chain strategies and circular economy initiatives are underexplored (Velenturf & Purnell, 2021). Hence further research is needed to identify how the circular practises can impactfully help to achieve the supply chain decarbonisation in the energy sector (International Energy Agency, 2019b).

2.6 Research Gap and Synthesis

The past literature highlights that the circular economy theory and circular supply chain management contribute in significant manner improve sustainability by enhancing efficiency of the resources, reducing waste, and minimising the potential environmental impacts (Geissdoerfer et al., 2017a; Ghisellini et al., 2016). Circular terminologies such as remanufacturing, recycling and reverse logistics enables companies to transform from linear model to closed loop systems and contribute to the sustainable production and consumption (Farooque et al., 2019). But all though the literature shows the fragmentation with limited coordination between circular economy, supply chain management, and decarbonisation research studies.

The main gaps exist within the sectors and for the current studies. Most of the circular supply chain research studies focus on manufacturing industry while the energy sector has been underexplored, even though its critical role of global emission and sustainability transformation (Genovese et al., 2017). Further, research for the decarbonisation mainly focus on technological solutions mainly renewal energy, most of the time overlooking the supply chain initiatives, specially to provide solution for scope 3 emission which is indirect from the processes, contribute as a major share of the emission compared to other two emission types (Mohsin et al., 2025b).

Another key limitation is the lack of appropriate research studies and evidence connecting circular supply chain initiatives to measurable outcomes when it comes to economic and environmental outputs, as most of the research remain conceptual (Farooque et al., 2019). Additionally, the implementation of the digital technology to enable circular supply chain to remain emerging and new and most of the existing studies are insufficient (Abdelmounaim Aggour, 2025). Hence, the further research needs to be done to integrate circular initiatives, supply chain principles, and decarbonisation target, especially in the energy sector.

3 Research Methodology

3.1 Research Design and Approach

This research uses qualitative research design to explore how circular economy practices within supply chain management lead to decarbonisation effort in energy-based companies. The main reason for selecting qualitative method due to nature of the research problem which aim on explore complex company strategies and sustainability initiatives than calculating general relationship though statics and numerical data. Qualitative design is best when searching "how" and "why" questions in practical world scenarios where the variables are not easily isolated (Mubarik et al., 2025).

In the case of decarbonisation within the circular economy, supply chain initiatives are embraced in regulatory, institutional, and organisational sectors. These things are not fully standardised but are driven through stakeholder interventions, firm-based interpretation, and policy guidelines. Hence, qualitative methods provides deeper understanding to explore these dynamics, providing researcher to identify the meanings and frameworks related to circular economy practices in supply chain (Kirchherr, 2023).

In the case of energy-based companies, CE can be referred as the tactics focus to close the material and energy loops in line with the production of energy and the distribution networks. This consists of enhancing the efficiency of the resources in material usage and fuel, enhancing the lifecycles of the energy infrastructure like wind turbines, and the asset of the hydro power, incorporate with waste to energy implementations, and utilising sustainable procurement practises in SCM. It is not like conventional manufacturing based CE initiatives, circularity of the energy sector is strongly connected with longevity of the infrastructure, minimisation of emissions, and recovery of the resources in industrial processes and systems (Geissdoerfer et al., 2017a; Kirchherr, 2023).

This study demonstrates a perspective where the disclosures and reports related to each company were analysed and interpreted in a way to understand the sustainability practises rather than through purely objective measurements. From this framework, circular economy practices are not fully technical driven solutions but constructed by firms in a different manner based on the company strategies and institutional settings. For instance, terminologies such as circular procurement or resource efficiency might have different meanings in various organisational environments, especially in the context of energy-based companies where the operational complexity is considered as high (Finamore & Oltean-Dumbrava, 2024).

In line with this perspective, this research construct with interpretivist approach, aiming to understand how the firms construct and design circular economy values in the supply chain operation. This concept reflects the value, meaning, and subjective interpretation in the context of organisational research (Saunders & Bristow, 2023).

The approach of the research can be explained as primarily inductive, since it enables patterns and themes to emerge from the given data than exploring previously defined hypotheses (Thomas, 2003). At the same time research consists of abductive reasoning, as the theoretical foundations from the literature reviews are reviews constantly in terms of empirical findings. This methodology provides framework to strengthen the relationship between theory and practise make sure that the interpretation remains solid in term of both empirical evidence and conceptual framework (Dubois & Gadde, 2014).

3.2 Research Strategy: Multiple Case Study Design

Case study design strategy is used to operationalise the research objectives. This method is mostly used in qualitative studies to explore the unique phenomena in the practical world context, especially the territories to the research topic is not specifically defined (Annamalah, 2024). In this research supply chain management and circular economy is deeply aligned with the organisational structures, regulatory environments, and technological perspectives, enable case study method is the ideal way to analyse the selected topic.

To improve the analytical framework and enhance the robustness of the study, multiple case study is used. It provides holistic advantage to compare the cross-cases, lead to identify the recurring patterns and the differences in various organisations, unlike a single case study method (Eisenhardt & Graebner, 2007). This method enables to deeply analyse the case studies and explore the findings which derived from various empirical settings than a single study cases.

The research study focusses on four energy-based companies for the analysis:

- Fortum Oyj
- Pohjolan Voima Oyj
- Statkraft
- Enel Group

The reason for selecting these companies due to their active involvement is decarbonisation, sustainability initiatives, and the availability of in-depth public reports related to supply chain management and circular economy practises. Since the energy sector is prominent in this study as they contribute to release of larger portion of greenhouse gases to the environment, play a unique role in achieving decarbonisations initiatives (IEA, 2023).

Each company represent with their unique characteristics regard to energy sector while in different geographics and strategic priorities. The study has a unique advantage as the multinational companies represent in Nordics and Europe region where the exploration can be done in a various context specially in regulatory and institutionally. This unique characteristic improves the analytical value of the results providing comparison across various situations, offering more comprehensive and constructive depth in circular supply chain practises.

3.3 Data Collection Method

The study is based on secondary data sources as a main source of data collection. The appropriateness of the secondary data is valid as these big companies constantly used to publish ESG, sustainability reports, which offer in dept insights to their decarbonisation, environmental and supply chain strategies (Johnston, 2014).

The research used secondary data from the company's official disclosures and documents. The primary data sources were consisted of annual reports, ESG reports, sustainability reports and websites published in each energy sector company. Most of the time, ESG and sustainability data was mentioned in the annual reports and hence considered as a single document source. Table 1 shows the data sources used in the research study, consist of title of the document, source type and published year.

Table 1: Data sources by company

Organization	Source Name	Source Type	Year
Fortum	Annual Report 2024	Annual Report (including sustainability data)	2024
Fortum	Sustainability and ESG Information	Official Website	2025
Pohjolan Voima	Annual and Sustainability Report 2024	Annual/Sustainability Report	2024
Pohjolan Voima	Sustainability Webpages	Corporate Website	2025
Statkraft	Annual Report 2024	Annual Report	2024
Statkraft	Sustainability Reporting and Climate Strategy	Sustainability/ESG Report	2024
Statkraft	Corporate Sustainability Website	Corporate Website	2025
Enel	Annual Financial Report 2024	Annual Report	2024
Enel	Sustainability Report 2024	Sustainability Report	2024
Enel	Group Sustainability and Circular Economy Website	Corporate Website	2025

These sources are used based on the relevance and the significance of the research question, objectives, especially the aiming on circular economy practises, supply chain management initiatives, and emission minimisation strategies. The main source of data used in the study in combined with sustainability reports which are available in publicly. This includes of ESG reports, annual reports, and sustainability disclosures. At the same time company official websites are used to extract the data in relation with sustainability practises for all companies related to CE, procurement, sourcing, and decarbonisation strategies to support the study further. The main reason for select these sources because of the comprehensive and comparable information in SC, sustainability initiatives, efficiency of resources, and emission reduction activities across the chosen cases. Sustainability reports offer in depth information on how firms work on strategies to reduce the waste, resource efficiency, extension of the life cycle of the product, and the stakeholder management.

The secondary data has an advantage of reaching to wide range of data sources which might be difficult to obtain from primary sources when it comes to a time constraining factor in master thesis. At the same time the reports are generated in a standard framework, enables researcher to analyse and compare the data sources among selected companies (Pederson et al., 2020).

Also, the secondary data has defined limitations as the companies try to keep their reputation as a positive manner and as a result some of the challenges and failures, they face related to sustainability performances may not be reported directly to the reports (Pederson et al., 2020). The intention is to cross refer the closures among companies in multiple sources and analyse in different angles to address this limitation of the study.

3.4 Case Selection and Sampling Strategy

Case selection of this study is guided by the organisations where the circular economy strategies are actively integrated in supply chain processes thereby achieving decarbonisation goals. The study aims to collect observable and relevant data from the selected sources related to the research topic rather than random selection. This approach is solid when it comes to qualitative design where the cases are selected based on the possibility to create meaningful out put into the research problem (Patton, 2014). This analysis is especially ideal for energy sector since most of the firms are operated in immense pressure to minimise the emission related to supply chain in terms of direct and indirect. When it comes to supply chain activities such as procurement and logistics, leads to release more indirect emissions which is key to manage decarbonisations goals (IEA, 2023).

