Aava Isotalus

Configurations for Sustainability: Exploring pathways to Carbon Footprint Reduction in Nordic Machinery Manufacturing

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Author:	Aava Isotalus
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Supervisor:	Jouni Juntunen
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ABSTRACT:

This study explores how different sustainability strategies are configured in Nordic machinery manufacturing companies, with particular focus on those strategies associated with carbon footprint reductions. Rather than assessing the impact of single actions in isolation, the study identifies which combinations of sustainability strategies are linked to positive outcome. The study builds on the understanding that sustainability transitions are complex and often shaped by multiple independent factors.

To capture this complexity, the study uses fuzzy-set Qualitative Comparative Analysis (fsQCA). This method allows for the comparison of different combinations of conditions across multiple companies while acknowledging that more than one pathway can lead to the same outcome. The empirical data consist of 16 machinery manufacturing companies from Finland, Sweden, Norway, and Denmark. Data from 2019 to 2023 were collected from public secondary data, focusing on annual and sustainability reports. The study examines four conditions: stakeholder and policy engagement, energy efficiency improvements, renewable energy adoption, and alignment with sustainable development goals.

These conditions represent both technical measures and broader strategic engagement. The analysis reveals that carbon footprint reduction is not explained by any single factor, but by specific combinations of conditions. Several distinct and effective configurations are identified, illustrating the principle of equifinality, different pathways can lead to the same successful outcome. Some companies achieve reductions by focusing on internal efficiencies, while others rely on a combination of public commitments, stakeholder interaction, and targeted investments in renewable energy.

The findings contribute to the understanding of how sustainability transitions unfold in industrial context. They show that meaningful emission reductions are more likely when companies align technical improvements with strategic action. This configurational perspective offers both theoretical insight and practical guidance for managers and policymakers aiming to support low-carbon transitions in manufacturing.

KEYWORDS: Sustainability, fsQCA, Carbon Footprint Reduction, Nordic Manufacturing, Renewable energy, Energy Efficiency, Stakeholder Engagement, Sustainable Development Goals

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TIIVISTELMÄ:
Tässä tutkimuksessa tarkastellaan, miten erilaiset kestävyyteen tähtäävät strategiat rakentuvat pohjoismaisissa koneteollisuus yrityksissä. Erityinen painopiste on strategioissa, jotka liittyvät hiilijalanjäljen pienentämiseen. Yksittäisten toimenpiteiden vaikutusten sijaan tutkimus keskittyy strategisten kokonaisuuksien tunnistamiseen: mitkä yhdistelmät johtavat myönteisiin lopputuloksiin. Lähtökohtana on ymmärrys siitä, että kestävyyssiirtymät ovat moniulotteisia prosesseja, joita muovaavat useat rinnakkaiset ja toisiinsa limittyvät tekijät.

Tätä monimutkaista kokonaisuutta lähestytään fuzzy-set laadullisen vertailuanalyysin (fsQCA) avulla. Menetelmä mahdollistaa useiden yritysten vertailun eri ehtojen yhdistelmien kautta ja tunnistaa, että samaan lopputulokseen voi johtaa useampi eri reitti. Empiirinen aineisto koostuu 16 koneteollisuusyrityksestä Suomesta, Ruotsista, Norjasta, ja Tanskasta. Aineisto kattaa vuodet 2019–2023 ja perustuu pääosin yritysten julkisiin vuosikertomuksiin ja vastuullisuusraportteihin. Tarkastelun kohteena ovat neljä keskeistä strategiaa: sidosryhmä yhteistyö, energiatehokkuuden parantaminen, uusiutuvan energian hyödyntäminen sekä sitoutuminen kestävän kehityksen tavoitteisiin.

Strategiat edustavat sekä teknisiä ratkaisuja että laajempaa strategista sitoutumista. Tulokset osoittavat, että hiilijalanjäljen pienentämistä ei selitä yksittäinen toimenpide, vaan tietyt yhdistelmät eri tekijöistä. Useita toimivia konfiguraatioita tunnistetaan, mikä havainnollistaa periaatetta, jonka mukaan eri polut voivat johtaa samaan tulokseen. Osa yrityksistä saavuttaa päästövähennyksiä panostamalla sisäisiin tehokkuustoimiin, kun taas toiset nojaavat julkisiin sitoumuksiin, aktiiviseen sidosryhmävaikutukseen ja kohdennettuihin investointeihin uusiutuvaan energiaan.

Tutkimuksen tulokset syventävät ymmärrystä siitä, miten kestävyyssiirtymät konkretisoituvat teollisessa ympäristössä. Tulokset korostavat, että merkittäviin päästövähennyksiin päästään todennäköisemmin, kun tekniset ja strategiset toimet yhdistetään tarkoituksenmukaisiksi kokonaisuuksiksi. Konfiguraatiolähtöinen lähestymistapa tarjoaa sekä teoreettista syvyyttä että käytännön työkaluja yritysjohdolle ja päätöksentekijöille, jotka pyrkivät edistämään vähähiilistä siirtymää valmistavassa teollisuudessa.

AVAINSANAT: Kestävyys, fsQCA, hiilijalanjäljen pienentämineen, pohjoismainen koneteollisuus, uusiutuva energia, energiatehokkuus, sidosryhmävaikuttaminen, kestävän kehityksen tavoitteet.

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1 Introduction

As sustainability becomes a strategic priority across industries, understanding how companies approach emission reduction has grown increasingly important. In sectors with high energy use and global reach, the ability to reduce carbon footprints is not only a regulatory expectation but also a question of long-term competitiveness. While many companies have adopted various environmental initiatives, how these are combined into effective strategies remain under-explored.

This study investigates how different sustainability strategies are configured in Nordic machinery manufacturing companies, with a particular focus on those strategies associated with reductions in carbon emissions. Using Qualitative Comparative Analysis, (QCA), the study examines how combinations of renewable energy adoption, energy efficiency improvements, alignment of sustainable development goals, and stakeholder and policy engagement relate to emission performance. The study contributes to a growing body of literature that calls for a more nuanced understanding of corporate sustainability in complex sectors. It offers both empirical insight into Nordic machinery manufacturing sector and methodological value by applying a configurational approach to a field often dominated by case studies and regression models. Most importantly, the study responds to the need to understand how sustainability transitions unfold at the company level and how diverse strategic choices can together shape industrial progress toward climate goals.

1.1 Background for the Study

Industrial decarbonization has become one of the central challenges in the global effort to address climate change. The manufacturing sector holds a dual position as both a key economic engine and a major contributor to greenhouse gas emissions. Globally, manufacturing industries account approximately 20% of direct CO_2 emissions, largely due to energy-intensive processes and reliance on fossil fuels (IEA, 2023). In response, increasing regulatory pressure, stakeholder expectations, and evolving market standards are pushing companies to adopt more environmentally responsible strategies. The transition toward low-carbon manufacturing is no longer optional but essential for long-term competitiveness and legitimacy in both national and international markets (Porte & Kramer, 2011; Bocken et al., 2014).

Within this global context, the Nordic region stands out as a leader in environmental governance and clean technology innovation. Counties such as Finland, Sweden, Norway, and Denmark have developed ambitions climate policies and sustainability agendas, often positioning themselves at the forefront of global environmental efforts. This progressive stance is supported by strong public institutions, high levels of environmental awareness, and industrial policies that encourage innovation in clean energy and sustainable manufacturing systems (Nordic Council of Ministers, 2011). As a result, Nordic industries operate in a context where sustainability is not only a regulatory expectation but also a strategic opportunity. Despite this enabling environment, the decarbonization of industrial sector stays a complex, resource-intensive, and often uneven process.

Machinery manufacturing is a relevant sector for sustainability research. It is one of the key economic contributors in all four Nordic countries and plays a central role in industrial value chains, both regionally and globally. At the same time, it is characterized by high energy demands, complex production systems, and often large-scale global operations. The sustainability challenges facing these companies are not only technical but also strategic, requiring decisions about how to distribute resources, which technologies to adopt, and how to align operational practices with broader environmental goals (Lozano, 2013; Baumgartner, 2014). To meet growing expectations, companies are increasingly engaging in sustainability practices such as investing in renewable energy sources, improving energy efficiency, aligning with international frameworks like the United Nations sustainable development goals, and taking part in policy and stakeholder initiatives. The way these strategies are adopted varies significantly from one company to another.

A central observation appearing from both practice and scholarship is that sustainability in industry is rarely achieved through a single initiative. Instead, it involves the interaction of multiple strategic choices and actions that are embedded in company culture, structure, and market environment (Lozano, 2013). For instance, adopting renewable energy technologies might have limited impact if not supported by energy efficiency improvements or coherent goal setting. Similarly, engaging in stakeholder dialogues may not lead to meaningful outcomes unless the company has internal mechanisms for translating external feedback into operational change. This makes it important to not only look at what companies are doing for sustainability, but also to understand how they integrate and coordinate these efforts.

Even though this issue is becoming more important, research has often looked at individual sustainability practices on their own, without fully considering how they fit into broader corporate strategies (Evans et al., 2017). There is a need for more holistic and configuration-oriented approach that acknowledges the complexity of real-world decision-making and the possibility that different combinations of sustainability actions may lead to similar or diverging outcomes. This study addresses this need by focusing on configurations of sustainability strategies in Nordic machinery manufacturing and examining how these configurations relate to actual carbon footprint reduction.

By applying Qualitative Comparative Analysis (QCA), the study aims to identify which combinations of conditions are associated with lower emissions among companies operating in the Nordic machinery manufacturing sector. QCA is well-suited for this type of analysis, as it enables the investigation of multiple causal pathways rather than relying on assumption of linear or additive effects (Ragin, 2008; Fiss, 2011). The aim is not to isolate individual drivers, but to uncover how companies build their sustainability strategies in practice, and how different patterns of action contribute to or hinder carbon footprint reduction.

1.2 Research Gap

Although the sustainability literature in manufacturing is extensive, much of it examines individual practices in isolation. For example, there are studies on the effects of renewable energy (IRENA,2020), stakeholder engagement (Freeman et al., 2007), or energy efficiency, but fewer studies look at how these elements interact withing broader company strategies. This fragmented view can overlook the complexity and diversity of real-world decision-making in industrial context.

Most existing studies apply linear or regression-based methods that are well suited for identifying average effects but may not capture how different combinations of conditions can lead to the same outcome, a concept known as equifinality (Fiss, 2011). In contrast, the configurational approach used in this study acknowledges that companies may follow different but equally effective paths toward sustainability goals.

There is also limited empirical research that focuses specifically on the Nordic machinery manufacturing sector, despite its strategic importance and potential as a global example in sustainable industrial practices. The need to better understand how companies in this sector navigate their sustainability choices, and what combinations of efforts lead to real carbon footprint reductions, stays unexplored.

This study addresses these gaps by applying Qualitative Comparative Analysis (QCA) to identify which configuration of renewable energy adoption, energy efficiency improvements, stakeholder and policy engagement, and alignment with sustainable development goals are associated with carbon footprint reduction. By doing so, it contributes to both the academic literature on sustainable manufacturing and to the practical understanding of industrial decarbonization in the Nordic context.

1.3 Research Question and Objectives

The purpose of this study is to explore how sustainability strategies are configured in Nordic machinery manufacturing and how these configurations are linked to the measurable reductions in carbon emissions. Instead of focusing on individual strategies, the research takes a configurational approach to understand how companies combine various efforts in practice. By examining real-world patterns rather than isolated actions, the study aims to uncover how companies succeed in reducing their carbon footprint through different strategic pathways.

The research is guided by the following question:
What configuration pathways of renewable energy adoption, alignment with sustainable development goals, stakeholder & policy engagement and energy efficiency improvements lead to carbon footprint reduction in Nordic machinery manufacturing?

This question reflects the aim of identifying different ways companies can achieve similar outcomes in terms of carbon footprint reduction. It also highlights the role of strategic alignment across multiple sustainability factors, rather than relying on a single factor or solutions.

To address this question, the study sets the following research objectives:

1. To identify key sustainability strategies adopted by Nordic machinery manufacturing companies, with a focus on renewable energy, energy efficiency, stakeholder & policy engagement, and sustainability goal setting.
2. To examine how these strategies are combined across companies and whether certain configurations are more often associated with reductions in carbon emissions.
3. To apply Qualitative Comparative Analysis to identify necessary and sufficient combinations of conditions associates with carbon footprint reduction.
4. To contribute to sustainability research by offering a configurational-based understanding of industrial decarbonization pathways in a Nordic context.

Through these objectives, the study looks to provide insight into how different sustainability efforts work together and how companies can develop more effective and coherent approaches to decarbonization.

1.4 Structure of the thesis

Following this introductory chapter, the thesis is organized into 5 chapters that build toward a comprehensive understanding of how sustainability strategies are configured in Nordic machinery manufacturing and how these configurations relate to carbon footprint reduction. Chapter 2 presents a literature review that outlines key theoretical and empirical perspectives on corporate sustainability, configuration theory, and decarbonization in industrial context. This chapter also discusses the role of energy efficiency, renewable energy adoption, stakeholder and policy engagement, and sustainable development goals in shaping sustainability performance. Chapter 3 introduces the methodological framework of the study, focusing on the use of Qualitative Comparative Analysis (QCA). It details the case selection process, calibration procedures, and the operationalization fuzzy-set QCA approach.

Chapter 4 presents the empirical results from the QCA, including necessity and sufficiency analyses for both positive and negative outcomes. The chapter explores how different configurations of conditions are associated with reduced carbon footprints among the selected companies. Chapter 5 interprets these findings in the light of literature, offering theoretical reflections and practical implications for sustainability management in the Nordic machinery manufacturing sector. The closing chapter concludes the thesis by summarizing the key points.

2 Literature review

This chapter reviews the body of literature on sustainability strategy in industrial contexts, with an attention to the machinery manufacturing sector. The purpose is to find a conceptual foundation for examining how companies develop and implement practices aimed at reducing their carbon footprint. The review focuses on key themes, such as renewable energy adoption, energy efficiency improvements, stakeholder and policy engagement, and sustainability goal setting. It also reflects on the limitations of reductionist or linear analytical approaches in this domain and present configurational thinking as a more suitable alternative for capturing the complexity of sustainability in practice.

2.1 Sustainability in the Machinery Manufacturing Sector

A pillar of world economic activity, the manufacturing sector greatly influences employment, trade, and technology development. Still, its environmental effect still presents a difficulty. Due mostly to energy-intensive operations and reliance on fossil fuels, the manufacturing sector is responsive for more than 20% of global carbon dioxide (CO_2) emissions according to the International Energy Agency (IEA, 2021). Beyond carbon emissions, the industry creates waste and uses vast amounts of water, therefore aggravating global environmental issues including resource depletion and pollution (Rockström et al., 2009).