The selected companies are more into sustainability activities in relation to supply chain operation. These firms offer comprehensive sustainability and ESG reports which enable to identify the circular economy activities like material reuse, efficiency of the resources, lifecycle management and extension, and supplier management. These practises are required to identify how circular practises are embedded and operationalised in supply chain functions to minimise the impact to the environment. In order to develop the logic of the selection of cases, it is significant to define the unit of analysis of the research. The unit of analysis of this research can be defined as upstream and internal SC activities in the chosen energy-based companies. This is inclusive of sourcing processes, supplier relationship management, procurement of energy-based fuels and materials, logistics activities, managing lifecycles for the assets of the energy infrastructures. Consumer energy utilisation related to the downstream has been eliminated from the study since the aim is to concentrate on supply side CE initiatives that contribute to decarbonisation. Current studies reflects that the implementation of the circular economy activities within the supply chain function needed a connection between internal procedures and external parties, especially vendors, which highlight the significance of the selected firms which provide transparent and structured reports for analysis (Farooque et al., 2019), (Geissdoerfer et al., 2017a).

At the same time the selected companies provide significant geographical variation and the institutional context which improves the depth of the analytical aspect of the research. The Nordic based companies provide regulatory framework where they promote the sustainability initiatives related to circular economy practises while the multinational nature of Enel group expose to the diverse policy conditions. This combination provides the depth to the study and how external implications influence the integration to the circular practises with focus on the main research objectives. Such various selection of cases enables to perform the research consistently with qualitative research context as the different variations in the cases provide broader framework to understanding the patterns and the specific differences (Eisenhardt & Graebner, 2007). As the cases are limited to this kind, the focus is to create more analytical depth than analyse statistics which is the intention of the qualitative method.

3.5 Method of Data Analysis

The research study intent to use thematic content analysis to analyse the data collected. This approach is used widely to identify which involves identifying, analysing, and reporting patterns and themes in the textual data (Ahmed et al., 2025). Since the corporate reports are the main use of data collection, this method is ideal to identify the narratives and the descriptive information.

The method assists an interpretive direction to define how companies implement CE activities in SCM and how these efforts lead to decarbonisation contributions. In line with this approach, the research aims to explore the main terminologies and recurring patterns combined to resource efficiency, closed loop systems, sustainable procurement, and lifecycle management. The findings of this approach assist cross company evaluation bridge the findings with theoretical concepts of CE (Geissdoerfer et al., 2017a).

The selection of the thematic method due to its flexibility and relevance to the study which can analyse larger set of unstructured and raw qualitative data in order to create a structured framework to interpret data to understand the sustainability related initiatives across the companies.

3.6 Analysis Framework and Thematic coding Process

The analysis of the data for the study was done through thematic analysis, which is used commonly in relation to qualitative analysis to identify, explore, and interpret recurring patterns within raw data in the reports (Braun & Clarke, 2006). The selection for thematic analysis for this study is ideal since the study aim to explore how CE practises are integrated into SCM to contribute to decarbonisation related to energy companies. The process of the analysis is done in a methodical way using Braun and Clarke (2006) for thematic analysis. In the first stage, the annual reports, ESG, sustainability reports, and policy disclosures are carefully read and understand few times to familiarise with the data. The first observation in relation with CE, SCM and decarbonizations practises are recorded in this phase. In phase two, specific sections of the raw data were coded in line with the recurrent theories and insightful patterns. The aim of this phase is to explore the references connection with supplier management, sustainable procurement, efficiency of the resources, lifecycle extension, recycling patterns, reverse logistics, carbon emission minimisations, and closed loop material systems (Geissdoerfer et al., 2017a). In third phase, the intention is to make group of the similar codes into wider categories and preliminary themes. For instance, under resource efficiency and circular SC initiatives, models in line with recycling, reuse, and life cycle extension were grouped and vendor related practises and sustainable procurement activities categorise under sustainable SCM themes (Seuring & Müller, 2008).

In the case of fourth and fifth phases, the themes which recognised were reviewed, refined and compare with the chosen companies to make sure that they are align with research objectives yet consistent and relevant. The analytical approach is based on differences and the similarities of the company strategies how CE initiatives are embedded into their SCM activities contribute to decarbonisation. At the end, the themes were analysed and interpreted in line with theoretical framework of CE, SCM and decarbonisation. This enables research to further analyse the role of CE which impact to reduce the emission to achieve sustainability transformation in energy sector (Kirchherr, 2023).

3.7 Case company Overview

This sector highlights the brief of the selected case companies of the study, Fortum Oyj, Pohjolan Voima Oyj, Statkraft, and Enel Group. These firms operate in an energy sector and the reason for specifically choosing these organizations is because of their active interaction in the sustainability aspect and in relation to circular economy initiatives, supply chain management, and decarbonization performances. The intention of this sector is to highlight the company brief and background and the operational environment they are focusing on their business and how the circular principles are embedded to their supply chain process to achieve the decarbonization targets.

Fortum Oyj is an energy company based in Finland aim to produce clean energy, inclusive of sources of renewal energy like solar, hydro, and wind power. Speciality of this company is that they are more in to promote resource efficiency and circular solutions in waste to energy and recovery of the materials. The company demand to have the carbon neutrality and sustainable value creation while put more emphasis to align the supply chain activities into the environmental and climate goals (Fortum,2024).

Pohjolan Voima Oyj (PVO) is a finished-based energy company which generates heat and electricity at the cost price for their stakeholders, from hydro power, bioenergy, and nuclear power. The significant of this company is the generation of low carbon energy and it is one of the most key companies in the finish energy sector. The company is always concerned about environmental implications and high resource efficiency which highlight in company's supply chain reporting (pohjolan_voima, 2024).

Statkraft is a Norwegian public own company and one of the Europe's biggest renewal energy producers. The key activities involved in the company are generating wind power, hydro power, and solar energy. Companies value sustainability, mitigation of climate change and the responsible player of their own supply chain activities. The company makes tremendous efforts to actively reduce carbon emissions not only in their operation but also in the value chain of the company, making the company one of the best companies for the research study to gather data (Statkraft, 2024).

Enel Group is one of the biggest energy companies based in Italy and presence over 30 countries. The company stands out as the global leader in renewal energy and prioritizes the decarbonization and circular practices activities in their operation. The company in cooperate the sustainability to its business model, inclusive of supply chain management, by highlighting usage of circular resources, emission reduction and innovation across its global operation (Enel,2024).

Altogether, these companies offer different sets of cases highlighting various organizational scales, various business models, and geographical diversity. This combination provides comprehensive analysis of the way circular economy activities are embedded in to supply chain to contribute to decarbonization in the energy sector mentioned in table 2.

Table 2 : Overview of selected companies

Company	Country	Core Activities	Sustainability Focus	Relevance to Study
Fortum Oyj	Finland	Renewable energy, waste-to-energy, energy services	Carbon neutrality, resource efficiency, circular solutions	Strong focus on circular economy and supply chain sustainability
Pohjolan Voima Oyj	Finland	Hydropower, nuclear power, bioenergy	Efficient resource use, low-carbon energy production	Relevant for analyzing cost-efficient and low-emission supply chains
Statkraft	Norway	Hydropower, wind, solar energy	Renewable energy expansion, emission reduction, responsible sourcing	Emphasis on supply chain decarbonization and sustainability
Enel Group	Italy (Global)	Renewable energy, electricity distribution	Circular economy integration, innovation, global decarbonization	Provides global perspective on circular supply chains

3.8 Reliability and Validity of the Research

It is important to make sure to main the reliability and the validity of the research to contain the trustworthiness of the research findings. In this case, explore the role of circular economy practises in supply chain supporting decarbonisation, each element is address in a transparent and methodical manner in the research process. Validity can be identified as for the extend that the information extracted from the reports and disclosures accurately to analyse the theories which aim to explore, reliability refers to the consistent way that the research flows with the procedures and the possibility to replicate the study (Erdal Arslan, 2025). As the study is simply based on the qualitative method using corporate data, special focus is given to the concepts and procedures each company incorporate related to circular economy practises, supply chain initiatives and the decarbonisation efforts to reduce the emission and strategies they embedded into their process throughout the research.

To improve the validity of the research, multiple sources are used specially the sustainability reports, ESG reports and corporate documents, which offers extensive data for the study and the practises of each firm follow. These sources validates that the data triangulation, which enables to minimise the risk of bias and improve the research accuracy of the findings (Handan Akkas, 2024). At the same time, the cross cases are analysed in structured way using themes related to circular economy and decarbonisation while this allows the interpretations are solidly articulated from the data than assumptions. Even though the corporate disclosures might give a bias view of the performance of the sustainability for each firm, analysis is based to remove the over reliance on the reported data from each company (Olivier Boiral, 2013).

Reliability of the study is maintained in each phase of the study offering transparency and recording data accordingly. To continue the case selection, data collection, performing thematic analysis in a consistent way, the research aims to improve the reproducibility of the finding. Since the qualitative approach does not offer any statistical data, multiple cross case comparison enables to provide analytical element to the research, enabling to offer similar context in relation to energy sector (Eisenhardt & Graebner, 2007). All in all, the presence of having multiple data sources, methodical analysis, and transparent methos provide to improve the credibility of the findings of the research.

3.9 AI Declaration

This study has been aiding with AI assistance to help language clarify and structures. Use of AI was limited to improving the clarify of the sentences, grammar and coherence and the text formatting. At the same time AI tool has not been used to create the original ides of the research, data collection and interpretation, and the conclusion of the research study. All the main aspects of the research such as research problems, literature review, methodology, data analysis, cross case selection, are output of the author's work. All the sources used and cited in the paper have been done in accordance with the university writing guidelines and carefully vetted to remove any possible AI to improve the accuracy, originality and the relevance and take full responsible to the generated texts in this paper.

3.10 Limitation of the Methodology

The one key limitation is the rely on publicly available data for the analysis and make the assessment of circular economy initiatives within the supply chain management function. Even though these references provide a structured insights to their sustainability practices, they often reflect their strategic position rather than showcasing the actual reality. In the light of decarbonisation, firms may disclose the initiatives they take for sustainability and reduction of emission or resource efficiency without completely showcasing the possible challenges they come across specially the underperformance sectors. This may produce a gap between actual and the reported to the public for references specially in the supply chain function where the lack of visibility across the various tiers in the processes (Mora-Contreras et al., 2023).

Second limitation can be identified as the complexity to identify the actual depth and the complexity of the practises related to circular economy and circular supply chain from the aid of document-based interpretation only. The implementation of circular economy practises is always involving in the interaction between vendors, technological aspects and the regulatory bodies which is often not reported in the disclosures. Because of this, aspects such as supplier related constraints, risk of operation level, or the cost factors related to the circular economy can be not explored properly. This is always case in the energy sector as the supply chain operations are complex and significant, which is find it difficult to assess in terms of statistics how the circular practises convert into de-carbonisation outcomes (Olivier Boiral, 2013).

Further limitation can be identified as the selected firms run in an environment where the sustainability operations and circular economy practises are complex and diversified in terms of policy making which might not reported accurately. Further, the information obtain from this research might highlight terms which are not completely report in all regions or sectors. At the same time the research finding help to understand how the circular practises are contributed to support decarbonisation goals in relation to energy supply chain (Schaltegger & Burritt, 2017).

4 Analysis and Findings of the Research

This chapter presents the empirical findings and the analysis of the research, concentrating on how circular activities in the supply chain function contribute to decarbonisation in the energy-based companies. As the previous sections explained about the introduction, literature review and the methodology, this chapter aim to highlight the qualitative analysis to create a meaningful output. In the case of qualitative approach, it is important for the analysis to be focused on the qualitative evidence and the cross-company themes and patterns in relation to real world context, especially when explore complicated and context dependent theories such as sustainability initiatives

The focus of the analysis is identified how the company reports related to sustainability initiatives are converted into SC functions to reach decarbonisation targets. The way companies are aimed to achieve their expected resource efficiency, material utilisation, and lifecycle management in the operational functions is paramount rather than discussing on theoretical aspects. This analysis identifies how the companies are practically co-operating with sustainability principles in the real-world operation than conceptual models alone. Since the energy sector supply chain generates most of the emission and directly impact to the environment, it is important to explore the insights how firms are address the indirect emissions and the way they utilise the raw materials and resources across their value chain

To make sure that the results are transparent and ethical, the findings are presented in key analytical themes by using the coding process. It is necessary to identify the recurring patterns and perform the cross-company analysis from the selected energy companies from the use of thematic analysis. The tables, visual graphs enable to further clarify the analysis process and provide comprehensive evaluation in terms of similarities and differences how CE practises in SC function linked to decarbonisation outputs. This method reflects that the chapter provides evidence-based information to the reader while not deviating on the research objectives.

4.1 Framework for Thematic Data Analysis

The analysis related to this section is systematic thematic coding analysis approach which were applied to ESG, sustainability, annual reports for each company. This method enables to explore the recurring patterns and themes and interpretation on how CE in SCM contribute to decarbonisation.

Table 3 represents examples of thematic coding analysis done in relation with four case companies.

Table 3 : Example of Thematic Coding Process

Organization	Data Extract	Initial Code	Thematic category	Theme
Fortum	Waste-to-energy solutions	reuse	resource efficiency	Circular Economy
Enel	Supplier sustainability requirements	Supplier control	procurement strategy	SCM
Statkraft	Renewable energy efficiency	efficiency	operational sustainability	Decarbonization
PVO	Long asset lifecycle	durability	lifecycle management	Circular Economy

For instance, Fortum reflects the process of waste to energy and recovery of the materials which are considered as a main part of company's sustainability and CE strategy. Fortum utilized the non-recyclable waste to energy and metal recovery and other important materials from combustion residues. Further, the company highlights considerable volumes through the company's waste to energy section while aiming on ash treatment and recovery of metals in order to create a closed looped material unit and minimize the landfill (Fortum,2024.pp.62-68). Further the company's sustainability strategies highlight the importance of circular solutions, material recovery, and the proper utilizations of industrial by products in their operation. As mentioned, in table 2, under the initial code, the sustainability initiatives were recognized as the Fortum's waste to energy concept aims on regenerating value from the waste materials rather than direct disposal. These terminologies were categorized into thematic category "resource efficiency" which address the deeper sustainability initiatives to management of resources and efficient waste management (Fortum, 2024). Further, company has been able to strengthen the circular battery economy process. From recycling, the application of both mechanical and hydrometallurgical systems in company's Harjavalta center to recover considerable percentage of valuable battery components. This enable company to recover almost 95% of the metals such as cobalt, nickel, and lithium which can be reuse in new production of batteries which enables to create a closed loop system in relation to energy value chain (Fortum, 2024).

At the same time, Enel focuses on sustainability of the suppliers as a strong benchmark. The company intentionally embedded ESG criteria to the supplier selection, evaluation, and monitoring. Suppliers are selected based on comprehensive assessment in technical, economical, human rights, safety, and environmental dimensions. Company further supports the outstanding performance from "sustainability Ks" which is awarding system in tender processes, enables suppliers to provide recognition reaching traceability of the materials, circular design, water reduction methods, carbon footprint engagement and sustainable sourcing of main and important raw materials (Enel,2024). Further, company actively reflect the important of CE in procurrent activities incorporating special circularity requirements in the company tendering activities by having vendor development programs to contribute to sustainable future and company value chain (Enel,2024, pp. 89-94). This extraction initially coded as "supplier control" and categorized under thematic category "procurement strategy" connect to broader SCM.

The Statkraft reporting strongly reflects the efficiency of renewal energy and improves the operational elements. The utilization of its resources, especially assets for hydro power, which act as a prominent player which balances the renewal of production through wind and solar. The company' extensive energy management and optimization of markets allow company to achieve high rates of utilization while controlling greenhouse gas emission in lower level (Statkraft,2024). In the year 2024, company recorded low greenhouse gas emission power generation intensity at 14.8 g CO_2eq/kWh, which is considerably low than the company strategic target levels stay under 20g CO_2eq/kWh through 2030. This achievements are mainly driven by the company's operational performance in the hydropower section and enhancement of efficiencies in company renewal energy portfolio (Statkraft, 2024). The initial code set as "efficiency" and categorized under "operational sustainability", contributes to decarbonization.

PVO considered the strategy as a long operational lifespan of assets related to energy creation. The company consists of 18 power plants and aims to perform methodical asset control from long term planning and investments, measuring repairs, and maintenance to improve the service level life of the nuclear, hydro power, and bioenergy sources. This produces high utilization rates and less generation of the carbon energy over the long period of time (pohjolan_voima, 2024). The company exclusive reflects the efficient measures for maintenance, timely investments, and enhance the lifecycle of their power plants to improve the value of the production assets and resource efficiency improvements (pohjolan_voima, 2024,pp. 38-42). For instance, the use of new regulators for the turbines and ultracapacitors which minimize the mechanical stress and improve the service life of the power plants. As per the analysis, Initial code was considering as "durability" and kept under the thematic category "life cycle management" link to the CE.

The significant of this coding patterns lie in its potential to showcase the interrelationship between of the three main element of the study, CE, SCM and decarbonization. These elements are not independent and link altogether, this method highlights how the various firms are contributing to sustainability framework in different ways. For instance, supplier management is not only considered as a supply chain activity but it is also a mechanism to minimize the indirect emissions by monitoring their activities to produce the raw materials in a sustainable manner, while management of the life cycle is a way of reduce the emission in a long run due to the efficiency of the resource usages. This indicates that the sustainability efforts need long term comprehensive understanding of the system level approach than individual solution for each supply chain function.

Further, applying coding system to all four companies direct to perform the cross-company comparison related to the research analysis. It is essential to use the same analytical categories for all the four companies to explore the differences in incorporating sustainability approaches towards their decarbonization goals. This step enables us to identify not only the sustainability activities within the company but also how it truly impacts the decarbonization goals in each company, which is relevant to the research problem as well. The coding approach offers structured framework for further analysis, providing research to methodically identify how the various methods in circular supply chain management contribute to sustainability measurements.