Aiming to divorce industrial expansion from environmental damage, the immediacy of these concerns has resulted in worldwide calls for sustainability in manufacturing. This aim conforms to main international frameworks such as the United Nations Sustainable Development Goals (SDGs) and the Paris Agreement. While SDG 12 emphasises the need of sensible consumption and production patterns, SDG 9 supports resilient infrastructure and sustainable industrialisation (United Nations, 2015).

Addressing global sustainability challenges in the manufacturing sector requires adopting sustainable practices that enhance resource efficiency, reduce emissions, and promote responsible production. Innovations such as energy-efficient machinery, renewable energy integration, and waste recycling systems have been identified as key enablers of sustainable manufacturing. However, the adoption of these practices differs widely across regions and industries, resulting in factors such as economic conditions, policy support, and organizational capabilities (Alayón et al., 2022).

2.1.1 Global Sustainability Challenges in Machinery Manufacturing

Although the machinery manufacturing contributes significantly to world economic development, it also affects the environment, runs out of resources, and creates social issues. Advancement of sustainable development and preservation of long-term economic and ecological balance depend on addressing these problems.

A main cause of greenhouse gas emissions and resulting climate change are manufacturing processes. Particularly because of energy-intensive manufacturing techniques and reliance on fossil fuels, the industry makes a significant share of world carbon dioxide emissions. Managing manufacturing emissions is essential for national and regional climate targets in the Nordic area, where industrial output dominates the economy. Furthermore, resulting in pollution of air and water are industrial activities, which harm ecosystems and human health by means of their harmful effects on Natural resources, minerals, water, and energy, have a major impact on manufacturing. Exploitation of these resources disturbs the natural equilibrium and hinders the future generations of these people. Nordic nations have underlined circular economy ideas, investments in sustainable raw material sourcing and industrial symbiosis projects (Nordic Council of Ministers, 2022), therefore helping to slow down resource depletion.

Waste creation is another issue in the manufacturing industry. Massive amounts of industrial waste, including hazardous chemicals, present disposal issues and cause environmental damage. Pollutants can enter soil and water systems without effective waste management strategies, causing long-term environmental harm and public health risks (Ghisellini et al., 2016). Nordic manufacturers have been in the forefront of waste reduction efforts, with Sweden, Denmark, and Finland ranking as global leaders in industrial recycling and material efficiency (European Environment Agency, 2023).

Beyond environmental difficulties, the sector has significant social sustainability challenges. In some industries, occupational health hazards, violations of labour laws, and bad working conditions continue to be prevalent. Maintaining corporate social responsibility and legitimacy in global supply chains requires corporations to ensure ethical employment standards and safe working conditions (Jabbour et al., 2019). Nordic countries, known for their rigorous labour restrictions and high social standards, have established objectives for equal manufacturing employment (OECD, 2024). However, knowledge problems remain in the integration of sustainability into global supply networks on which Nordic enterprises rely for raw materials and components.

Furthermore, limiting the general acceptance of sustainable manufacturing are economic restrictions. Small and medium-sized businesses may find it difficult to afford the often-large financial commitment needed for the shift to green technology. Although large multinational enterprises have the means to carry out sustainability projects, many smaller businesses might find it difficult to afford the high expenses of equipment upgrades and cleaner manufacturing methods (Bocken et al., 2014). Making sustainable investments more available to all manufacturing enterprises depends critically on government incentives, subsidies, and regulatory systems.

The intricacy of global rules hinders efforts at sustainability even more. Different nations have very different environmental legislation, which presents difficulties for multinational companies attempting to apply consistent sustainability standards. Inconsistent enforcement and regulatory uncertainty make it challenging for businesses to match their activities with worldwide environmental goals. Steps towards addressing these policy issues are harmonising international regulations and establishing explicit sustainability criteria (Porter & Kramer, 2011).

Handling these several issues calls for cooperation among legislators, business executives, and others. Approaches like support of worldwide cooperative projects, better manufacturing practices, and investment in sustainable research and development might assist to propel the transformation towards a manufacturing sector more sustainable. Including social, environmental, and financial aspects into industrial processes helps the manufacturing sector enhance long-term sustainability and raise competitiveness in a worldwide market.

2.1.2 The Role of Machinery Manufacturing in the Nordic Economy and Climate Goals

The Nordic economy depends much on the machinery manufacturing industry, which also greatly influences industrial production, exports, and employment. Complementing the region's lofty standards for quality and sustainability, the sector specialises in advanced engineering, industrial automation, and energy-efficient technology as a natural element of global supply chains (Johnsen et al., 2015). Including Sweden, Finland, Denmark, and Norway, Nordic nations have built internationally competitive machinery industries providing precision manufacturing, energy generation, and construction equipment (Lager et al., 2023). Driving technological innovation across the area and supporting a highly qualified workforce, the industry is also a key employer (OECD, 2024).

Though its economic value, manufacture of machinery is a significant contributor to industrial greenhouse gas (GHG) emissions. Energy-intensive operations such metalworking, machining, and material processing, which produce significant carbon emissions, are relied upon in the sector. Nordic companies have responded to these difficulties by using process innovations, electrification, and energy efficiency gains as well as by improving their own products. Sweden, for instance, has established a legally enforceable objective to reach net-zero emissions by 2045, therefore reducing significant emissions in industries like machinery manufacture (Government Offices of Sweden, 201). Emphasising on improving energy efficiency and raising the use of renewable energy within its industrial sectors, Finland also an even more ambitious target to strive for carbon neutrality by 2035 (Ministry of the Environment, Finland, n.d.).

Changing to low-carbon materials is one of the most effective ways machinery manufactures may cut emissions. A substantial portion of the sector's carbon footprint comes from the manufacturing of steel and other metals utilised in industrial equipment. Nordic businesses are, for instance, funding green steel technologies that reduce the demand for iron produced from fossil fuels. Aiming to lower CO_2 emissions by up to 98% per metric tonne of steel compared to conventional blast furnace methods, the HYBRIT project, a cooperation between SSAB, LKAB, and Vattenfall—pioneers the use of hydrogen in steel production (Åhman et al., 2018). This project might significantly lower Sweden's overall carbon dioxide emissions, therefore supporting somewhat large national climate targets. Adoption of green steel is likely to have broad effects on machinery manufacture since it will let businesses create industrial equipment with less embedded emissions.

The Nordic approach for sustainable machinery manufacturing depends critically on electricity. Although historically industrial processes have depended on fossil fuels, there is a significant movement towards electric substitutes. To lower operating emissions, companies in Finland, for instance, are using electric and hybrid-powered industrial gear more and more. General-purpose technologies like electricity and information and communication technology (ICT) diffused inside the Finnish industrial sector help to smooth this transition by increasing production and energy efficiency (Myllyntaus, 1985). Likewise, Danish businesses have been leading in incorporating technology for energy-efficient automation. Building automation and control systems implemented in Danish buildings have proved to maximise interior environmental quality and energy consumption (Pedersen et al., 2022). These improvements complement the Industrial Strategy of the European Union (EU), which supports the acceptance of sustainable energy solutions throughout European industrial sectors (European Commission, 2020).

Apart from reducing emissions, Nordic machinery manufacturers are also implementing circular economy methods to cut waste and enhance resource effectiveness. Re-manufacturing and industrial symbiosis are two circular business concepts that are starting to show up in the area somewhat often. Re-manufacturing initiatives, renovating old machinery, and extending product lifecycles to lower raw material consumption have been investments made by businesses such Sandvik and Wärtsilä (Ghisellini et al., 2016). By cutting material prices and guaranteeing long-term resource availability, this strategy not only lessens environmental consequences but also increases economic competitiveness.

Another transforming power influencing Nordic machinery production's sustainability is digitalisation. Adoption of Industry 4.0 technologies, including artificial intelligence (AI), digital twins, and Inter-net of Things (IoT), has let manufacturers maximise production efficiency and lower waste (Chari et al., 2021). For example, AI-driven predictive maintenance solutions let businesses lower energy usage and machine downtime, so enhancing the general sustainability performance (Jamwal et al., 2021). With many businesses employing AI-based process optimization technologies to lower resource use and improve production efficiency, Sweden's industrial sector has been exceptionally innovative in embracing digital solutions (Business Sweden, 2022).

Even with improvements in sustainable methods, there are still great difficulties matching machinery manufacture with Nordic climate targets. The great expense involved in implementing sustainable technology, particularly for small and medium-sized businesses, is a main obstacle. Although big companies have the financial means to invest in low-carbon technology, many smaller companies find it difficult to get the necessary money for green transition projects (Alayón et al., 2022). Although government subsidies and innovation grants have been very helpful in promoting sustainable investments, more policy actions would be required to hasten the decarbonisation of the industry (OECD, 2019).

Sustainable machinery manufacturing suffers from supply chain dependencies. Nordic machinery manufacturing companies may source its raw materials and components elsewhere, where environmental rules could be less strict. Achieving real sustainability in the sector depends on resources being respirally sourced and traceable. Several Nordic businesses have responded by using recycled materials more widely and working with suppliers to improve environmental responsibility across their value chains (Wiktorsson et al., 2008).

To make sure Nordic machinery manufacture fits with climate objectives, future public-private cooperation, investment in green technologies, and legislative backing will be very vital. The Nordic area has great potential to lead worldwide in sustainable industrial production by using its strengths in innovation, digitalisation, and resource economy. Even if there are still difficulties, the continuous shift towards electrification, circular economy models, and digital optimisation offers a strong basis for the future of climate-friendly machinery production in the region.

2.1.3 Configurations of Sustainability in Machinery Manufacturing

Sustainable manufacturing demands businesses to embrace configurations of technologies, regulations, and operational strategies that support sustainability while preserving efficiency by including environmental, financial, and social aspects into production processes (Ghobakhloo, 2020). Although these setups differ across sectors, generally they reflect acceptance of circular economy ideas, digitalisation, regulatory compliance, and renewable energy sources (Bocken et al., 2014). Sustainability is progressively addressed in Nordic machinery manufacture by means of digitalised processes, low-carbon materials, and energy-efficient manufacturing techniques. National climate legislation, industry pledges, and technology capabilities all help to define these setups.

The reconfigurable manufacturing system is one often used method that lets businesses change production capacity and functionality in response to sustainability needs (Koren & Shpitalni, 2010). Reconfigurable manufacturing system offers adaptive processes that enhance resource efficiency, lower waste, and enable the incorporation of cleaner production technologies (Koren et al., 2018) unlike conventional mass production. For instance, the utilisation of modular manufacturing lines in automotive and electronics sectors enables enterprises to turn towards low-carbon operations without massive infrastructure expenditures (Monostori et al., 2016).

Another configuration includes circular economy practices, which focus on designing products for longevity, reusability, and recyclability (Geissdoerfer et al., 2017). The change from linear production models (take-make-dispose) to circular systems requires integrating re-manufacturing, industrial symbiosis, and closed-loop supply chains. Nordic machinery manufacturers have pioneered re-manufacturing programs that extend product lifecycles while reducing material waste and, for example, Finland has been an early adopter of resource-efficient business models in the metal and machinery industries, aligning with EU sustainability regulations (Korhonen et al., 2021).

The Fourth Industrial Revolution (Industry 4.0) technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics, also play a significant role in sustainable manufacturing configurations (McKinsey & Company, 2023). Digitalized production processes enable Nordic manufacturers to optimize energy use, reduce emissions, and minimize material waste. AI-driven predictive maintenance systems, for example, are helping companies like Metso and Kone enhance operational efficiency while lowering carbon footprints (Jamwal et al., 2021) The World Economic Forum’s Global Lighthouse Network has recognized several companies that have successfully implemented AI-driven sustainability solutions, leading to substantial reductions in energy consumption and industrial waste (World Economic Forum, 2022).

Regulatory and policy configurations also shape sustainability in manufacturing. Companies operating in the European Union must follow with climate policies, emissions trading systems, and corporate sustainability reporting standards (European Commission, 2020). These policies reward manufacturers to invest in low-carbon technologies, adopt lifecycle assessments, and integrate sustainability metrics into business operations (Kim et al., 2022). With their strict environmental policies, Nordic nations have driven producers of machinery towards ambitious carbon reduction plans. Sweden's legally binding net-zero targets for 2045 and Finland's carbon neutrality goal for 2035 create strong regulatory incentives for sustainable manufacturing investments. Research shows that companies in countries with stringent environmental policies tend to adopt more proactive sustainability measures, compared to companies in regions with weaker regulatory enforcement (Porter & Linde, 1995)

2.2 Evaluating Sustainability Strategies for Carbon Footprint Reduction in Machinery Manufacturing

Reducing carbon footprints in machinery manufacturing is essential because of its meaningful environmental impact from energy-intensive processes (IEA, 2021). Nordic manufacturers are at the lead to sustainability efforts, actively integrating renewable energy, energy efficiency, circular economy initiatives, and stakeholder engagement, driven by regulatory frameworks and technological advancements (Nordic Council of Ministers, 2022; OECD, 2022). Reliable evaluations methods and metrics as well as theoretical frameworks like configurational theory, which allow complicated strategy interactions and multiple paths lading to similar outcomes, help one to understand how these strategies and their configurations effectively reduce carbon footprints (Fiss, 2011).

2.2.1 Metrics for Assessing Carbon Footprint Reduction

Effective evaluation of sustainability strategies depends on standardized and widely recognized metrics. The Greenhouse Gas (GHG) protocol identifies emissions as direct emissions (Scope 1), indirect emissions from electricity use (Scope 2), and other indirect emissions within the value chain (Scope 3). Scope 3 often is the largest emissions share, encompassing activities like supply chain logistics, product disposal, and employee commuting (World Resource Institute, 2004; Pandey et al., 2010).

Carbon intensity, measuring emissions per production unit, is another essential metric. It reflects both environmental impact and resource efficiency, helping manufacturers assess improvements and align with international climate objectives like the Paris Agreement (Ke et al., 2024; UNFCCC, 2015). Also, renewable energy adoption metrics, such as the proportion of renewable energy in total energy mix or carbon dioxide reductions from renewable energy sources, provide crucial indicators of progress and transparency to stakeholders (IEA, 2021; CDP, 2023).