The credibility and the transparency of the study have enhanced by using thematic analytical method. The way the data has been articulated, categorized and documented, enables how the findings have grounded using empirical evidence than subjective assumptions. When it comes to reviewing the publicly available disclosures, it is important as the data reported may be selective in favor of the company standards. The coding approach assists with performing standardization interpretation and keeping the logical nature from start to end of the study.

All in all, the thematic coding approach enables us to bridge the objective of the research to empirical findings. This helps to transit the raw qualitative data into meaningful insights, exploring interrelationship between theories and concepts and offers a comprehensive evaluation of how CE practices in SCM contribute to decarbonization in relation to energy companies.

4.2 Circular Economy Practices in Energy Supply Chain Management

This topic discusses how circular economy activities in supply chain function related to the broad spectrum of decarbonization in selected energy companies. The study is not only focus on CE initiatives in the companies but also explore how these practices inline into SC functions such as sourcing of materials, procurement, lifecycle extensions, and vendor-based sustainability initiatives based on the data available in the ESG, sustainable, and annual reports. This can be crucial in the case of energy sector as the operations require high resource intensity and assets life cycles are long which make both opportunities and challenges in relation to circularity.

The findings highlight the CE initiatives in relation to energy SC are basically aim on optimization of the resources and extensions of the life cycles than the recycling of the products. These activities are inherently connection with supply chain activities such as purchasing, material management, and optimization of assets, creating supply chain an important enabler for circularity. As per the findings of the study, circular SC initiatives enhance the efficiency of the resources and minimise the emission across company value chain network.

The below data extracted based on the reports and disclosures of selected companies in relation to their qualitative interpretation and sustainability strategies. The denotions of high, medium, and low has been used as an analytical indicators in order to explore the relative demonstration of each company's sustainable SCM practises, and decarbonisation activities in each organisation. The classification of high, medium and low mentioned in Table 4 was created from thematic qualitative analysis of sustainability, annual, ESG, and other policy documents for selected companies. The analysis shows the clarity of the CE activities were defined and the level of degree which they integrated into function and whether the practices are in line with decarbonization strategies. A "high" is defined as the company's strong and concrete evidence CE application in SCM function. For instance, the Fortum's waste to energy system and material recover process and recovering of materials which can be reused, reflects the closed loop system for materials management in the SC (Fortum,2024, pp.36-39). Also, Enel reflects the circular procurement initiatives, sustainability of the suppliers, lifecycle development link to wider decarbonization strategies (Enel, 2024,pp.78-84).

Medium classification demonstrates that the CE activities are visible but have less integration towards SCM. For example, Statkraft reflects the efficiency of the resources and asset management initiatives in renewable energy section but offers less evidences of complex circular systems like material recovery through closed looped systems or comprehensive circular sourcing programs (Statkraft, 2024,pp.52-56). Further, the classification is considered as low reflects that the very limited CE activities are involved in the company operations PVO is focus on renewal energy solutions and generate low carbon energy but little emphasis on material reuse, life cycle management comparison to the other companies (pohjolan_voima, 2024, pp. 18-22). Hence these categorizations highlight the visibility, tactical integration, and operationalized efficiency integrate to CE practice in each company.

Table 4 : Circular Economy Practices Across Companies

CE Practice	Fortum	PVO	Statkraft	Enel
Material Reuse	High	Low	Medium	High
Waste-to-Energy	High	Low	Low	Medium
Lifecycle Management	High	Medium	High	High
Resource Efficiency	High	High	High	High

As per the above chart, the companies are more into resource efficiency which highlights it as a foundational element related to sustainability in the energy sector. Also, the chart shows the slight variation in the functions of material reuse and waste to energy systems which considered to be more advanced circular initiatives. This phenomenon is crucial when addressing the research objective, as it reflects variations in how the firms process beyond complex circular economy models.

Fortum Oyj reflects high standard of circular economy implementation in relation to their supply chain processes, especially in material recovery processes and waste to energy solutions (Fortum, 2024). These activities demonstrate the way waste streams can be converted into inputs, significantly creating closed resource loops within the supply chain operation. This initiative minimizes emission in relation to disposal of waste and virgin material extraction, hence in cooperation with lower carbon emission related to decarbonization efforts.

At the same time Enel group's contribution is to circular economy approaches is significant in a different way more in strategic and methodical nature as the circularity principles are integrated into to supply chain operation as well as the innovation and design phases. This consists of material reuse strategy, optimization of the supply chain infrastructure and life cycle management (Enel,2024).This move highlights the companies shift from efficiency in the operation towards systematic circular transformation, as the emission minimization plans and sustainability decisions are aligned with supply chain implementations (Geissdoerfer et al., 2017a).

When it comes to Pohjolan Voima Oyj, it indicates the limitation of circular supply chain activities in their supply chains. Even though company works on resource efficiency and the low carbon energy production, there is less emphasis on organized circular efforts such as reuse and closed loop processes. This reflects even the one function related to efficiency may not fully work within the company set up to achieve decarbonization goals than not considering other functions related circularity such as material reuse and waste to energy (*Pohjolan Voima - Annual Report*, 2024).

Statkraft remains at an intermediate level where the CE activities are demonstrated but not fully up to the industry standards and broader level. The company fully focuses on operational efficiency and renewal energy which indirectly helps to reduce the emission and resource usage. However, it is visible that the proper supply chain strategies are missing and have implicit nature than proactive approach toward circularity practices (Statkraft, 2024).

From the analytical point of view, the findings demonstrate deep insight relate to the study where the circular economy process adaptation in supply chain function varies in significant manner and this differentiation led to the degree where each company considers their contribution to decarbonization in different ways. Companies which use advanced technologies to achieve material reuse and waste optimization stand in a better position than the other companies when it comes to targeting decarbonization goals. The reason for this is that circularity practices enhance the efficiency of resources while making environmental impacts intact with upstream and downstream, which are always neglected in conventional sustainability methods.

Further, findings demonstrate how the circular economy activities are aligned with supply chain management and cannot be separated from each other in the company's whole operation. This analysis shows that CE practices are highly effective when they are implemented with supply chain systems such as procurement, sourcing of the materials, lifecycle management, in relation to research objective as well. This implementation assists companies to incorporate sustainability not only within the internal environment but with external parties to achieve decarbonization.

Overall, this analysis shows that all companies demonstrate some sort of circularity activities, but the strategic alignment towards the implementation differs each other. These variation offers an opportunity to further analyses the similar sections, specially to understand how SCM contribute to create the effectiveness of CE in relation to decarbonization.

4.3 Sustainable Supply Chain Management Practices

Findings of the study reflect that SCM has directly impact on the integration of CE initiatives in energy-based organizations. In case of this study, SCM is not a supporting function at all but is a main driver which creates CE initiatives into procurement, sourcing, and supplier relationship management as this is directly relevant to the research problem. Knowing that emissions originate from upstream and downstream activities in a certain proposition, the total decarbonization effectiveness in the company depends on how circular economy and supply chain activities are align with the sustainability goals of the company.

The energy companies utilize intense energy sources which interfere with multiple stakeholders internally and externally, in production, logistics and development of the infrastructure. Because of that, procurement, supplier engagement, and flows of the materials are significantly influenced by the degree that the company is aligned with sustainability practices through the value chain. It is important to monitor suppliers' sustainability practices and their adherence to material efficiency, sustainable procurement, and waste elimination to integrate CE practices into SCM functions in organizations. This confirms that the firms are not only integrating sustainability activities on their own but external stakeholders' contribution to these practices as well, considering all the parties lie on a chain of networks regardless of which party contributes to release of emission to the environment.

The initiatives mentioned in Table 5 have been explored through thematic analysis of sustainability reports, ESG disclosures, annual reports, and corporate disclosures reported by each company publicly. The selected functions such as sustainable procurement, supplier management, and circular SC implementation were articulated based on the recurring themes recognized in the coding stage in line with CE implementation, supplier engagement, sustainability governance, procurement tactics, and lifecycle-based SC practices (Miles et al., 2014).

Table 5 : Supply Chain Sustainability Comparison

SCM Function	**Fortum**	**PVO**	**Statkraft**	**Enel**
Sustainable Procurement	High	Medium	High	Very High
Supplier Management	High	Low	Medium	High
Circular SC Implementation	High	Low	Medium	High

The above classification of “very high” demonstrate the company’s strategically strong and comprehensive sustainability initiatives incorporated in their SC operation with high level of supplier management and CE integrations. “high” reflects the considerable amount of sustainability practices and alignment of sustainability to the procurement function and SCM. “medium” indicates moderate operations with partial implementation of sustainability practices, and “low” reflects the less visibility or poor evidences operationalized sustainable SC initiatives in the public reports (Miles et al., 2014).

As per above chart, there are variations as to how companies are integrated sustainability supply chain practices into their businesses, showcasing significant level of alignments to the CE, SCM and decarbonization implementations. Enel and Fortum showcase a higher level of integration as the sustainability procurement tactics are embedded into environmental goals. The high degree involvement of supplier management and circular supply chain integration demonstrates a proactive approach which goes beyond the conventional cost-based procurement strategies. Instead of that, decision making processes are always in line with sustainability initiatives which enable the companies to enhance the CE practices in internal processes to contribute to decarbonation (Enel,2024; Fortum, 2024).

Enel’s procurement and sustainability reports demonstrates that the ESG parameter has been incorporated in supplier evaluation and selection stages and this shows the sustainability consideration in the procurement function lead to decision making (Enel,2024). This makes sure they do not deviate from environmental performance throughout their processes and contributes to reduction of scope 3 emissions which is considered as the biggest emission player in the energy sector. At the same time, Enel always benchmarks the innovation and creativity among their suppliers, and which motivates them to come up with practices which help to contribute to the environment in a positive manner such as innovations with reference to material reuse systems and life cycle extensions (Enel,2024). Also, Fortum makes sure to get sustainability involved into their procurement and supplier engagement activities to enhance the sustainability supply chain activities beyond the existing process. As a result, they were able to extend and upscale the CE initiatives using closed looped material reuse systems and eliminating waste in their production to support decarbonization (Fortum, 2024).

In contrast, Pohjolan Voima Oyj demonstrate limited number of activities towards supply chain implementation. The low supplier engagement allows companies to limit to contribute for CE operations within the internal operations which lead to involve in moderate sustainable procurement while limited contribution to the indirect emission through upstream activities (pohjolan_voima, 2024). Statkraft lies in an intermediate position as the main functions can be identified as compliances and sustainable sourcing to contribute to sustainability. Even though this is considered towards environmental standards, companies need to evolve in their implementation of strategic thinking towards circular transformation (Statkraft, 2024,). When considering the findings of this section, to effectively achieve CE practices to lead to decarbonization, it is required to integrate solid sustainable supply chain integration plans to the company values and operations. Companies who involve suppliers in their sustainability supply chain plans and CE practices always stand much better positions to integrate circular solutions and thereby reduce the emission in the company value chain.

4.4 Circular Economy and Decarbonation Linkages

The correlation between CE and decarbonization is considered as a systemic linkage than two various sustainable concepts. To obtain net zero carbon emissions, the systematic transformation required in an energy source and the material systems across the global value chain. From this analysis it demonstrates that considerable amount of portion of emissions released from the SC practices related to upstream such as logistics and extraction of the materials.

The model of CE and decarbonization defines this concept as a cascading system where the downstream emissions can be reduced in the early part in the lifecycle stage with the involvement of circular activities from less material demand, minimized intensity for production, and reduced end of life.

4.4.1 Energy Centric Decarbonization and Beyond: The Hidden Carbon Dimension

Traditional decarbonization strategies aligned with scope 1 and scope 2 emission types, which is straight forward and visible while directly connect to energy consumption. But, as per the global commission assessments, indirect emission or scope 3 emission contributes more than 70% of total emission in line with the supply chain operations in most of the sectors (Hertwich & Wood, 2018).

These emissions are generated from:

- Raw material processing and extraction
- Industrial infrastructure manufacturing (Turbines, equipment, grids)
- Transport and logistics activities.
- End of Life (EOL) functions of industrial equipment

As per the International Energy Agency, material production and heavy industry accounts for large portion of CO_2 emissions globally, especially from the industries such as cement, steel, and production of chemicals.

For example, when it comes to waste to energy processes such as which are integrated by Fortum highlights how residual waste can be transformed into energy factors thereby minimizing the methane emission relevant to landfill and the requirement of fossil fuel (Fortum, 2024). Also, Enel’s decarbonization strategy is driven by the suppliers and embedded in their procurement strategy and control the emissions in upstream by in cooperating sustainability initiatives to their supplier selection criteria (Enel,2024). When it comes to Statkraft and PVO, decarbonization concepts are not fully in line with their operation, but they manage to reduce operational emission for some extend but need to focus on reducing upstream emissions in the case of material supply chains.

4.4.2 Circular Economy as a Carbon Removal Strategy

The research evidence that the CE activities minimize the emission by declining the demand of the material requirement and enhancing the life cycles of the assets (Fortum, 2025).This difference is reflected on sustainability, as avoidance is articulated as a prevention prior to occur, than reducing current sources of emission.

This generated through below three main mechanisms:

- Recycling of materials: The recycling of the materials in relation with energy sector involves materials such as steel, copper, and aluminium as a waste from the Operations and infrastructure decommissioning, which have been reprocessed and reused in the systems for new production of energy and distribution, allows to reduce the requirement of virgin materials sourcing and therby reduce the generation of carbon emissions.

- Life cycle extension of the products: This refers to extending the operational life of the energy infrastructure like transformers, turbines, and equipment related to grids through upgrading of the components, refurbish, and maintenance, as a result minimizing the requirement for new manufacturing cycles and related emissions.

- Waste valorizations: Prevention of methane emission from decomposition of landfill while controlling energy generation from fossil fuels.

The study interprets that the CE activities impact considerably to the emission reduction in complex and heavy industries like energy.

Fortum's emission minimization and avoidance mechanism highlights from the integration of waste to energy concept while Enel's circular strategy related with procurement defines on reduction of emission towards upstream from design and integration of suppliers. PVO and Statkraft are effective with the usage of renewal energy and operate under framework design for decarbonization.

4.4.3 Role of SCM in emission reduction

SCM consider as the operational backbone which CE principles are converted into countable decarbonization outputs.

i. Sustainable procurement and emission reduction

The decisions of the procurement directly impact to the environment in line with selection of the suppliers, sourcing of materials, and sustainability requirements and major player to minimize the scope 3 indirect emission in energy organizations and decarbonization efforts can reduce scope 3 carbon emission by 15-40% in organization in industrial sector as the sustainability processes are fully utilized.

Enel has been able to implement sustainability strategies in supplier selection processes, take the responsibility to minimize the carbon emission in the upstream. Fortum implements sustainable and circular methods to sourcing principles that create to have closed loop flow of materials.

ii. Supplier networks and impact of emissions

Network of the supplier functions directly impact to the degree of emission generated in SC based on the sustainability strategies incorporated and monitored. the Enel's governance of the suppliers are highly standardized and align with ESG functions and carbon reduction criteria are integrated into procurement function (Enel,2024). This allows companies to contributor to decarbonization efforts in upstream, corporate for emission related to direct and indirect. Even though the Fortum's waste to energy and CE practices are collaborated with supplier networks, the supplier governance across supply chain process is considered to be uneven which reflects the partially integrated framework (Fortum, 2024). Statkraft operates in a limited supplier coordination, focus is mainly of sourcing of energy infrastructure, that indicates the less ability to contribute to upstream emissions, though less operational emissions (Statkraft, 2024). PVO demonstrates the weakest supplier network and governance where minimal contribution to the upstream supply chain contributed to bigger scope 3 emission which is not controlled properly. The comparison reflects the between coordination with the supplier network and governance help companies to contribute to decarbonization in a better way, transformation into passive emission into active minimization framework (*Pohjolan Voima - Annual Report*, 2024).

iii. Lifecycle management and emission reduction

The emission can be minimized by improving the lifecycle of the equipment and related infrastructures through minimizing the requirement of the extra materials to the manufacturing processes and production of the materials. In the case of Fortum, the company uses recycling methods and reduces the emission relation to disposal while incorporating life cycle thinking through waste to energy processes and resource efficiency to their supply chain operations (Fortum, 2024). Enel uses recycles, refurbishment, and designs supports circularity into procurement and planning of infrastructure, leading to supply chain decarbonization (Enel,2024). While other two companies are limited in lifecycle thinking and more into operational energy, enables them to work in a limited ground to minimize the emission related to materials (*Pohjolan Voima - Annual Report*, 2024; Statkraft, 2024).

4.4.4 CE-Decarbonization integration through maturity levels

When it comes to identify the CE-decarbonization maturity levels of the selected companies, it showcases clear understanding of how the companies integrate circular practices to reduce the carbon emission in systematic way. This refers to the degree in which CE activities are embedded in SCM in a strategic manner to contribute to emission minimization in longer run and achieve sustainability targets. Companies which are having a stronger implementation of sustainability practices such as life cycle management, sustainable procurement, resource utilization, and supplier engagement are more mature to achieve decarbonization targets. As PVO has limited ability to reduce carbon emission related to scope 3 and the focus is on the creation of renewal energy and operational efficiency and less use of CE practices in their operation (*Pohjolan Voima - Annual Report*, 2024). Even though Statkraft operates with renewable energy integration along with efficiency enhancements, yet unable to meet required level of circularity practices in their supply chains and operates in moderate sustainable levels (Statkraft, 2024). Fortum showcases well defined circular practices by integrating waste to energy systems material recovery frameworks into their main activities, in connection to circularity to emission reduction (Fortum, 2024). Enel has been able to incorporate CE practice into their procurement, innovations, and designs to create system based decarbonizations across its value chain (Enel,2024).