2.2.2 Effectiveness of Sustainability Strategies

Empirical evidence highlights the effectiveness of targeted sustainability strategies in machinery manufacturing. Energy efficiency measures, such as adopting high-efficiency motors, automation, digital monitoring, and AI-driven optimization, consistently achieve significant emissions reductions (20-30%) in Scope 1 and Scope 2 emissions over a five-year period (Govindan & Hasanagic, 2018). However, achieving ambitious carbon emission targets typically requires integrating energy efficiency measures with added strategies.

Renewable energy integration is a complementary strategy that substantially reduces emissions. Companies sourcing over half their electricity from renewables shows significantly lower Scope 2 emissions (Huang et al., 2018). Practices such as long-term renewable power purchase agreements and onsite renewable energy investments help stabilize energy costs and reduce reliance on fossil fuels (Horbach et al., 2012). The combined use of energy efficiency improvements and renewable energy often leads to even greater reductions in overall intensity.

Circular economy approaches also contribute to emissions reduction. Re-manufacturing, component reuse, and closed-loop recycling reduce lifecycle emissions by up to 40% compared to traditional linear production (Lieder & Rashid, 2015). Successful circular economy implementations often depend robust supply chain cooperation and regulatory support, reinforcing the importance of strategic integration rather than isolated actions.

Stakeholder engagement and policy alignment further amplify the effectiveness of sustainability strategies. Active participation in cross-sector collaborations, policy advocacy, and supplier sustainability programs enhances reductions especially in Scope 3 emissions. Companies engaged in voluntary disclosure and sustainability reporting typically outperform counterparts lacking such initiatives, partly because of the influence of rigorous frameworks like the European Green Deal (Brammer et al., 2011; Pandey et al., 2011).

2.2.3 Configurations and Pathways to Carbon Footprint Reduction

Although individual sustainability strategies give measurable results, variations exist in how these strategies are combined and configured by different companies, industries, and regions. Comparative studies show that industries tailor their sustainability strategies according to their technological capabilities, regulatory environments, and market conditions (Ghobakloo, 2020; Geissdoerfer et al., 2017). For instance, energy-intensive industries prioritize renewable energy adoption and process optimization, because precision and high-tech sectors lean towards digital transformation and smart manufacturing technologies (Mattingly, 2020).

Nordic manufacturers consistently improve carbon footprint reductions compared to global peers, influenced heavily by stringent regional regulations, governmental funding, and early adoption of sustainable practices like renewable energy and circular economy models (OECD,2022; Åhman, 2018). Companies in less regulated regions rely more often on voluntary initiatives and carbon offsetting programs, showing that regulatory contexts shape the chosen sustainability pathways.

Supply chain strategies also vary, with European and Japanese manufacturing embedding sustainability deeper through difficult audits, green procurement, and lifecycle assessments, compared to North American manufacturers, who often prefer broader sustainability reporting standards (Wiktorsson et al., 2008; Kim et al., 2022). Digitalization plays an important role across industries in enabling sustainability configurations, with Industry 4.0 technologies, such as AI-driven predictive maintenance enhancing resource efficiency and emissions reductions, especially in advanced manufacturing contexts (World Economic Forum, 2022).

While suitable empirical evidence exists on individual strategies, studies often overlook the complexity of strategy interactions. Configuration theory, operationalized through methods such as Qualitative Comparative Analysis (QCA), addresses this gap by emphasizing the concepts of causal complexity, equifinality, and conjunctural causation (Fiss, 2011; Ragin, 2008). Recognising that different configurations of activities and contextual elements might produce identical environmental effects, QCA offers a methodical approach analysing several sustainability strategy combinations. This theoretical viewpoint is relevant to the varied terrain of Nordic equipment production, where businesses employ different configurations yet result in similar carbon footprint reductions (Misangyi et al., 2017).

2.3 Adoption of Renewable Energy Technologies in Machinery Manufacturing

As businesses strive to lower their carbon footprint and obey more stringent environmental rules, the use of renewable energy technology in machinery manufacturing becomes an increasingly significant issue. Offering substitutes for fossil fuels, renewable energy sources such solar, wind, and bioenergy enable businesses to move towards more ecologically friendly manufacturing methods. Particularly in the Nordic area, where governments offer incentives to hasten the use of renewable energy, this transformation fits both company sustainability aims and more general policy frameworks (European Environment Agency, 2022). Excluding obvious advantages, there are also difficulties ranging from high first investment costs to technical and operational limitations affecting the viability of extensive deployment.

Since machinery manufacturing is an energy-intensive sector, using renewable energy may have a major impact on cost structures and operational effectiveness. Studies reveal that certain businesses struggle with integration owing to infrastructure constraints and energy intermittency even if some others obtain favourable financial and environmental outcomes by means of renewable energy technology adoption (Usman et al., 2024). Nordic nations well-known for their strong environmental goals offer a valuable setting for research on how equipment producers negotiate these challenges. Reviewing empirical data on the subject, the following sections investigate the main drivers and obstacles affecting the acceptance of renewable energy sources and provide case studies showing actual use in Nordic corporations.

2.3.1 Drivers and Barriers to Renewable Energy Adoption in Machinery Manufacturing

Many factors inspire the use of renewable energy technologies in the machinery manufacturing. Regulatory systems are very important with policies like carbon reduction targets, subsidies, and tax incentives inspiring businesses to go towards sustainable energy sources (International Energy Agency, 2021). Nordic governments have created aggressive energy policies that promote renewable integration by helping companies involved in clean energy solutions financially (Pereira et al., 2019). Beyond environmental issues, the industry has major social sustainability challenges. In some sectors, occupational health dangers, labour rights breaches, and poor working conditions still rule. Maintaining corporate social responsibility and preserving legitimacy in worldwide supply chains depends on companies guaranteeing ethical labour standards and safe working conditions (Jabbour et al., 2019). Renowned for their strict labour regulations and excellent social standards, Nordic nations have set goals for equitable manufacturing employment (OECD, 2024). Knowledge challenges, however, remain in integrating sustainability into global supply networks Nordic companies depend on for raw materials and components.

Technological developments help to assist the change by raising the dependability and efficiency of renewable energy sources. Various energy storage, smart grid, and energy management system improvements have lessened certain associated issues with renewable energy (IEA, 2021). Long-term cost cuts are also a major motivator as businesses investing in renewable energy can eventually lower power costs, therefore reducing the risk associated with fluctuating fossil fuel prices (Raventós et al., 2022).

Despite these benefits, adoption is hampered in certain ways also. Mostly for small and medium-sized businesses without significant financial means for large-scale investments, the high upfront costs of building renewable energy infrastructure remain one of the key challenges (Gielen et al., 2019). Especially in older industries not built for distributed energy sources, integrating renewables into current production processes might be challenging. Another obstacle is energy intermittency as industrial activities depend on consistent, uninterrupted power supply, which can be challenging with varied renewable sources like solar and wind (Pappas, 2018). Adoption of the new energy systems is further hampered by organizational opposition to change and the necessity of qualified people to oversee them (Kemp et al., 2022). To enable a more seamless shift towards renewable energy in industrial environments, these obstacles call for concerted initiatives incorporating regulatory support, technological developments, and financial resources.

2.3.2 Empirical Evidence on Renewable Energy in Industrial Production

Empirical studies on the acceptance of renewable energy sources in industrial production offer insights on both the advantages and difficulties in switching to sustainable energy sources. Many studies reveal that businesses including renewable energy into their manufacturing operations save long-term costs, have better energy security, and improve environmental performance (Raventós et al., 2022). Companies investing in on-site renewable energy generation—such as solar photovoltaics or wind turbines—report cheaper power prices and less dependency on outside energy sources, therefore strengthening general resilience (Traxler et al., 2020).

Companies employing a broad renewable energy portfolio, including solar, wind, and bioenergy, achieved more consistency in energy supply compared to those depending on a single energy source, according to a study concentrating on Nordic industrial sectors (Dancker et al., 2021). Furthermore, evidence points to the notion that including renewable energy sources into industrial processes supports environmental rule compliance and improves stakeholder relations, hence aiding larger business sustainability initiatives (Pereira et al., 2019).

Empirical studies also point to certain difficulties. Studies on industrial energy transitions emphasise that, while small manufacturers sometimes struggle with money and technological capability, larger multinational corporations have the financial and technical means to invest in renewable energy (Usman et al., 2024). Integration of renewable energy sources is effective depending on several elements including regional grid infrastructure, availability of storage technologies, and consistent policy. Sometimes regulatory uncertainty or market changes have made it impossible for businesses to guarantee consistent renewable energy sources (Pappas, 2018).

Although the acceptance of renewable energy sources in industrial production shows obvious advantages, overall empirical results imply that the success of such projects depends on a combination of economic, technological, and policy-related elements. Investigating how various industrial sectors maximise renewable energy utilisation and minimise adoption difficulties is still much required.

2.4 Energy Efficiency Improvements in Machinery Manufacturing

Reducing growing energy prices, carbon emissions, and the demand for sustainable production depends on machinery manufacture improving its energy efficiency. Two main areas of development have evolved when industrial operations change to fit these demands: systematic energy management strategies and technical and process advances.

2.4.1 Technological and Process Innovations for Energy Efficiency

Often driven by indirect or peripheral energy usage rather than the core material transformation itself, industrial operations in the machinery manufacturing industry consume a lot of energy. While machining involves material removal and shaping, only a small part of the total energy consumed is dedicated to this transformation. Instead, a sizable part is dedicated to activities like cooling, lighting, and machine standby (Fysikopoulus et al, 2013). As a result, focusing energy improvements at the process and machine-tool levels offers a significant opportunity to reduce total energy demand. Tooling innovations, smarter control systems, and more efficient machine configurations can all help to reduce direct and indirect energy consumption. Adjusting process parameters like feed rates, cutting speed, and depth of the cut, for example, can result in more efficient energy utilization while maintaining product quality.

Technological advantages in digital infrastructure have also played an important role. As Hong et al. (2024) demonstrated in semiconductor manufacturing, real-time monitoring of energy consumption via IoT sensors and machine learning models allows facility managers to gain granular insights into energy usage. These findings support targeted interventions, particularly at the tool and chamber levels, where variations in energy use are often overlooked in aggregated reporting. While originally developed for semiconductor fabrication, such data-driven methods are increasingly applicable to machinery manufacturing, particularly in operations with complex tool sets and batch variability. The adoption of variable speed drives in chilled water systems, for example, has yielded energy reductions of up to 30%, while upgraded coolers have delivered 40-50% efficiency improvements (Hong et al.,2024).

In addition to direct energy savings, many of these interventions provide non-energy benefits. These may include increased process stability, higher product quality, less material waste, and lower maintenance costs. Worrel et al. (2003) discovered that in their review of over 70 industrial case studies, these non-energy benefits often outweighed the financial value of energy savings, especially in capital-intensive industries. Energy efficient technologies can increase overall productivity by reducing downtime and improving yield consistency. In the machinery manufacturing industry, where dependability and uptime are critical performance indicators, incorporating non-energy benefits of investment evaluations can alter the perceived cost-benefit ration of energy efficiency projects.

2.4.2 Energy Management Systems and Optimization in Industrial Operations

While individual technological upgrades can result in measurable improvements, it is only by integrating these innovations into a structured energy management frameworks that manufacturers can fully realize their potential. Energy management systems, such as those defined by ISO 50001, provide a structured and repeatable method for identifying, tracking, and improving energy performance over time. According to Ioshchikhes at al. (2025) the energy management systems framework is based on a Plan-Do-Check-Act (PDCA) cycle, which includes identifying significant energy uses, setting up baselines, and implementing corrective measures based on real-time or historical energy data.

Expert systems have appeared as complementary tools within energy management frameworks to aid decision-making in increasingly complex production environments. These systems mimic human expertise and enable consistent, rule-based decision-making in identifying inefficiencies and proposing interventions. Expert systems assist to institutionalise energy knowledge while also lessening dependence on human expertise in manufacturing environments when trained energy engineers may be rare. Using such a system in a metalworking manufacturing line, Ioshchikhes et al. (2025) showed how well it lowered energy usage while preserving operational flexibility. Along with pointing out areas for improvement, the system encouraged knowledge transfer across organisational levels, auditability, and openness.

Especially in relation to dynamic power price, manufacturing schedule optimisation is another crucial area for raising energy efficiency. Time-of-Use power rates, in which costs change depending on peak and off-peak hours, have given firms incentives to move high-energy operations to less expensive tome windows. Investigating this in flexible flow shops, Zhang et al. (2019) created a multi-objective optimisation model weighing make span against electricity cost. Their methodology produced a more whole view of operational energy consumption by including setup energy, standby energy, and active processing energy. They produced Pareto-optimal answers balancing cost minimisation and production efficiency by use of a stronger Pareto evolutionary algorithm. This approach shows how closely production planning should match power pricing to lower running costs and improve sustainability measures.

Limited technical knowledge, budget constraints, and lack of data availability often stymies energy efficiency efforts. Ketenci and Wolf (2024) proposed a practical framework that combined energy flow analysis and greenhouse gas accounting and is specifically designed for non-energy-intensive small and medium-sized companies. Their application in two European case studies resulted in energy saving of 16% and 22%, respectively, thanks to cost-effective inventions that did not require large capital investments. These findings demonstrate that even small companies with limited resources can make improvements in energy efficiency when guided by structured and transparent evaluation methodologies. Such frameworks increase operational personnel awareness and ownership of energy performance, thereby contributing to the development of an efficient culture over time.

2.5 Stakeholder & Policy Engagement in Sustainability Strategies

Stakeholder and policy engagement also play an important role in companies' sustainability strategies, especially in industries with high environmental impacts, such as Nordic machinery manufacturing. Companies in this sector operate in a complex landscape where sustainability performance is shaped by regulatory requirements, industry collaborations and higher stakeholder expectations. Drawing on stakeholder theory (Freeman, 1984), this section explores how companies engage with sustainability policies, industry partnerships, and public commitments to improve their environmental and social performance.

2.5.1 Corporate Engagement in Sustainability Policies and Regulatory Frameworks

Stakeholder theory, originally introduced by Freeman (1984), provides a conceptual foundation for understanding the strategic role of external engagement in sustainability. It highlights that businesses should consider the interest of multiple stakeholders beyond shareholders, including regulators, policy makers, customers, and local communities (Donaldson & Preston, 1995). This is relevant in sustainability governance, where corporate engagement in regulatory frameworks and policy approval is essential for aligning business practices with environmental goals. (Freeman et al., 2020).

As already mentioned, Nordic countries have implemented strict climate policies, requiring companies to follow emission reduction targets, energy efficiency regulations, and extended producer responsibility programs (Meckling & Nahm, 2019). The European Union's Corporate Sustainability Reporting Directive further directive transparent disclosure of sustainability performance, reinforcing corporate accountability (European Commission, 2023).