4.4.5 Insight of system integration: Why Energy and transition must coexist.

The comparison in the selected companies demonstrates that decarbonization is not a challenge which is a single dimension but requires system level integration and transformation. The emission reduction happens when the energy is being transitioned at the point of generation of energy, But the elimination of the carbon does not happen which incorporated in the materials and infrastructures needed to create and sustain energy systems. This is the reason only relying on renewal energy systems makes a structural gap.

This reflects that the transformation of energy is not alone sufficient to achieve full decarbonization, as it covers operational emissions and does not consider the emissions occurring from materials and infrastructure which are not addressed. At the same time, the CE itself is unable to obtain the full reduction of emissions if the energy sources which are utilized in production are carbon intensive. Hence, both terminologies should coexist as the energy transformation minimizes the amount of emission related to energy supply, while CE minimizes the demand of the overall materials and emissions of the lifecycles.

For example, Statkraft and PVO have been able to minimize the operational emission from renewal energy processes. However, their circular economy practices are limited due to their operation involved in extraction of materials, manufacturing of equipment, and development of infrastructure. This demonstrates their decarbonization efforts are operational than lifecycle based (pohjolan_voima, 2024 ; Statkraft, 2024).

Fortum can bridge this gap by incorporate circular activities such as waste to energy and recovery of materials used in the production (Fortum, 2025). This enables them to reduce the demand for virgin materials and reduce the emission as a result in the stages of production and disposal (Fortum, 2024). Enel has able to further improve their circularity in their procurement and supplier management, in relation to their sourcing materials, designed, and reused in their supply chain. This enables to minimize not only internal emissions but also system based and upstream emissions (Enel,2024).

The main element related to the study is the energy transition, circular economy, and supply chain management which act as an independent pillar. Transition of energy covers direct emissions, CE minimizes material driven emissions, SCM governance makes sure to embed the practices across the value chain. This integration required for the companies for emission elimination than controlling. Hence, the isolation strategies are no more working across supply chain as it requires holistic, lifecycle-based systems, as it is essential to inline energy, materials, and SC towards a one objective which is to reduce the carbon.

4.4.6 Final analysis related to research objective

The findings reflect that the more depth the CE are involved in the supply chain operation the more chance of effectively achieving decarbonization goals. The differences in the strategies for the selected company indicate the degree they implement CE initiatives to tackle, especially the scope 3 emission in their supply chain operations. Enel's strategies to prevent emissions act beyond the company internal processes and demonstrate a systemic method to incorporate CE into their sourcing, procurement and supplier management activities in the upstream emissions (Enel,2024). Fortum acts in a different way as the company incorporates in recovery of materials, and circular resource flow leads to lifecycle management and minimizes the emission release (Fortum, 2024).

In contrast to other two companies, there are limited measures taken to prevent the emission in relation to their supply chain as the CE practices are not up to the standards comparatively with Enel and Fortum, rather to focus more on renewal energy generation in their operation (Pohjolan Voima - Annual Report, 2024; Statkraft, 2024). Overall, it is identified that the broader the CE practices are the more emissions reductions in relations to supply chain management rather than applied as a standalone practice.

4.5 Cross Company Comparison

The cross-case comparison gives holistic understanding of how each company incorporates CE practices in their supply chain to achieve decarbonizations goals set by company. The examination of four company cases, the analysis goes beyond traditional individual practices but broader level analysis and reflects perspectives which determine the variations in each company's sustainability performances, in relation to the research objectives.

As per table 6, the cross-company comparison is done based on each company's reports such as ESG, sustainability, and corporate disclosures. CE and sustainable SCM initiatives were coded based on the main themes and elaborated in four level classification low, medium, high, and very high. Each level demonstrates the degree of level the company incorporated CE to SCM integration inclusive of procurement, supplier management, and life cycle management and respective tactical connection to decarbonization goals(Miles et al., 2014).

Table 6 : Cross-Case Comparison Matrix

Theme	Fortum	PVO	Statkraft	Enel
Integration of Circular Economy	High	Low	Medium	Very High
SCM Integration	High	Low	Medium	High
Decarbonization Link	High	High	High	Very High

As per the above chart, companies which integrate CE and SCM altogether lead to stronger decarbonization presence, especially Fortum and Enel. These firms integrate systemic and holistic approaches where the CE practices are embedded into their supply chain not in isolated manner which is in line with procurement, supplier engagement, and life cycle management. This helps companies to perform sustainability activities in their downstream and upstream to address emissions, leading to better environmental performance. Both PVO and Statkraft limit their CE to supply chain integration as they depend on operational efficiency and production of energy in low carbon strategies than deeper circular supply chain initiatives. Still, it helps to reduce the emission in certain ways but not up to the level which can perform through long term sustainability through transformative approach.

Statkraft demonstrate moderate levels of CE integration in their supply chain but focus on operational efficiency through renewables. The lack of advanced sustainability supply chain strategies diminishes them from achieving long-term suitability targets. This high-lights that even the renewal of energy itself cannot completely contribute to the full spectrum of sustainability goals in long run, as it requires more focus on material reuse and regeneration, waste generation, and lifecycle impacts and management. From the analytical point of view, the comparison differentiates the maturity of integrating sustainable supply chain approaches to obtain sustainability goals. The feedback of the study highlights the central argument of the study, which the decarbonization considers as more effective when it strategically aligns with CE and SCM activities. Further, results show that the shift from isolation strategies to more transformative systematic approach when innovations, designs and long-term planning play a vital role. Overall, the cross-company comparison reflects the importance of incorporating CE into SCM practices to drive sustainability transition in energy sector.

4.6 Key Findings and Analysis

The analysis of ESG and sustainability reports of each company highlights the decarbonization attempts companies are taken into consideration, but the role of CE and circular supply chain activities varies significantly in terms of depth and maturity. One of the key findings is that the circular economy has not placed as an independent concept rather than placed it as an integration with deeper supply chain, resource efficiency, and energy transition practices. But the companies which exclusively integrated CE to supply chain framework such as procurement, supplier management, and life cycle extension happen to truly translate sustainability efforts to decarbonization outputs. The results demonstrate the differentiation between organizations aiming on internal process efficiency and implementing sustainability in the company value chain.

In case of Enel group, ESG reports highlight the extremely structured CE model integrated within the company business model. The company exclusively pay attention circularity in each phase of like sustainability inputs, life extensions of their assets, and end of life recovery, which are embedded in SC operation. In the companies procure policies, the supplier needs to align criteria set for environment, the innovation programs involve suppliers to come up with new innovations related to circularity such as component recycling, modular infrastructure. This demonstrates that the company is not only SCM for compliances but as a model for redesigning their value chain. One key analysis refers to Enel is their decarbonization strategy in which expands beyond generation of energy to incorporate in infrastructure and material emission, assisting to tackle the scope 3 emissions in effective manner. In this case the company can be defined as a system level integrator, as the CE and CSM act as joint mechanisms to reduce both direct and indirect emissions (Enel,2024).

Fortum's sustainability report highlights its contribution to operational efficiency, especially to waste of energy, recycling of materials and carbon free production of energy. These activities showcase on company's resource utilization and emission reduction directly in the value chain. But from the ESG reports, it suggests that the circularity is concentrated in its own operation but not specifically embedded within supply chain activities. Even though the supplier relationship exists, it is only for sustainability compliances but not directly driving circularity in their internal operations. This directs to a main finding; their internal circular systems are the key to achieving considerable decarbonization and limited apply of circularity restrict the scalability of the benefits can obtain from sustainability. All in all, Fortum is running with a concept of operational excellency than fully integrated systematic operation (Fortum, 2024).

For Statkraft, ESG reports reflect deep commitments to production of renewable energy and ethical business practices, inclusive of responsible sourcing and risk mitigation. Though these activities contribute to sustainability to some extent, CE is not exclusively considered as a strategic priority in the supply chain operation. Instead of that, some aspects of circularity such as efficient asset use and long-life cycles for infrastructure can be identified but not in a systematic way. The analytical finding is that company's emission control is energy driven than the resource driven, where the company tends to reduce the emission through clean energy production, but the CE applications are not fully embedded into material emissions. This is a partially driven sustainable concept as the CE potentiality held underutilized (Statkraft, 2024).

In the case of PVO, ESG highlights its deep focus on its cost effective and low carbon energy production, especially from nuclear and hydro power. But there is less proof that the company integrates the CE related practices and sustainable supply chain initiatives. Companies' procurement policies are efficiently driven in cost effective manner but focus less on supplier management and life cycle extensions for resources in use. Because of that, company's decarbonization tactics are defined on a narrow basis, depending on energy production on a low emission basis not considering impacted related to upstream and materials. The critical finding considers the lack of CE applications into SCM, as a result decarbonization held as a constraint factor further due to lack of systemic integration (*Pohjolan Voima - Annual Report*, 2024).

When compared with all the cases, the pattern below can be identified for each company that the degree which the company integrates CE to SCM considered whether decarbonization is incremental or transformative.

Fortum – Sustainability reporting of the Fortum reflects the strong CE practices in operationally, especially in waste to energy processes, recycling of materials, and energy production in low carbon intensity (Fortum, 2025). However, these activities are incorporated in its internal operations, and SC interference is mainly restricted to compliances of sustainability than strong circular procurement or lifecycle management. This reflects the company decarbonization is integrated based on internal efficiency of the operations than a fully implemented circular SC concepts (Fortum, 2025).

Enel – Company's ESG reporting reflects a high level of circular economy integration presented in the business model inclusive of life extension of the assets, circular procurement, and recovery for end of life embedded into SC operations. The relationship with the suppliers is solid and circular innovations are made such as developing recycling solutions, and infrastructure development for modular design. This highlights that the CE activities are not restricted only to company operations but in the whole value chain and make the company as system level integrated organization to reduce the emissions in each direction (Enel,2024).

Statkraft – Company's corporate report suggest on its integration towards the renewable energy production and ethical business operations inclusive of efficient use of assets, and long-life infrastructure. But CE initiatives are not implemented systematic way in their SC or material handling processes and limited connection with suppliers for circularity practices and is simply the compliance driven than the circular driven. This indicates the company is more into energy driven circularity through clean energy production and CE implementation in SCM is limited (Statkraft, 2024).

PVO – The ESG reports suggests the cost based and low carbon energy generation specially from nuclear and hydro power. But there is limited evidence on supplier engagement to the sustainability approaches and basically aim on cost efficiency than the life cycle extension or circular procurement practices. This highlights the company's decarbonization strategy is based on low emission of energy generation, and less integration of CE to SCM (pohjolan_voima, 2024).

Overall finding can be defined as decarbonization is more effective in energy sector when the CE initiatives integrated strategically in SCM, allow firms to work on both energy and material related emissions at the same time.

5 Discussion

5.1 Theoretical Contribution

When considering the empirical depth to the four companies, the study explores that the relationship between CE and decarbonizations is not a direct relationship but mediated through SCM implementation. This aligns with the argument that sustainability output is based on systematic integration rather than the separate initiatives (Geissdoerfer et al., 2017a). One main theoretical consideration is the identification of the integration depth phenomena, explains the difference in performance of sustainability which affected by the extent to which CE concepts are integrated in SC systems. Further, the research evaluates that the independent adoption of circular practices itself does not guarantee the emission reduction, instead the real output can be takin if they are in line with procurement, supplier engagement, and life cycle control and management. This allows current study shifting from presence of implementations to implementation quality, giving a more comprehensive structure for analyzing sustainability practices (Bocken et al., 2016).

The study also highlights the importance of focusing on material centric perspective than the conventional energy focused approach to achieving decarbonizations. It is important to use renewal energy for emission control, but the significant portion of the scope three emission generated from material use and SC activities. The way material efficiency and the lifecycle extension react to influence the emission, the research widens the understanding of pathways related to decarbonization in the case of energy sector (Hertwich & Peters, 2009).

Further, the study extends the sustainable SCM theory by placing SCM as a strategic enabler of circular transformation. SCM plays a critical role in extending circular practices throughout boundaries of the organizations and assist for emissions in line with value chain than acting as an independent tool. This is in line with the previously done studies on sustainable supply chains, which highlight the significance of collaboration in reaching environmental outcomes. Overall, the study contributes in a comprehensive analytical framework, reflecting the significance of system-based thinking delivering sustainability obstacles in energy industry (Genovese et al., 2017).

Apart from above contributions, the research offers a context specific advancement by reflecting on CE implementation and SCM demonstrates in the case of European and Nordic regions. From the analysis of four selected companies, though they have comprehensive sustainability and regulatory framework within the company context, the difference exists since they translate the strategic thinking in relations to sustainability into real world operations. The insight of the research concludes that the maturity of the sustainability is nor uniform cross the sector and determine the application by priorities of the organization, governance, and the SC maturity. The study offers a in depth knowledge of the current studies, stating that offering a company-oriented explanation on how CE integration evolves in the real-world context, especially the regions which are considered as rich in sustainability performances in the world (Genovese et al., 2017)

6 Conclusions and Recommendations

This study can be concluded that the effective decarbonization practices in the case of energy sector depend on the incorporation of CE principles in the SCM than independent sustainability practices. The analysis of Fortum, Enel, PVO and Statkraft reflects that each company differentiate their CE to SC integration remarkably, lead to obtain different level of sustainability output in long run. The main impact is how depth these practices are embedded in the systems. Companies which have better performance in supplier management, procurement, and lifecycle management get an upper hand to influence the emission in positive manner beyond the direct operations, especially scope 3 emission. In contrast, the approaches which are fragmented minimize the CE practices and impact to internal efficiency, minimize the contribution towards environmental outputs.

The study explores that renewable energy itself is not sufficient to achieve full decarbonization gains. The focus on efficiency of the materials, resource optimization, and lifecycle management is mandatory to tackle the emission in relation to supply chain. Overall, SCM is the critical player who creates the shift of CE principles to impactful and measurable, system-based carbon minimizing output. Finally, the study replicates the system level coordination and strategic correlation in obtaining sustainability goals. The internal organization support is not enough to achieve the effective decarbonization, but require support through SC actors, assist by structures of the governance and mutual sustainability objectives. This support the argument that tackling complex challenges related to the environment demands coordination and collaboration approaches which go beyond company boundaries (Genovese et al., 2017).

6.1 Summary of Findings

As stated in the topic, this research intends to explore CE initiatives in SCM contribute to decarbonizations in energy-based companies. The study was led by three key objectives, to explore the CE practices in energy SC, analyses the role of SCM in performing these practices, and explore their contribution to decarbonizations outputs. These findings offer a comprehensive outlook of how the aspects are integrated, giving a methodical response to the problem of the research (Geissdoerfer et al., 2017a).

One of the main findings of the study is the level of degree in which companies are integrated the CE and SCM across the energy companies selected, Fortum, Enel group, Statkraft, and Pohjolan Voima Oyj. This variation highlights the tactics to the sustainability approaches, varying from fragmented nitration where CE initiates are embedded to company operations to system aligned integration, as the CE methods are integrated in procurement and supplier ends. The findings suggests that the firms which are focusing on proper alignment of environmental goals and SC activities, allow them to implement sustainability activities beyond the organizational territories. This lead to address the first and second objectives of the research, reflecting the CE initiatives itself not enough and required structured SC framework (Genovese et al., 2017).

In connection with the second research objective, study explored that SCM acts as a transformative and enabling role in implementing CE initiatives. It is obvious that rather than SCM reacts as a cost optimized and operational activity in a company, SCM plays a strategic role where the CE practices can be scaled and coordinated across the company value chain. This is inclusive of applying sustainability frameworks to the sourcing, supplier relationship management, and assisting life cycle-based concepts to resource management. Further, efficiency of the application of CE depends on how well SCM terminologies are placed in a company as a linking mechanism in relation to internal sustainability strategies and external stakeholders' commitments. Hence, SCM presence in the company environment acts as a critical factor deciding whether to align with only conceptual CE principles or act as a actionable and measurable outputs (Seuring & Müller, 2008).

In relation to the third research objective, they explore that the CE contribution to decarbonizations is indirect and system dependent. CE emission reduction is not same as the reduction as renewable energy adoption, instead of that, it assists decarbonizations with the aid of material efficacy, and asset lifecycle extensions. These phenomena are extremely significant in tackling scope three emissions, which contribution to a considerable amount of emission release but less focus in company cooperation strategies. The findings highlight that organizations which often have stronger CE to SCM integration get an upper hand for contribution to sustainability in effective manner. This supports the research problem by showcasing that decarbonizations outputs are deeply linked with SC commitments and lifecycle-oriented thinking (Hertwich & Peters, 2009).

Overall, the research concludes that interrelationship between CE, SCM, and decarbonizations can be understood perfectly as an integrated system rather than a collection of independent practices. Even though all companies perform sustainability practices in various manners, the level of integration between two factors determine the scale and the measurements for decarbonization outputs. These findings offer a clear answer to the research problem, highlighting that in order to obtain effective output towards environment, this sector needs not only to embed the circular activities but also their tactical alignment in supply chain system (Geissdoerfer et al., 2017a).

6.2 Theoretical and Integrated outlook for CE, SCM and Decarbonization

This study offers several key theoretical implications analyzing the insights of CE, SCM and decarbonizations literature in line with energy-based companies. Even though the current studies have explored these domains separately, the finding of this research reflects the necessity of more connected theoretical perspectives that demonstrate the methodical nature of sustainability transformations.

First, study reflects CE conceptualization as a system-based concept than isolated operational level practices. The current literature identified CE in connection with closing, slowing, and narrowing resource loops (Geissdoerfer et al., 2017a). But the finding reflects that the way it has affected depend on how organizations implemented into their processes in the business. This explains existing theoretical knowledge by showcasing that CE must explore independently at the company level. Instead of that, it should be defined in a broader level with the inclusion of value chain, as the flow of resources and the environmental implications are circulated in various actors.