Many Nordic machinery manufacturers go beyond compliance by actively implementing sustainability policies. This includes participation in government-industry dialogues, lobbying for incentives supporting green technologies, and contributing policy discussions on circular economy initiatives (Zomer et al., 2022). By integrating sustainability into corporate strategies, companies increase their legitimacy, mitigate regulatory risks, and strengthen relationships with key stakeholders.

2.5.2 Industry Collaborations and Stakeholder Influence in Nordic Machinery Manufacturing

Stakeholder engagement in sustainability extends beyond compliance and regulation to include voluntary collaboration, knowledge sharing, and co-development of solutions. From the perspective of stakeholder theory, such multi-actor collaboration is a strategic response to stakeholder expectations and environmental complexity. Partnerships with government bodies, NGOs, academic institutions, and industry peers enable companies to jointly address sustainability challenges, reinforce legitimacy, and build collective capacity for environmental performance (Ansari et al., 2013).

The GreenOffshoreTech project, a European Union-funded initiative that connects companies, research institutions, and public sector actors from several countries, including Nordic and Baltic regions, is a well-known example of collaborative sustainability efforts in the Nordic region. This alliance aims to accelerate the development and adoption of environmentally sustainable offshore technologies by providing small and medium-sized businesses with innovation funding, cross-border collaboration, and shared R&D resources. Participating companies are encouraged to experiment with new materials, implement energy-efficient systems, and develop sustainable production methods, especially in the maritime and offshore manufacturing sectors, where individual actors may lack the resources or expertise to innovate their own (GreenOffshoreTech, 2023). These kinds of initiatives demonstrate how industry alliances can both drive technological innovation and advocate for supportive regulatory frameworks and financial mechanisms that promote long-term environmental responsibility in industrial development (European Commission, 2022).

Beyond formal industry alliances, machinery manufacturer also engages with suppliers, customers, and competitors in sustainability-focused partnerships. Supply chain sustainability initiatives are becoming increasingly important, as companies recognize that their environmental impact extends beyond their direct operations. Strict green procurement rules help Nordic equipment businesses to guarantee that their suppliers follow sustainability standards include using recycled materials, lowering carbon emissions, and using energy-efficient technologies (Lozano, 2015). By allowing businesses to build more transparent and responsible value chains, collaborative supply chain solutions help to reduce environmental risks and raise general industry sustainability (Engert et al., 2016).

Stakeholder engagement in Nordic machinery manufacturing also involves non-governmental organizations and consumer advocacy groups, which plays an important role in holding companies accountable for their sustainability commitments. Organizations such as the Nordic Council for Sustainable Industry actively check corporate sustainability performance and push for more ambitions environmental policies. This external pressure encourages companies continuously improve their sustainability practices, adopt circular economy models, and invest in long-term sustainability strategies (Bocken et al., 2014).

Institutional investors are increasingly integrating Environmental, Social, and Governance criteria into their investment decisions. Investors following the Principles for Responsible Investment prioritize companies with strong sustainability policies, pushing companies to align their business strategies with global environmental objectives (Eccles et al., 2020). As a result, many machinery manufacturers are enhancing their environmental, social and governance disclosure practices, implementing carbon reduction initiatives, and aligning their operations with the United Nations Sustainable Development Goals.

Cross-sector collaborations between Nordic machinery companies and technology providers are driving sustainability innovation. By investing in digitalization, artificial intelligence, and data analytics, companies can optimize resource use, reduce waste and support predictive maintenance strategies that contribute to energy efficiency improvements. The integration of Industry 4.0 technologies allows manufacturers to minimize emissions and process efficiency, leading to more sustainable production methods (Beltrami et al., 2021)

2.5.3 Public Commitments, Sustainability Disclosures and Reporting Standards

From a stakeholder-oriented perspective, public sustainability commitments and corporate disclosures are not only tools for transparency but also a mechanism for building trust, legitimacy, and long-term stakeholder alignment. Stakeholder theory frames sustainability reporting as a strategic activity through which companies demonstrate responsiveness to the expectations of investors, customers, employees, and regulators (Freeman et al., 2020; Kolk et al., 2017).

Nordic machinery manufacturing companies are aligning more and more with worldwide reporting guidelines such the EU Green Taxonomy, Task Force on Climate-related Financial Disclosures, and Global Reporting Initiative (Kolk et al., 2017). These models give stakeholders organised instructions for revealing corporate sustainability performance, therefore enabling them to evaluate the environmental effect and risk management strategy of a corporation. Apart from official reporting, businesses improve openness by means of interactive environmental, social, and governance dashboards, sustainability conferences, and outside validation of environmental performance (Awa et al., 2024). The integration of sustainability metrics into financial disclosures further underscores the increasing recognition of sustainability as a strategic business priority, rather than an outlying concern.

Through strategic stakeholder engagement, industry collaborations, and transparent sustainability reporting, Nordic machinery manufacturers strengthen their resilience, align with regulatory expectations, and reinforce their leadership in sustainable industrial practices.

2.6 Sustainability Goals and Strategy Formulation

As sustainability transitions become a requirement, companies in the Nordic region are increasingly aligning their strategies with the United Nations Sustainable Development Goals (SDGs) (Figure 1). Specifically, SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate action) are central to guiding sustainable industrial practices. The alignment in sustainability goals, encompassing renewable energy adoption, energy efficiency improvements, stakeholder engagement, and carbon footprint reduction, reflects the need for a comprehensive approach to sustainability in industrial settings (Engert & Baumgartner, 2016).

Figure 1: The 17 United Nations Sustainable Development Goals. Source: United Nations (2019).

SDG 9 focuses on promoting sustainable industrialization and innovation, which are important for reducing the environmental impact on manufacturing. However, energy-related CO2 emissions reached a record 36.8 billion metric tons in 2022, underscoring the urgent need for cleaner production needs (United Nations, 2023). While high-tech industries are expanding in developed regions, least developed countries are falling behind in industrial growth, making it difficult to implement sustainable technologies at scale.

SDG 12 highlights the disproportionate environmental footprint of high-income countries, where material consumption per capita is 10 times higher than in low-income nations (United Nations, 2023). Fossil fuel subsidies stay a major barrier to sustainability, nearly doubling from $375 billion in 2020 to $732 billion in 2021. Corporate sustainability efforts have improved, with sustainability reporting tripling since 2016, but stronger policies are needed to shift industrial production toward climate-friendly solutions (United Nations, 2023).

SDG 13 focuses on reducing emissions and improving climate resilience, both important for sustainable manufacturing. The world is projected to exceed 1.5°C warming by 2050, necessitating 43% emissions reductions by 2030 and 60% by 2040 to mitigate severe climate impacts (United Nations, 2023). However, developing nations need $6 trillion in climate financing by 2030, far beyond the $803 billion currently available annually. Also, sea-level rise has doubled in the past decade, posing risks to industries reliant on coastal infrastructure (United Nations, 2023).

To achieve sustainability objectives, companies often adopt either holistic or focused strategies. Holistic sustainability strategies integrate environmental, social, and governance factors into corporate decision-making, securing a balanced approach to sustainability. Targeting certain sustainability features, like supply chain carbon reductions or energy efficiency improvements, focused sustainability strategies help businesses to get desired results more effectively (Baumgartner & Ebner, 2010). This section investigates how multi-dimensional sustainability approaches, strategic commitment, and value chain involvement help to lower carbon footprint in Nordic equipment production.

2.6.1 The Role of Value Chain Engagement in Machinery Sustainability

In machinery manufacturing, sustainability depends on interaction with the value chain as it promotes cooperation among manufacturers, suppliers, consumers, and legislators to lower environmental effects. Promotes circular economy ideas, improves efficiency gains, and reduces emissions across manufacturing and distribution systems by means of sustainable value chain management (Gualandris et al., 2014). This fits SDG 12, which emphasises responsible resource usage and sustainable manufacturing methods.

Companies in the Nordic setting have progressively set sustainability requirements for procurement strategies by choosing low-carbon footprint suppliers and enforcing rigorous environmental performance standards. Furthermore, included into their procurement policies are life-cycle assessments including life-cycle evaluations of materials and components by Finnish and Swedish producers of machinery. Research shows that companies actively engaging suppliers in sustainability efforts can reduce indirect emissions (Scope 3 emissions) by up to 20%, demonstrating the importance of collaboration across the value chain (Beske & Seuring, 2014).

Technological advancements allow real-time tracking of energy consumption and emissions across the value chain. Nordic companies using blockchain technology for transparent supply chain monitoring have improved traceability and accountability in their sustainability initiatives, making sure of compliance with regulatory frameworks such as European Union Green Deal and Fit for 55 policies (Jabbour et al., 2018). However, aligning sustainability priorities across diverse stakeholders stays a challenge. While Nordic companies are leaders in sustainable procurement, suppliers in region with less stringent environmental regulations may not align with similar sustainability standards, necessitation capacity-building efforts and supplier incentives to improve sustainability performance across the entire supply chain (Glover et al., 2014).

2.6.2 Strategic Commitment to Holistic vs Focused Sustainability Goals

The commitment to sustainability in Nordic machinery manufacturing varies based on whether companies adopt holistic or focused sustainability strategies. Holistic strategies, aligned with sustainable development goals, highlight the simultaneous pursuit of environmental, social, and governance aims, creating long-term resilience and sustainability leadership (Baumgartner & Rauter, 2016). These strategies integrate carbon reduction, circular economy initiatives, employee well-being, and corporate social responsibility efforts into business operations. Studies show that companies implementing holistic sustainability frameworks tend to outperform their competitors in long-term financial stability and regulatory adaptability (Bansal & DesJardine, 2014). Holistic strategies require remarkable financial investment, organizational change, and sustainability governance mechanisms to align various aspects of sustainability with corporate operations (Engert et al., 2016).

Conversely, focused sustainability strategies allow companies to direct resources towards specific sustainability challenges (Engert & Baumgartner, 2015). Several Danish and Finnish machinery manufacturers have, for example, successfully reduced emissions over 30% thought targeted investments in renewable energy technologies and process optimization (Wiesenthal et al., 2012). Such strategies align closely with SDG 13, which calls for urgent efforts to reduce emissions and mitigate climate change.

Despite the benefits of focused strategies, they risk overlooking broader sustainability issues, such as equity, biodiversity loss, and resource depletion (Darnall et al., 2008). Companies adopting narrow sustainability objectives may find it challenging to adapt to appearing regulatory challenges, especially as governments introduce more comprehensive environmental, social and governance reporting requirements. Therefore, the decision to pursue on factors such as regulatory pressures, industry expectations, and corporate sustainability maturity (Jenkins, 2008).

2.6.3 The Impact on Multi-Dimensional Sustainability Strategies on Carbon Reduction

Multi-dimensional sustainability strategies, which include environmental, economic, and social aspects of sustainability, offer a systematic approach to carbon footprint reduction in the machinery manufacturing sector. Research highlights that companies adopting multi-pronged sustainability strategies achieve larger carbon footprint reductions compared to companies focusing on single sustainability dimensions (Hussain et al., 2016). These strategies align with SDG 9 and SDG 13, as those promote innovation in sustainable industrial practices and emphasize climate action.

One of the most effective approaches to carbon footprint reduction in Nordic machinery manufacturing is the integration of energy efficiency improvements, renewable energy adoption, and circular economy principles (Korhonen et al., 2017). Studies indicate that companies implementing comprehensive sustainability programs, including green procurement, eco-design and closed-loop supply chains, experience remarkable reductions in emissions and energy use (Seuring & Müller, 2008). For example, Norwegian machinery manufacturing companies that have integrated closed-loop recycling systems for metal and electronic components report up to 40% reductions in material waste, contributing directly to SDG 12.

The implementation of multi-dimensional sustainability strategies also comes with challenges related to operational complexity and stakeholder alignment (Lozano, 2013). A key issue is interdepartmental coordination, where different business units operate with competing priorities, making it difficult to integrate sustainability into core business functions. Also, companies that are missing clear sustainability reporting mechanisms are most likely to struggle to measure and communicate the impact of their sustainability initiatives (Boons & Lüdeke-Freund, 2012). To address these challenges, companies have increasingly adopted third-party sustainability certifications and reporting frameworks, such as Science-Based Targets initiative and ISO 14001, ensuring larger transparency in their sustainability efforts (Hertin et al., 2008).

By using a multi-dimensional approach to sustainability, Nordic machinery producers may significantly lower their carbon footprints and match world sustainability targets. Companies may attain long-term competitive advantages, improved regulatory compliance, and more stakeholder confidence by means of holistic value chain participation, strategic sustainability planning, and integrated carbon reduction projects (Hart & Dowell, 2010). The lessons from these businesses may be used as useful models for worldwide sustainability changes in manufacturing sectors as the Nordic area keeps leading to sustainable economic practices.

2.7 Literature-Based Insights for Further Analysis

This literature has explored how sustainability is approached in machinery manufacturing, with a focus on the Nordic region. Due to its energy- and emissions-intensive operations (IEA, 2021; Kannan et al., 2023), the industry is both a main driver of environmental strain and a major actor in the economy. Growing legislative demands and stakeholder expectations have impacted how businesses handle climate-related issues, usually by means of many strategic actions. High regulatory standards, encouraging policy frameworks, and a developed culture of environmental responsibility (OECD, 2022; Nordic Council of Ministers, 2022) shape these reactions in Nordic nations. The research emphasises how businesses are negotiating difficult trade-offs between operational needs, carbon reduction, and long-term sustainability pledges (Alayón et al., 2022).

Some trends in how businesses approach to-wards sustainability objectives show themselves throughout the studied issues. Key initiatives usually seem to include renewable energy integration, energy efficiency improvements, circular economy models, and digital innovations (Jamwal et al., 2021; Geissdoerfer et al., 2016). These are joined with public sustainability pledges, policy alignment, and stakeholder involvement (freeman et al., 2018). Many businesses use multidimensional approaches spanning environmental, social, and financial concerns rather than viewing sustainability as a single goal. These combinations show the necessity to accommodate several contexts, including institutional contexts, technical capacity, and supply chains architectures (Lozano, 2015).

A recurring concept in the literature is that sustainability transitions are not linear or uniform. Companies rarely follow identical paths but apply different combinations of strategies based on their specific circumstances (Baumgartner & Ebner, 2010; Hussain et al., 2018). This has caused more people's curiosity in seeing sustainability from a configurational standpoint. Recent research stresses the need of how various variables combine to provide desired results instead of separating separate elements (Fiss, 2011). Such an approach better captures the diversity of sustainability practices and recognizes that related results can be achieved through multiple pathways (Ragin, 2008).

Taken this all together, the reviewed literature provides a broad yet detailed foundation for understanding sustainability in machinery manufacturing. It underlines the relevance of analysing not only which strategies are used, but how they are combined, adapted, and embedded within broader policy and market context. These insights support the move toward more nuanced methods of analysis that reflect the complexity of sustainability practice, and the form the basis for the following chapters, which examine these patterns.

3 Research methodology

The research methodology chapter provides an exploration of the approach taken to investigate the pathways to carbon footprint reduction in Nordic machinery manufacturing companies. This chapter outlines the research design, the selection of conditions and configurations, the data collection process, and the data analysis techniques employed in this study. By adopting Qualitative Comparative Analysis (QCA), this research aims to identify the combinations of conditions that lead to successful carbon footprint reduction in the Nordic machinery manufacturing sector.

3.1 Methodological Approach

The design of this study is an important aspect of answering the central research question: What configuration pathways of renewable energy adoption, alignment with sustainable development goals, stakeholder & policy engagement and energy efficiency improvements lead to carbon footprint reduction in Nordic machinery manufacturing? the order to address this question, the research follows case-based research design, where the sustainability practices of 16 companies from Finland, Sweden, Denmark, and Norway are analysed. The objective is to examine how various conditions interact and combine to produce the outcome of interest: carbon footprint reduction.

This research applies Qualitative Comparative Analysis (QCA), as the core methodological approach. QCA is particularly well-suited for small-N case-oriented research, where the goals are not to generalize statistically but to uncover causal configurations, different combinations of conditions that can lead to the same outcome. (Ragin, 1987; Schneider & Wagemann, 2012) Unlike conventional statistical methods that isolate the effect of individual variables, QCA enables the exploration of how multiple factors interact simultaneously to influence outcomes (Rihoux & Ragin, 2009). This makes it a powerful tool for identifying causal complexity, such as situations where renewable energy adoption contributes to carbon footprint reduction only when paired with energy efficiency or stakeholder engagement (Schneider & Wagemann, 2012).

The selection of QCA is therefore justified by its ability to analyse combinatory effects and identify multiple pathways to carbon footprint reduction. With a sample of 16 companies, QCA enables the analysis of different sustainability strategies without requiring large-scale quantitative data. It is especially appropriate here, as the effectiveness of sustainability actions often depends not on anyone condition in isolation, but on how practices are configured together in specific organizational contexts.

The company sample includes four companies from each of four selected Nordic countries. These companies represent a cross-section of the machinery manufacturing sector, varying in size, geographic location, and sub-sector (e.g., heavy equipment, precision machinery, or components). All companies included are considered prominent and well-established in their respective national markets. This sampling approach ensures a diversity of cases, allowing the study to capture a broader range of sustainability practices and to explore contextual variation in how companies pursue carbon reduction.

To carry out the QCA, the analysis was conducted using the statistical software R. R provides a flexible and transparent environment for processing both crisp-set and fuzzy-set QCA, enabling the construction of truth tables, calibration of data, and minimization of configurations. The use of R ensured that all analytical steps, from data transportation and condition scoring to the identification of sufficient and necessary configurations, were carried out systematically and reproducibly. It also allowed for the integration of numerical data from multiple sources and the handling of logical contradictions or limited diversity, which are common in configurational analysis. The software's capacity to display detailed outputs, including consistency and coverage scores, XY plots, and solution tables, supported both the rigor and clarity of the results presented in this study.

Table 1 of the QCA methodology

Stage	Description
Data collection	Secondary data gathered from sustainability reports and annual reports and upright project database of 16 companies
Calibration	Data calibrated fuzzy scores based on company performance in each condition
Truth table construction	The truth table identifies all possible combinations of conditions and the outcome (carbon footprint reduction
Analysis	Identifies which combinations of conditions are sufficient and necessary for carbon footprint reduction
Consistency and Coverage	The analysis evaluates consistency (how consistently the combination of conditions leads to the outcome) and coverage (how well the combination of conditions explains the outcome).

3.2 Configurational model

For this study, four key conditions were identified as factors influencing the outcome condition carbon footprint reduction in Nordic machinery manufacturing companies. These conditions were selected based on existing literature on sustainability practices and industry reports that highlighted drivers of environmental performance in manufacturing industries. The conditions explored are as follows:

The first condition, Renewable Energy Technologies (RET), examines the extent to which companies have adopted renewable energy sources such as wind, solar, and bioenergy. The transition to renewable energy is central to reducing carbon emissions, especially in energy-intensive industries like machinery manufacturing, where reliance on fossil fuels has traditionally been high. Companies that adopt renewable energy can reduce their carbon footprint, and this condition measures the percentage of energy used by the company that comes from renewable sources.

The second condition, Stakeholder & Policy Engagement (SPE), assesses the company's degree of participation in policy advocacy for sustainability and with outside stakeholders like government, NGOs, and industry groups. Active participation in these fields indicates a company's congruence with worldwide sustainability models and its support of group projects aimed at mitigating climate change. Companies that are more engaged in such initiatives are typically more proactive in adoption ambitious sustainability practices. In this study, SPE values were collected from the Upright Project's net impact model, specifically summing the impact scores for 'Societal Infrastructure' and 'Societal stability'. These two dimensions reflects how a company supports societal systems and contributes stability through its operations and external collaborations. Higher summed scores indicate that companies are more engaged in forming and promoting sustainability discourse, so they get better values in the QCA calibration.

The third condition, Alignment with Sustainable Development Goals (SDGA), measures the extent to which companies align their business strategies with the United Nations Sustainable Development Goals (SDGs) based on a percentage sum of the most aligned goals. Comprising environmental, social, and economic elements, the SDGs offer a complete sustainability framework. Strong linkage to multiple SDGs helps companies to apply sustainability strategies addressing carbon emissions with more general targets like social responsibility, economic resilience, and environmental conservation. As the Up-right Project reports, the rating for this condition is based on the total percentage alignment with the most important SDGs. Companies with higher summed alignment percentages to key sustainability goals—such as SDG 13 (Climate Action), SDG 9 (Industry, Innovation, and Infra-structure), and SDG 12 (Responsible Consumption and Production)—get higher scores; companies with lower overall alignment percentage score lower.

The fourth condition, Energy Efficiency Improvements (EEI), focuses on the efforts made by companies to improve energy efficiency across their operations Energy efficiency is one of the most straightforward ways to reduce carbon emissions, since it includes using less energy to create the same result, which is a crucial lever for lowering environmental impact. Companies that implement energy-efficient technologies, optimize production processes, and reduce energy consumption contribute directly to carbon footprint reduction. The scoring for this condition is based on the percentage change in energy consumption per unit of revenue between 2019 and 2023. A negative percentage indicates improvement, as the company is using less energy per euro of revenue, while a positive EEI value means that energy consumption has increased relative to output – reflecting a decline in energy efficiency.

The outcome condition, carbon footprint reduction, is measured as the percentage reduction in scope 1 and scope 2 (market-based) emissions per unit of revenue (€ billion) from 2019 to 2023. This metric captures both operational improvements and structural changes. The scoring of this condition is based on the level of emissions reduction achieved relative to revenue, where higher reduction corresponds a higher score.

3.3 Data collection

The data collection process for this research relied entirely on numeric secondary data, drawn from publicly available sources. The core of the dataset was built using the sustainability and annual reports published by the selected companies for the years 2019 and 2023. These two years were chosen to allow a five-year comparison, offering a meaningful timeframe to observe measurable changes in sustainability performance.

The reports provided standardized and detailed figures on key environmental metrics such as total energy consumption, scope 1 and 2 (market-based) greenhouse gas emissions, renewable energy usage and financial data including revenue. These indicators formed the basis for calculating each company's energy efficiency improvement and carbon footprint reduction over the period. Because this study focuses on identifying patterns through QCA, the availability of consistent numeric values was essential to ensure comparability across cases and accuracy in the calibration process.

In addition to the company reports, this study used data from the Upright Project's Net Impact Model, which served as valuable external data source for standardized sustainability metrics. The Upright Project provides scores for various impact areas, including the company's connection to sustainable development goals. The use of Upright Project data ensured that all conditions, even those traditionally evaluated qualitatively or doesn't have similar reporting standards in annual/sustainability reports, were expressed in a numeric format and thus suitable for calibration into QCA.

4 Results

This chapter presents the empirical results of the Qualitative Comparative Analysis (QCA) conducted to understand how different sustainability strategies contribute to carbon footprint reduction performance among Nordic machinery manufacturing companies. The analysis is based on a sample of sixteen companies from Finland, Sweden, Norway, and Denmark, representing a cross-section of the Nordic machinery manufacturing sector. Using Qualitative Comparative Analysis, the chapter explores both necessary and sufficient conditions, with attention to the presence and absence of specific strategy combinations in cases of high and low emissions reduction.

4.1 Overview of the Data

The dataset consists of four key conditions: Energy efficiency improvements (EEI), Stakeholder and policy engagement (SPE), Alignment with sustainable development goals (SDGA), and Adoption of renewable energy technologies (RET). These conditions were selected based on them represent the main strategic areas in which manufacturing companies may reduce their environmental impact and promote long-term sustainability.

The SDGA condition captures the extent to which companies align their operations with global sustainability frameworks. A higher SDGA score reflects a broader commitment to sustainability, encompassing environmental, social, and economic dimensions. As illustrated in Figure 2, there is a notable variation among companies in their sustainable development goals alignment. Vestas leads with score of 245, demonstrating strong commitment to multiple SDGs, followed by Danfoss (111) and Wärtsilä (87). On the lower end of the spectrum, Epiroc (36), Volvo (33), and Sandvik (30) display more limited SDG engagement, suggesting narrowed focus on sustainability initiatives. Similarly, Nilfisk (38) and Metso (37) show only moderate alignment

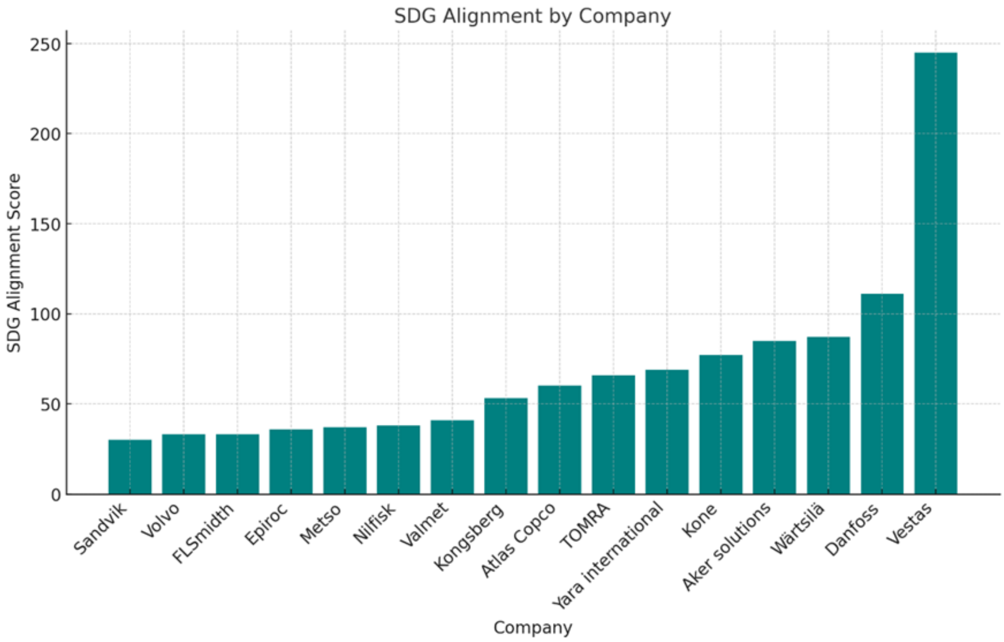

Figure 2. Bar chart for SDGA condition data

The RET condition data reveals significant differences in the extent to which Nordic machinery manufacturing companies have integrated renewable energy into their operations. As shown as in figure 3, Vestas and Kone exhibit the highest levels of renewable energy adoption, surpassing 90%, indicating a strong commitment to sustainability and decarbonization efforts. These companies have likely invested heavily in renewable energy procurement or on-site generation to minimize their reliance on fossil fuels. In contrast, companies such as Nilfisk and Valmet report considerably lower adoption rates, with Nilfisk displaying the lowest renewable energy share at just over 6%.

The distribution of RET adoption also reflects broader industry trends and strategic differences in sustainability approaches. Companies with moderate adoption levels, such as Atlas Cocpo, Wärtsilä and Yara International, indicate a partial shift towards renewables but still rely on conventional energy sources to some extent. The findings highlight that while renewable energy adoption is important factor in reducing carbon footprints, its implementation varies significantly among companies, emphasizing the need for targeted policy support and internal capability building.

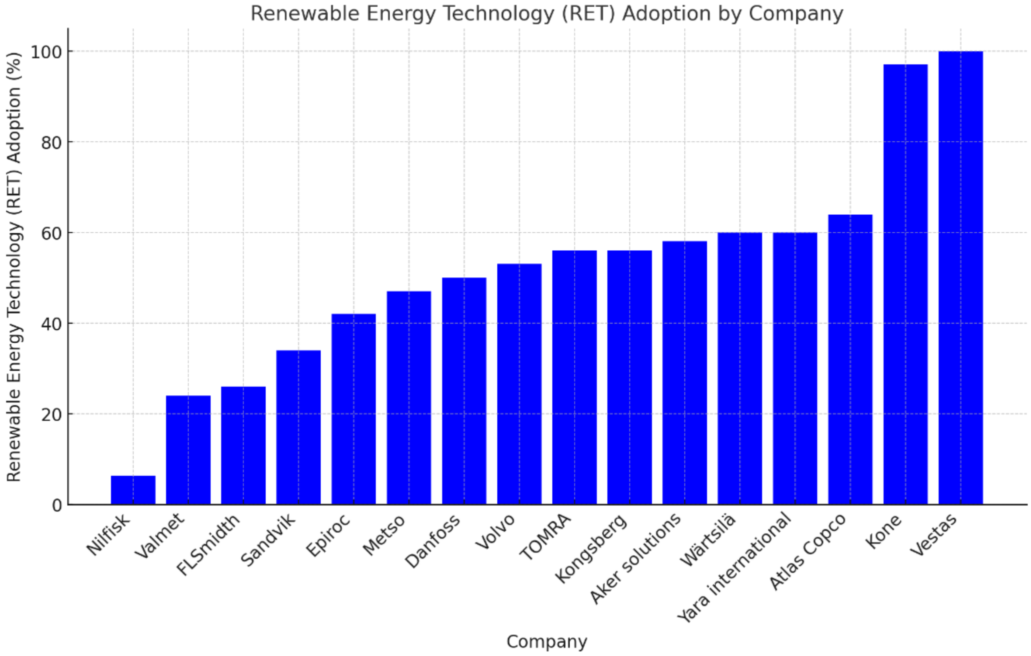

Figure 3: Bar chart for RET condition data

The EEI data illustrates how effectively companies have reduced their energy consumption relative to revenue over the period from 2019 to 2023. As shown in Figure 4, nearly all companies reported negative EEI values, indicating improvement in energy efficiency. The more negative the value, the greater the reduction in energy used per unit of output. Metso and Kongsberg stand out with the most substantial improvements, showing reductions of over 65%, suggesting strong efforts in optimizing energy use. Other companies, such as Sandvik, FLSmidth, and Yara international, also show notable improvements, reinforcing the importance of energy efficiency as a key sustainability measure.