Second, the research assists with the theory of sustainable supply chain management concept reflecting the main role of SCM in line with CE initiatives. The conventional SCM discusses mainly cost optimization, efficiency and coordination but recent studies emphasize the importance of sustainable practices (Seuring & Müller, 2008). However, the basic findings of discuss SCM as a critical integration mechanism which defines whether the CE practices can be converted beyond the internal company operations. This highlights that the SCM must be positioned not only as a typical management function but architecture mechanism and driver for sustainability transformation. In this light, the study able to bridge the gap between CE and SCM by demonstrating the CE outputs depend on SC governance and designs in the company operations.

Third, the study introduced how the literature of decarbonizations characteristics to the reduction of emission in relation to SCM in the energy sector. The current processes are built to reduce direct emissions only focus on technological points of view, particularly by using renewable energy sources. But the study findings suggest the CE related to the decarbonizations indirectly from lifecycle utilization and material efficiency. Even this suggests by the emerging existing literature and the necessity of discussing embedded emissions, which can be extended from the aid from sustainable SCM in operationalizing these reductions (Hertwich & Peters, 2009). In that case, the study suggests shifting from traditional technology-based view of decarbonizations to systematic and holistic perspective that integrate with resources and the value chain dynamics.

The study demonstrates that the presence of having circular practices in the internal operation is the not the important part, but how the circularity has been embedded and integrated into the supply chain management processes. The differentiation between systemic and fragmented implementation offers a new direction to explore the changes in sustainability activities in organizations. It emphasizes that the future study should aim not only to find sustainability initiatives, but for which extend the integration between strategies of the organization, supply chain structure, and environmental goals are implemented.

Finally, the research assist to the theory by proposing a more connected framework where the CE represents the “principle,” SCM represents the “mechanism,” and decarbonizations represents the “outcome.” This relationship of a comprehensive framework explores the sustainability transformation in the energy sector which is always considered as complex in operation. Also, it is identified that these components are independent of each other, and if one element is absent or weak, it causes directly to the effectiveness of the systems related to the circularity.

In summary, the contribution towards theory of this research lies in extending beyond fragmented perspectives and giving a more comprehensive understanding of how CE, SCM and decarbonizations engaged. By highlighting integration, dynamics of the value chain, and indirect emission methods, the research offers a basement for future research to construct more holistic models of sustainability in case of energy sector.

6.3 Practical Implications

This study offers several practical suggestions to managers, policy makers, and practitioners connected with energy sector highlighting how CE principles can be implemented to SCM to contribute to decarbonizations. Since the conventional sustainability tactics in energy firms aim on energy transitions and emission minimization technologies, this study emphasis the significant of addressing on material flow and SC framework to contribution to environment as a complementary direction. This is in line with the argument that transition of sustainability needs methodical ways that go beyond technological change (Geissdoerfer et al., 2017a).

First the study highlights that the CE initiatives must be integrated into the core business of the organizations than treated as a separate initiative. For practitioners, this can be considered as a lifecycle thinking into strategic decision making, inclusive of assets management, maintenance, and utilization of resources. Since energy companies are dependent on the long-life infrastructures, it can enhance the sustainability initiatives by improving the assets lifecycles and minimizing the resource intensity. This method is solid with the view that CE strategies such as repair, reuse, and lifecycle extension, act as an important role in enhancing resource efficiency and minimizing environmental implications (Bocken et al., 2016). By implementing these methods, firms can achieve environmental and economic benefits.

Second, the study demonstrates the strategic significant of SCM in implementing CE integration. In view of the practical scenario, it requires how procurement and supplier management are controlled. Instead of focus on cost savings and efficiency, companies must make sure to analyses the supplier base and embed environment aspects into selection of the suppliers, analysis, evaluation, and their development stage. This is significant as the considerable portion of the environmental impact originated from the upstream SC practices. It requires strong supplier relationships and long-term mutual understanding and can improve the circularity of activities in the value chain, leading to enhanced sustainability of activities. This is in line with the argument that sustainable SCM is mandatory to improve the responsibilities towards environment beyond the company territories (Seuring & Müller, 2008).

Third, the study demonstrates how the decarbonization tactics can be extended through the implementation of CE practices. Even though the renewal of energy plays a vital role in reducing emission, the finding demonstrates that the extra benefits can be taken through efficiency of the materials and the life cycle extensions. Further this concept suggests that the efficiency of the materials can mainly minimize the release of greenhouse gas across companies (Hertwich & Peters, 2009). For practitioners, this implies in cooperate comprehensive approach to decarbonizations that are inclusive of both resource and energy dimensions, enabling companies to identify the hidden way of releasing emissions to the outside in their operations and supply chain.

Further, study reflects the requirement of further strategic relationships towards SCM. Integrating CE practices always requires the connection between internal stakeholders, suppliers, contractors, and logistics providers. Hence, companies should go beyond the relationships which are limited to transactional and build partnership based on trust, sharing of information, and joint innovation frameworks. This partnership allows companies to develop advanced circularity solutions, inclusive of reverse logistics, closed loop SC, which are important to develop long term sustainability goals (Genovese et al., 2017).

Apart from the managerial suggestions, the findings also help policy makers. The study highlights that the importance of regulatory support and policies plays vital role in integrating CE practice into companies in the supply chain function. Policymakers can take the findings into the considerations to promote the standards in relation to life cycle management, resource efficiency, and SC transparency. This perspective is important as the coordinated policy structures are important to fast track the transformation towards low carbon and circular processes and systems (IEA, 2023).

Overall, practical considerations of this research highlight the effective decarbonizations in the case of energy industries needs an integrated method which CE practices along with strategic SCM. By implementation CE into internal systems and enhancing across SC, firms can proceed beyond strategic improvements and aim for more sustainable outputs.

6.4 Limitation of the Study

This study contains some limitations which should be considered when interpreting the findings. The primary limitation can be identified in relation to the nature of the cross-company analysis. As the study highlights the differences in companies when it comes to implementation of CE in SCM in relations to their business, these variations are identified in a conceptual level not along with the operational and measurement levels.

Because of that, the conclusion demonstrates the integration patterns than the outcomes for measurable performances in each company. Though the research reflects how implementations in line with the decarbonizations, the exclusive definitive relationship among certain initiatives and emission reductions are limited.

Another limitation can be identified as a visibility and measurement of CE attempts to decarbonizations. These finding highlights that the CE activities indirectly support efficiency of the resources, extension of lifecycles, and material optimization. However, the implementations are not always exclusively reported or quantified in firms' sustainability frameworks, find it hard to link the certain circular initiatives to emission minimizations which can be measurable. Further, the argument is based on in relation to CE, SCM, and decarbonizations, which highlights a broader perspective and challenge to obtain environmental impacts related to sustainability in separated and quantifiable manner (Hertwich & Peters, 2009).

Finally, the research focuses on existing strategic orientations than the dynamic transition processes in energy sector. The analysis focuses on the integration of CE and SCM in a certain time but not fully concentrates on evolving nature of sustainability tactics or variations in company trajectories. Also, the selected companies are comparable in their structure and integration, but the other factors such as culture, leadership tactics, and external stakeholder presence have not been taken into consideration. As per these limitations, findings should be demonstrated as offering analytical depth to integration, and further analysis and research is required to find long term performances.

6.5 Future Research Direction

The findings of this research expose several directions for future study which can further understanding the way how CE initiatives in SCM assist in decarbonizations. As this study provides holistic understanding of conceptual and comparative analysis, further research can be performed in relation to more quantitative and mixed method concepts. It is important to understand how to measure the direct and indirect emission patterns in relation to CE to achieve sustainability outcomes in statistical manner. This may assist to established standard relationship between CE-SCM integration and performance toward decarbonization, identifying key gaps described in this study (Hertwich & Peters, 2009).

One another aspect of further research is the finding of longitudinal dynamics in sustainability transformation. The existing study is done based on the current point of time, but it is important to analyze the evolving nature of the sustainability transformation in these companies which influenced technological advancements, regulatory changes, and market dynamics. Future studies can explore companies evolving from fragmented to systematic approach with time, offering clues for transition approach and the drivers that enable for limit the development. This may assist to a dynamic identification of how CE activities mature in energy sector and SC (Genovese et al., 2017).

Additionally, future research can be expanded territory by selecting companies which represent different range geographical contexts. Current study highlights the large companies which are sustainability oriented and may hinder the variability of searched parties. By Selecting smaller, small to medium companies may understand the evolving market contexts, different CE to SCM integration patterns within the company contexts. From this perspective, there is an opportunity to identify the nature of which the regulatory and institutional parties may act towards these companies shaping sustainability tactics.

Finally, there is an opportunity to analyze organizational and behavioral factors which contribute to integrating CE into SCM. Since this research focuses on structural and strategic elements, the requirement of leadership roles, organizational culture, engagement of stakeholders and how decision-making processes influence to drive sustainability transition in companies are vital for future research. Defining these roles enables us to provide comprehensive outlook to CE to SCM integration result in decarbonizations efforts.

To summarize, future studies should focus empirical, contextually, and longitudinal methods, and take into consideration behavioral and organizational factors. Thes patterns would strengths the theoretical perspective of CE to SCM integration and offer sustainable insight for transformation towards sustainability in energy sector.

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