In contrast, Aker Solutions is the only company with positive EEI value, indicating an increase in energy consumption relative to revenue, suggesting a decline in energy efficiency over the five-year period. This could reflect operational changes, increased production complexity, or a lack of investment in energy-saving technologies. The overall spread of values shows that while many companies are making progress, the depth and consistency of energy efficiency efforts still vary significantly across the sector. This highlights the need for sustained focus on energy management to ensure that energy efficiency remains a central pillar of industrial decarbonization strategies.

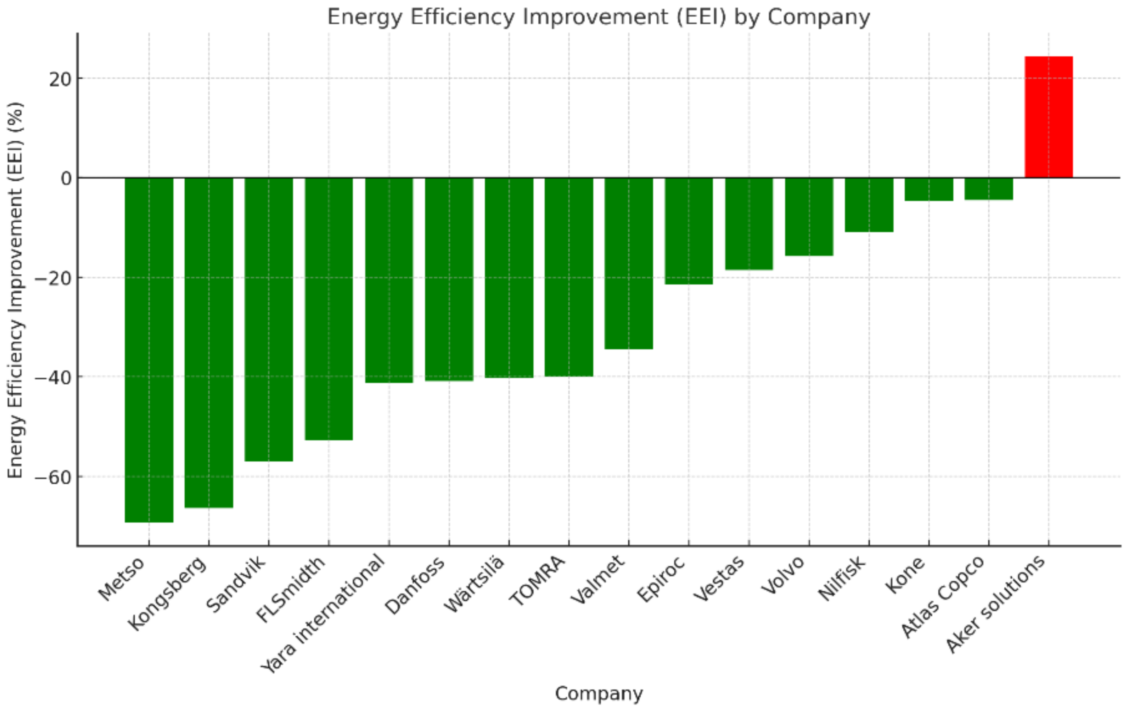

Figure 4: Bar chart for EEI condition data

The SPE condition captures how actively companies engage with external stakeholders and participate in sustainability-related policy frameworks. As shown in Figure 5, there is a wide range of SPE scores across the companies, indicating varying levels of external involvement and societal engagement. Vestas demonstrates the highest level of stakeholder and policy engagement, with score of 15.25, followed by Aker Solutions and Volvo, both of which also score highly. These companies are likely to more integrated into policy dialogues and collaborative sustainability efforts, which may enhance their ability to respond to regulatory expectations and align with global sustainability frameworks.

At the other end of the spectrum, companies such as FLSmidth, Yara International, and Kongsberg report notably low SPE scores, with Kongsberg showing a negative value, indicating limited or possibly even counter-impactful engagement in this area. This suggest either lack of public-facing sustainability activity or a limited presence in collaborative sustainability platforms. Most other companies fall somewhere in the middle, with moderate engagement levels. The spread of SPE scores reflects a broader divide between companies that treat external engagement as a strategic sustainability tool and those that focus more on internal performance. These differences are important when evaluating how sustainability outcomes – like carbon footprint reduction – are influenced not just by internal efforts, but also by external positioning and policy alignment.

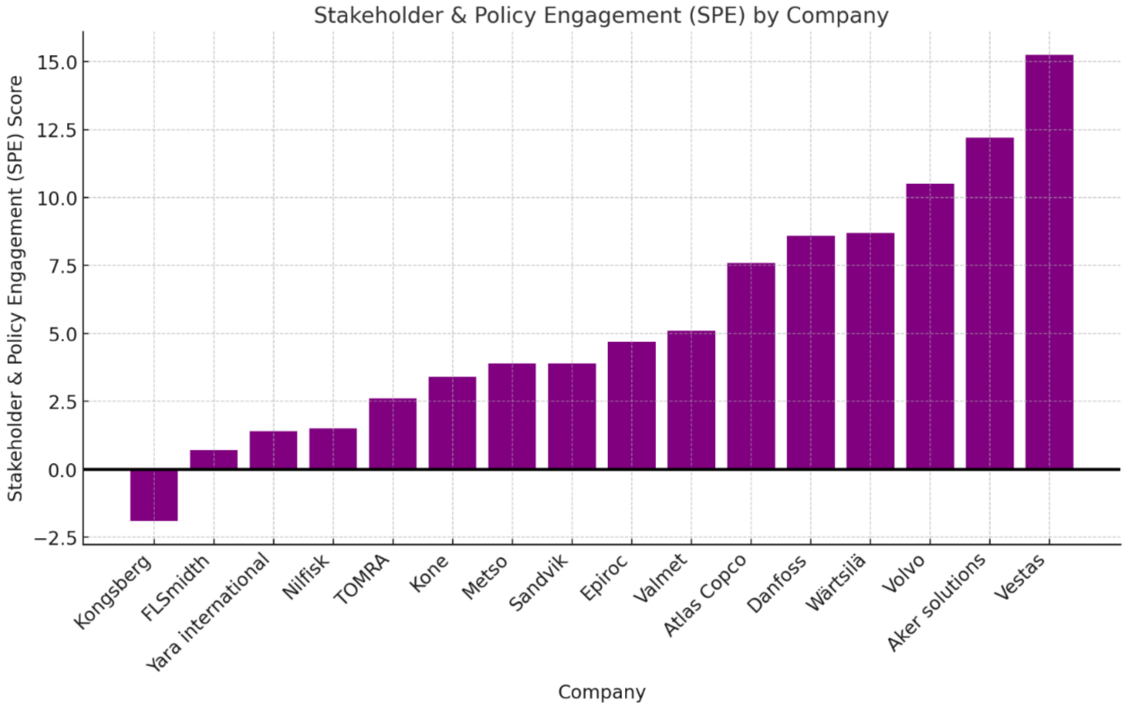

Figure 5: Bar chart for SPE condition data

The outcome variable in this study captures the percentage reduction in Scope 1 and 2 (market-based) greenhouse gas emissions per unit of revenue between 2019 and 2023. This metric reflects how effectively each company has managed the decouple its emissions from financial growth, an essential indicator of progress in corporate decarbonization. As shown in Figure 6, there is a considerable range in carbon footprint reduction outcomes across the sample. Metso, Kongsberg, and Valmet report the most significant reductions, with emissions intensity declines of over 70%, suggesting major progress toward operational decarbonization. These companies likely combined several sustainability strategies, including energy efficiency, renewable energy use, and strategic changes in production or sourcing.

On the lower end, companies such as Nilfisk, Vestas and Volvo show more limited reductions, with values below 35%. These modest improvements may reflect slower progress in emission reduction efforts, limited access to low-carbon technologies, or increases in overall energy use during the study period. The spread of results indicates that while many companies have made meaningful strides, the degree of carbon footprint reduction varies widely. This highlights the importance of not only adopting sustainability initiatives, but also ensuring they are implemented at a scale and depth sufficient to drive measurable environmental impact. The outcome data ultimately provides clear benchmark for assessing which configurations of conditions are most effective in reducing emissions across the Nordic machinery manufacturing sector.

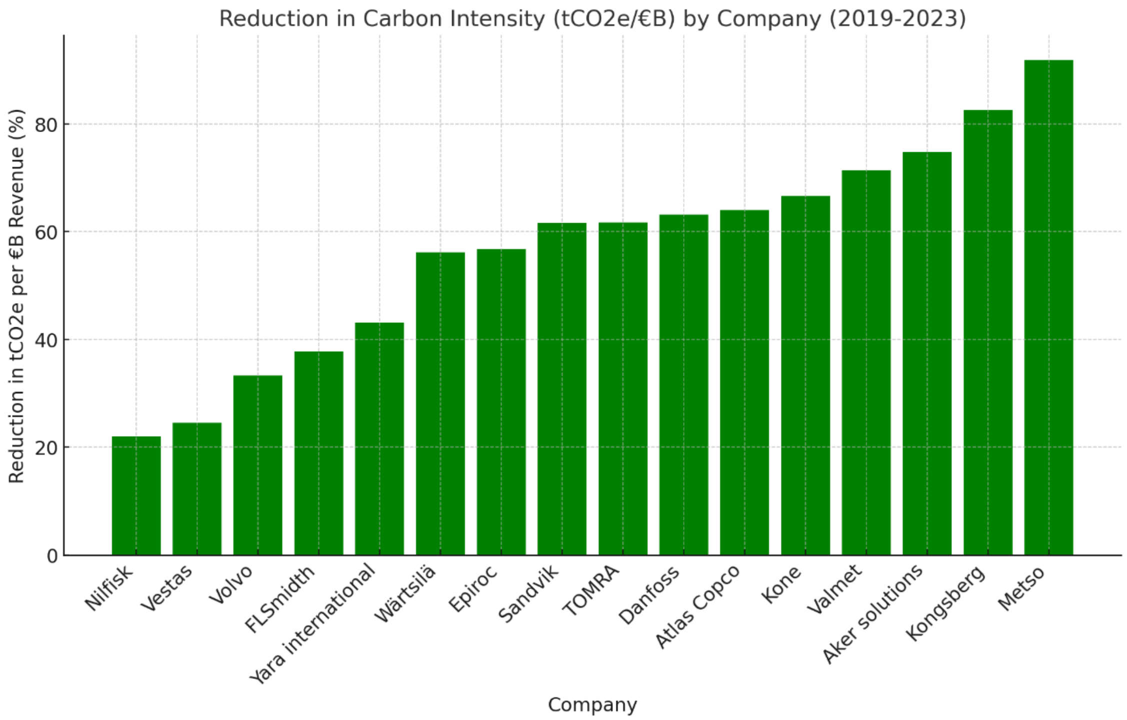

Figure 6: Bar chart for Outcome variable data

4.2 Calibration of Data for QCA

Before moving forward with the actual QCA, the raw numerical data gathered from company annual and sustainability reports and Upright Project needed to be calibrated. Calibration refers to the process of translating empirical data into set membership scores, aligning the data with the logic of set-theoretic methods. This step is important in enabling cross-case combinations of conditions that are associated with a given outcome. Without calibration, it would not be possible to meaningfully assess whether company can be considered "in" or "out" of a specific set – such as the set of companies committed to renewable energy adoption or those engaging with sustainability policy frameworks.

In this study, fuzzy-set QCA (fsQCA) were used to explore the relationship between sustainability practices and carbon footprint reduction. All the conditions where calibrated using three-value anchor system: full membership, cross-over point and full non-membership. The selection of these thresholds was guided by theoretical reasoning, practical relevance within the industry, and the actual distribution of values in the dataset. For instance, companies sourcing more than 80% of their energy from renewable sources were considered fully in RET condition, while those with less than 10% renewable energy were considered fully out. Values between these anchors were assigned scores accordingly.

Table 2. Qualitative thresholds of outcome and conditions.

Outcome and Conditions	Threshold Full Non-membership	Crossover Point	Threshold Full Membership
Renewable energy technologies (RET)	10%	50%	80%
Stakeholder & Policy Engagement (SPE)	0	6	13
Alignment with Sustainable Development Goals (SDGA)	35%	63%	150%
Energy Efficiency Improvements (EEI)	0	35%	50%
Carbon Footprint Reduction	30%	60%	85%

The calibration process was conducted using the R programming language, which allowed for consistent, transparent, and the replicable data transformation. Each company in the sample was assigned a fuzzy score between 0 and 1 for each condition, reflecting its degree of membership in the respective set. This approach enabled a more refined analysis of variation across cases, allowing for partial inclusion in sets rather than relying solely on binary distinction. It provided the flexibility to capture meaningful differences in sustainability performance that might otherwise be overlooked in a purely dichotomous framework.

The fuzzy-set calibration table, Table 3, reveals differences between cases, showing varying degrees of membership across all conditions. It enables the identification of partial patterns and cases near the cross-over threshold, which are particularly important in assessing consistency and coverage. To make the table clearer, scores that are over cross-over point are highlighted. The diversity of membership values across companies – especially those close to 0.5 – will be explored further in the analysis to uncover which configurations are more reliably associated with lower carbon footprints.

Table 3: Fuzzy-set calibration table for 16 cases.

Case	Outcome	Conditions			
Company	Carbon footprint reduction	Energy Efficiency Improvements (EEI)	Stakeholder & Policy Engagement (SPE)	Alignment with Sustainable Development Goals (SDGA)	Renewable Energy Technologies (RET)
Kone	0.6849	0.0728	0.2182	0.6642	0.9908
Metso	0.9772	0.9988	0.2629	0.0656	0.4287
Wärtsilä	0.4081	0.7324	0.7569	0.7294	0.7138
Valmet	0.7943	0.4905	0.3913	0.1129	0.1258
Epiroc	0.4219	0.2420	0.3457	0.0577	0.3438
Atlas Copco	0.6170	0.0718	0.6622	0.5387	0.7892
Volvo	0.0681	0.1659	0.8698	0.0377	0.5506
Sandvik	0.5469	0.9869	0.2629	0.0246	0.2278
FLSmidth	0.1014	0.9706	0.0609	0.0377	0.1424
Danfoss	0.5919	0.7609	0.7491	0.8501	0.4821
Vestas	0.0298	0.2009	0.9799	0.9933	0.9931
Nilfisk	0.0234	0.1158	0.0990	0.0756	0.0387
TOMRA	0.5502	0.7270	0.1586	0.5844	0.6242
Aker Solutions	0.8500	0.0067	0.9313	0.7170	0.6706
Yara International	0.1605	0.7726	0.0947	0.6061	0.7138
Kongsberg	0.9347	0.9979	0.0202	0.4269	0.6242

4.3 Necessity Analysis: Identifying Essential Conditions

This section examines whether any individual condition in the dataset can be considered necessary for the successful reduction of carbon footprint emissions among Nordic machinery companies. In QCA, necessity analysis plays an important role in identifying whether a presence or an absence of a condition can be considered, as necessary. If a condition is necessary, it means that outcome cannot occur without it, even if it is not alone sufficient to cause the outcome (Scheider & Wagemann, 2012).

4.3.1 Necessity Test for the Positive Outcomes

The necessity test was conducted for all individual conditions and their negations. This test identifies whether any single condition is required to achieve positive or negative outcome. The commonly required consistency threshold is 0.9 (Scheider & Wagemann, 2012). The results showed that no individual condition was necessary on its own.

The most notable finding is the relatively high consistency (inclN) value for adoption of renewable energy technologies (RET), which scores 0.715. Although this does not meet the conventional cutoff of 0.9 required to classify a condition as strictly necessary, it does indicate that RET is present in a substantial majority of cases where carbon footprint reduction observed. In addition, RET shows a reasonably high relevance of necessity (0.721), suggesting that when it is present, it is meaningfully tied to the outcome. The coverage value (0.656) also supports this view by indicating that many outcome-positive cases overlap with high RET scores. Together, these metrics suggest that RET plays a foundational, though not irreplaceable, role in carbon footprint reduction strategies.

Table 4. Fuzzy-set Necessity analysis: Presence of conditions in positive outcomes.

Condition	Consistency	Relevance of Necessity	Coverage
Energy Efficiency Improvements (EEI)	0.680	0.717	0.635
Stakeholder & Policy Engagement (SPE)	0.569	0.788	0.642
Alignment with Sustainable Development Goals (SDGA)	0.573	0.820	0.681
Renewable Energy Technologies (RET)	0.715	0.721	0.656

Energy efficiency improvements (EEI) show similar patterns, with consistency score of 0.680 and relevance of necessity of 0.717. These values indicates that EEI, like RET, is often associated with companies that successfully reduce their emissions, though again it is not universally present. In practice, this means that many companies pursue energy efficiency as part of their strategy, but others achieve similar outcomes through different combinations of conditions. For instance, a company may lack strong internal energy efficiency upgrades but still succeed in lowering emissions through substantial renewable energy investments or through external partnerships that contribute to decarbonization efforts across the value chain.

To deepen the analysis, the necessity test was also applied to absence of each condition. This helps explore whether companies may achieve carbon footprint reduction precisely by not engaging in certain practices. In other words, can success occur in the absence of stakeholder engagement, sustainability development goals alignment, energy efficiency initiatives, or renewable energy technologies? Table 5 summarizes the fuzzy-set necessity scores for the absence of each condition

Table 5. Fuzzy-set necessity analysis: Absence of conditions in positive outcomes.

Condition	Consistency	Relevance of Necessity	Coverage
Energy Efficiency Improvements (EEI)	0.540	0.704	0.545
Stakeholder & Policy Engagement (SPE)	0.742	0.671	0.631
Alignment with Sustainable development Goals (SDGA)	0.714	0.624	0.585
Renewable Energy Technologies (RET)	0.619	0.755	0.537

The results show that none of the absent conditions reach to the 0.9 consistency threshold required for necessity. However, the absence of SPE and SDG is relatively common among companies that achieved carbon reductions, with consistency values of 0.742 and 0.714. This suggest that a considerable number of companies successfully reduced emissions without engaging deeply with stakeholders or implementing high diversified sustainability agendas.

The findings highlight that there is no single condition that is universally required for carbon footprint reduction, reinforcing the QCA principle of equifinality. In the Nordic machinery manufacturing sector, companies appear to adopt diverse strategies on their unique capabilities and context. Some focus on internal measures like energy efficiency, while others may emphasize external engagement and collaboration.

4.3.2 Necessity test for the Negative Outcomes

Necessity test was also extended to examine whether the presence of any condition is necessary for the negative outcome to occur. This analysis helps determine whether some sustainability strategies may be present in unsuccessful cases. Table 6 displays the results.

Table 6. Fuzzy-set necessity analysis: Presence of conditions in negative outcomes.

Condition	Consistency	Relevance of Necessity	Coverage
Energy Efficiency Improvements (EEI)	0.576	0.683	0.571
Stakeholder & Policy engagement (SPE)	0.591	0.820	0.709
Alignment with Sustainable development Goals (SDGA)	0.523	0.810	0.660
Renewable Energy Technologies (RET)	0.667	0.718	0.650

The result of this analysis indicates that no condition reaches the threshold for necessity, as all relevance of necessity scores remain too low. To deepen the analysis, the necessity test was also applied to absence of each condition for negative outcome.

Table 7. Fuzzy-set necessity analysis: Absence of conditions in negative outcomes.

Condition	Consistency	Relevance of Necessity	Coverage
Energy Efficiency Improvements (EEI)	0.631	0.770	0.677
Stakeholder & Policy Engagement (SPE)	0.702	0.672	0.633
Alignment with Sustainable development Goals (SDGA)	0.748	0.663	0.650
Renewable Energy Technologies (RET)	0.646	0.793	0.706

The results reveal that absence of sustainability conditions is quite consistently present in companies with negative outcomes. The absence of alignment with sustainable development goals alignment shows the highest consistency (0.748) suggesting that companies that do not actively align with sustainable development goals are more likely to fall short in reducing their carbon footprint. Similarly, the absence of stakeholder and policy engagement also shows relatively high consistency.

Taken together, these results suggest that the absence of key sustainability conditions are more consistently associated with negative outcomes than their presence. However, it is important to note that none of the conditions reached the 0.9 score, as recommended by Scheider and Wagemann (2012). This indicated that while certain practices may be common in non-successful cases, no single condition can be considered strictly necessary for explaining the absence of carbon footprint reduction.

4.4 Sufficiency Analysis: Identifying Pathways to Carbon Footprint Reduction

In this section, the sufficiency analysis in conducted to explore which combinations of conditions are reasonable to produce the outcome of interest: carbon footprint reduction. Sufficiency analysis is a cornerstone of QCA, as it seeks to identify the multiple causal paths that the sufficient to bring about the outcome (Scheider & Wagemann, 2012). Unlike necessity analysis, which aims to determine what must be present for an outcome to occur, sufficiency analysis focuses on whether specific combinations of conditions are enough to lead to the desired result, even if other cases achieve the same outcome through different routes. This perspective of equifinality aligns closely with realities of complex organizational strategies, especially in sustainability where multiple paths may coexist.

To begin the analysis, I created truth table to identify which combinations of four conditions are associated with positive and negative outcome. These included configurations such as RET being present while other conditions are absent (e.g., Kongsberg), or SDGA and SPE being present in the absence of EEI and RET (e.g., Kone), and configurations combining strong internal sustainability elements (EEI, SDGA) while omitting external stakeholder engagement (e.g., Danfoss). To simplify the combinations of conditions, I used the process of minimization in R software, applying a consistency cut-off of 0.8 and a frequency threshold of 1.

Table 8. Truth table.

EEI	SPE	SDGA	RET	OUTCOME	n	incl	PRI	Cases
1	1	1	0	1	1	0.967	0.746	Danfoss
0	0	1	1	1	1	0.965	0.809	Kone
1	0	0	1	1	1	0.892	0.77	Kongsberg
0	1	0	1	0	1	0.818	0.298	Volvo
1	0	1	1	1	2	0.813	0.505	TOMRA, Yara international
1	1	1	1	0	1	0.776	0.192	Wärtsilä
0	1	1	1	0	3	0.761	0.463	Altas copco, Vestas, Aker Solutions
1	0	0	0	0	3	0.737	0.502	Metso, Sandvik, FLSmith
0	0	0	0	0	3	0.641	0.199	Valmet, Epiroc, Nilfisk

In truth table three key indicators help evaluate the strength of each configuration. The consistency score (Incl.) measures how often does the outcome occur when the recipe is present; values closer to 1 indicate a stronger relationship. The Proportional Reduction in Inconsistency (PRI) provides additional clarity by assessing whether a configuration leads to the outcome rather than its absence, helping to distinguish genuine sufficiency from ambiguous cases. The number of cases (n) refers how many companies fall into each configuration. Together, these metrics help identify which condition combinations are empirically strong enough to be considered sufficient, guiding the construction of the final QCA solution models.

4.4.1 Intermediate Solution: Balancing Theory and Empirics

The intermediate solution analysis identified three configurations that lead to successful carbon footprint reduction among Nordic machinery manufacturers. The intermediate solution is theoretically guided, incorporating directional expectations for energy efficiency improvements and renewable energy technologies (both expected to be positive contributors to the outcome) (Ragin,2008). These expectations help bridge the gap between empirically supported and theoretically plausible solutions.

The sufficiency plot for intermediate solution (Figure 7) shows strong consistency and moderate coverage of the identified configurations. Several case companies, such as Metso, Aker Solutions, and Valmet, are positioned above the diagonal line, supporting relationship between the configurations and the outcome. However, the top-right quadrant remains sparsely populated, suggesting that high configuration memberships does not always lead to high outcome memberships. Some cases, like Atlas Copco and Sandvik, show only moderate outcome scores despite moderate configuration membership. The solution coverage of 0.630 and a PRI value of 0.591 further describe the explanatory strength of the identified configurations.

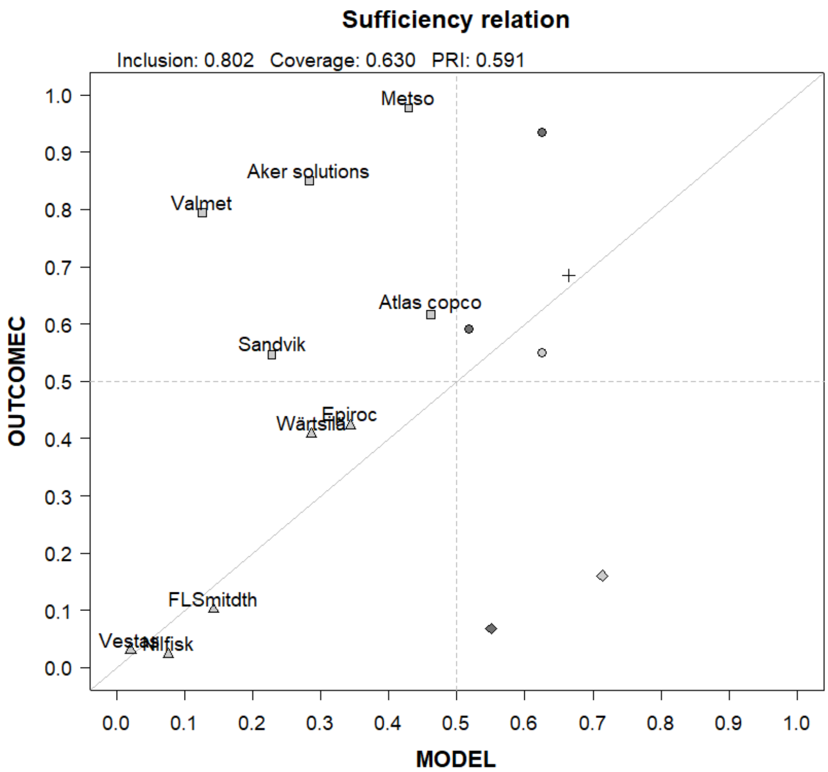

Figure 7. Intermediate solution positive plot.

To clearly illustrate and synthesize the identified configurations that contribute to carbon footprint reduction among Nordic machinery companies, a visualization based on Fiss (2011) was employed. Table 9 summarizes the core and peripheral conditions using direct symbols and sizes, clearly indicating their theoretical and practical significance.

In this visualization, core conditions (●, large solid circle) represent factors that are crucial and consistently influential for achieving carbon footprint reduction across configurations, while peripheral conditions (•, small solid circle) denote supporting elements that strengthen configurations contextually but carry less individual importance. Conditions whose absence is pivotal to outcomes are depicted as core absence (⨂, large, crossed circle) or peripheral absence (⊗, small, crossed circle). Blank cells denote conditions irrelevant or non-essential to the configurations.

Table 9. Configurations for positive outcome.

Condition	Configurations for positive outcomes		
	Operational efficiency focus (P1)	Goal-driven autonomy (P2)	Structured internal reform (P3)
Energy Efficiency Improvements	•		•
Renewable Energy Technologies	●	●	
Stakeholder & Policy Engagement	⨂	⨂	•
Alignment with Sustainable Development Goals		•	•
Consistency	0.812	0.861	0.967
Unique Coverage	0.051	0.057	0.036
Number of case companies under configuration	3	3	1
Strong cases under configuration	Kongsberg, TOMRA, Yara International	Kone, Tomra, Yara International	Danfoss
Solution consistency: 0.802 Solution coverage: 0.630			

Configuration P1: Operational efficiency focus

(fsQCA: EEI * ~SPE * RET)

This configuration is characterized by a strong internal focus on energy efficiency and renewable energy technologies, without active engagement with external stakeholder-policy processes or broad alignment with sustainable development goal frameworks. The companies in this group prioritize technical and operational levers for emission reduction while maintaining a relatively low profile in terms of external sustainability governance.

For example, Kongsberg gives a clear example of this pathway. In 2023, the company expanded its use of renewable energy, with 56% of its purchased electricity sourced from certified renewable suppliers and launched a major geothermal energy project at Kongsberg Technology Park to support its decarbonization goals (Kongsberg, 2024). Kongsberg has also implemented energy optimization programs across its production facilities, introducing digital monitoring systems to improve energy management and operational efficiency (Kongsberg, 2024). While the company's science-based climate targets were approved by Science Based Targets initiative (SBTi), its broader external stakeholder engagement remains limited, with primary focus on internal operational improvements rather than extensive participation in global sustainability coalitions. This pathway illustrates that emissions reduction can result from inward-looking, technical strategies without broader external alignment or extensive sustainability discourse.

Configuration P2: Goal-Driven Autonomy

(fsQCA:~SPE * SDGA * RET)

In this configuration, companies succeed by combining renewable energy adoption with strong internal alignment with sustainable development goal setting, even without engaging in formal stakeholder platforms. These companies tend to rely on voluntary initiatives, corporate strategy, and internal governance to achieve carbon reduction.

TOMRA exemplifies this approach by sourcing 56% of its purchased electricity from renewable sources globally in 2023 and aligning its corporate strategy closely with the

United Nations Sustainable Development Goals, especially SDG 12 (Responsible consumption and production) and SDG 13 (Climate action) (TOMRA, 2024). Under its “resource revolution” strategy, TOMRA voluntarily sets and tracks progress toward sustainability objectives, without extensive reliance on external stakeholder frameworks. The company emphasizes self-governance and transparency over external certifications, demonstrating that companies can successfully achieve carbon footprint reductions through internal goal-setting and renewable energy adoption without relying heavily on external multistakeholder platforms.

Configuration P3: Structured Internal Reform

(fsQCA: EEI * SPE * SDGA * ~RET)

The third positive configuration illustrates a comprehensive approach that combines internal efficiency measures, active stakeholder-policy engagement, and broad alignment with sustainable development goals, despite lacking full adoption of renewable energy technologies. This configuration suggest that companies can reach meaningful emissions reduction by compensating for gaps in one area through strength in others.

Danfoss fit this configuration well. In 2023, Danfoss reported improvements in energy efficiency across its global operations, with multiple factories achieving ISO 5001 certification for energy management (Danfoss, 2024). The company also demonstrated high engagement with external sustainability initiatives, being an active participant in the UN Global Compact and aligning its corporate strategy with SBTi. Danfoss has embedded the UN Sustainable Development Goals, particularly SDG 7 (Affordable and clean energy) and SDG 13 (Climate action), into its governance structure. Despite these strong internal and external efforts, the share of renewable energy in Danfoss total energy consumption remained relatively modest, illustrating that substantial emission reductions were primarily achieved through operational efficiency improvements and strong governance mechanisms rather than full renewable energy adoption.

The configurations visually presented highlight various pathways companies have towards sustainability. These specific configurations were chosen based on their consistency, coverage, and theoretical coherence from intermediate solutions identified through the QCA analysis. Strong adoption of renewable energy technologies (RET) appears as a critical core condition in two configurations, reinforcing its overarching relevance. Stakeholder and policy engagement (SPE) appears contextually sensitive, important in its absence for some configurations and in its peripheral presence in others, demonstrating the nuanced role of stakeholder interactions in sustainability outcomes. Also, conditions like energy efficiency improvements (EEI) and alignment with sustainable development goals (SDGA) play meaningful yet peripheral roles, demonstrating that companies approach sustainability through a variety of strategic combinations.

4.5 Sufficiency Analysis: Exploring Negative Configurations for Carbon Footprint reduction

In this section, the sufficiency analysis for the negative outcome (failure to reduce carbon footprint) is explored, focusing on identifying configurations of condition that might contribute to this outcome. The analysis uses intermediate solution to understand the various pathways through which companies fail to reduce their carbon footprints despite adopting certain sustainability strategies.

4.5.1 Intermediate Solution: Theory-Guided view on Emission Reduction Failures

The intermediate solution for the negative outcomes representing the absence of carbon footprint reduction, reveals four configurations among Nordic machinery manufacturers. This solution allows for a deeper understanding of interplay between different sustainability practices and the failure to reduce emissions. The solution produces a consistency score of 0.779 and a coverage of 0.626, suggesting that these four configurations explain substantial part of the negative cases in the dataset. A consistency cut-off of 0.83 and a frequency threshold of 1 were applied in the solution process to ensure sufficient empirical support. The sufficiency plot (Figure 8) shows a coverage of 0.717 and inclusion score of 0.703, indicating that the model explains a notable share of failure cases. Compared to the positive outcome, the model for negative cases appears less systematic, with a more scattered distribution of observations.

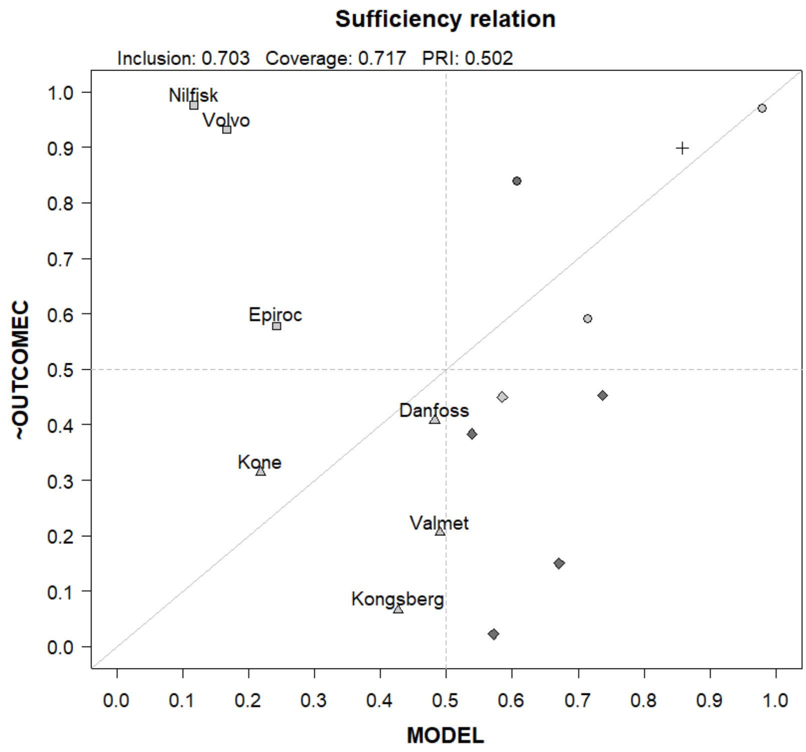

Figure 8. Intermediate solution negative plot.

Each configuration reveals a different failure more, ranging from a lack of technological investment to strategic misalignment and insufficient stakeholder involvement. The interpretation below is aligned with the condition symbols and configuration names provided in table 10. The visualization follows same pattern as in the Table 9, large solid circles show core conditions strongly linked to negative outcomes, while small solid circles represent peripheral conditions that are supportive but less critical. Large, crossed circles indicate crucial absences of conditions, and small crossed circles indicate less critical absences. Empty spaces means that the condition is irrelevant for that configuration.

Table 10. Configurations for negative outcome

Condition	Configurations for negative outcomes			
	Engaged but unstructured (N1)	Full spectrum misalignment (N2)	Passive non-adopters (N3)	Strategy-lacking operators (N4)
Energy Efficiency Improvements	⊗	•	⊗	⊗
Renewable Energy Technologies			⊗	⊗
Stakeholder & Policy Engagement	•	•	⊗	
Alignment with Sustainable development goals	⊗	•		⊗
Consistency	0.882	0.793	0.892	0.870
Unique Coverage	0.052	0.089	0.000	0.000
Number of case companies under configuration	1	2	3	3
Strong cases under configuration	Volvo	Wärtsilä	Valmet, Epiroc, Nilfisk	Valmet, Epiroc, Nilfisk
Solution consistency: 0.779				
Solution coverage: 0.626				

Configuration N1: Engaged but Unstructured

(fsQCA: ~EEI*SPE~SDGA)

This configuration describes a scenario where companies are externally engaged but internally fragmented. The presence of stakeholder-policy engagement indicates a willingness to participate in public sustainability efforts, yet the lack of energy efficiency and alignment with sustainable development goals undercuts effectiveness.

As a case company, Volvo exemplifies this configuration through its strong engagement with public and industry-wide sustainability initiatives, despite internal fragmentation in energy management and sustainability goal integration. In 2023, Volvo actively participated in international decarbonizing programs (Volvo group, 2024). However, its internal decarbonization results remained modest, direct scope 1 and scope 2 emissions intensity decreased only a slightly from 2019, reflecting limited operational emissions reductions relative to revenue growth. Volvo's sustainability reporting shows a focused but narrow approach to SDG integration, concentrating mainly on climate aspects without broader SDG governance structures. This mismatch between external advocacy and limited internal transformation helps explain why Volvo falls into the negative outcome group in this analysis.

Configuration N2: Full Spectrum Misalignment

(fsQCA: EEI*SPE*SDGA)

In this surprising configuration, three conditions are present, yet outcome is negative. This points to a situation where efforts exist but may be misaligned, fragmented, or insufficiently integrated to produce effective decarbonization.

Wärtsilä appears here. In 2023, the company reported extensive sustainability initiatives, including ISO 14001 certification, integration of SDG frameworks into reporting structures, and participation in maritime decarbonization alliances (Wärtsilä, 2024). However, Wärtsilä's direct Scope 1 and 2 emissions relative to revenue showed only modest improvement insufficient to drive strong decarbonization pathway. Several factors may explain this discrepancy: first, while energy efficiency programs exist, they may represent incremental gains rather than systemic transformations. Second, sustainability efforts may be dispersed across business units without centralized strategic coordination, and third, operational expansions or technological complexities in Wärtsilä's core activities may have offset emissions gains. Thus, the presence of EEI, SPE, and SDGA conditions does not automatically guarantee successful carbon footprint reduction when efforts are fragmented, limited scale, or undetermined by other corporate growth dynamics.

Configuration N3: Passive non-adopters

(fsQCA: ~EEI~SPE~RET)

This configuration captures companies that are disengaged across all cores technical and governance dimensions. The absence of energy efficiency improvements, stakeholder-policy engagement, and renewable energy adoption indicates a passive posture toward sustainability.

Valmet is a one case company that exemplifies this configuration. In 2023, Valmet reported limited advancements in energy efficiency initiatives, low levels of renewable energy integration, and minimal visibility in external sustainability collaborations (Valmet, 2024). While acknowledging environmental responsibility, the company's operational strategies appeared more reactive than transformational, with sustainability actions remaining isolated rather than systematically embedded. This passive stance toward technological and governance innovation helps explain why Valmet achieved only modest progress in carbon footprint reduction, placing it within the negative outcome group. m

Configuration N4: Strategy-Lacking Operators

(fsQCA: ~EEI~SDGA~RET)

The final configuration emphasizes the absence of energy efficiency, alignment with sustainable development goals, and renewable energy, but allows for possible variation in policy engagement. These companies operate without a defined sustainability strategy, lacking both guiding objectives and implementation mechanisms.

Epiroc provides a clear example of this configuration. In its 2023 sustainability reporting, Epiroc demonstrated limited progress across critical areas: no major energy efficiency achievements were highlighted, renewable energy usage remained marginal, and comprehensive alignment with the UN Sustainable Development Goals was absent (Epiroc, 2024). This structural passivity across both technical and governance dimensions helps explain why Epiroc remains in the negative outcome group.

The negative configurations were selected based on their high consistency, coverage, and relevance identified through the QCA analysis. The absence of energy efficiency improvements (EEI) stood out as a major barrier, as did limited stakeholder and policy engagement (SPE). The absence of renewable energy technologies (RET) and limited alignment with sustainable development goals (SDGA) were also significant factors that negatively impacted companies' sustainability outcomes.

5 Discussion

This chapter discusses the main findings of the study in the light of research question. Based on the QCA results presented in Chapter 4, this chapter interprets the identified configuration pathways and explores what they reveal about how sustainability is practiced in this industrial context. The aim is to make sense of the empirical results by reflecting on the role of different conditions, individually and in combination, and how they shape emission reduction outcomes. The discussion is divided into three parts: Section 5.1. provides an interpretation of the findings through the lens of key patterns and differences across successful and unsuccessful cases. Section 5.2 outlines the practical and theoretical implications of the results and Section 5.3. addresses the limitations of the study and suggests directions for the future research. Together, these sections position the findings within the broader conversation on industrial sustainability and configurational thinking.

5.1 Interpretation of results

The research question for this study was: What configuration pathways of renewable energy adoption, alignment with sustainable development goals, stakeholder & policy engagement and energy efficiency improvements lead to carbon footprint reduction in Nordic machinery manufacturing? Using fuzzy-set Qualitative Comparative Analysis (fsQCA), several distinct configurations were identified that explain both successful and unsuccessful outcomes. Rather than single formula for sustainability, the results support the idea of equifinality (Ragin, 2008): different combinations of strategies can lead to similar ends. This perspective is an essential in a complex field like sustainability, where companies vary in size, technological readiness, and stakeholder environments. At the same time, the findings show that there are many ways to fall short, often because of inconsistency, fragmentation, or a lack of strategic focus.

One of the clearest patterns among the successful configurations was the importance of internal operational strategies. Companies that concentrated on visible energy efficiency improvements and renewable energy adoption tended on achieve stronger carbon footprint reductions, even if their external engagement was limited. This finding confirms earlier research showing that technological upgrades can be powerful drivers of environmental performance (Porter & van der Linde, 1995). In the context of Nordic manufacturing, operational excellence seems to carry weight. This leads to the first proposition:

Proposition 1: Technically focused configurations, those built on concrete efficiency improvements and decarbonization technologies, can produce strong environmental outcomes even without extensive external collaboration.

This proposition supports the view that companies do not necessarily need broad external involvement to make real progress, technological depth and operational excellence can in themselves, be sufficient. It reflects what Porter and Kramer (2011) describe as "shared value", where internal operations become a central part of societal impact. Evans et al. (2017) argue that context-specific strategies based on organizational strengths are often more effective than externally imposed sustainability models. In this study, companies with strong technical performance were able to achieve meaningful results without necessarily engaging heavily in public-facing sustainability narratives.

Another pathway involved strong internal governance, especially clear sustainability goal setting that was embedded withing the company's strategy and daily management. Here, the emphasis is not so much on external signalling but on how well company holds itself accountable internally. Prior studies have pointed to the role of leadership and internal systems (Bocken et al., 2014), and the results here reinforce that view. Setting ambitious targets and tracking performance rigorously appear to matter as much than public stakeholder activities in this industrial context. This leads to the second proposition:

Proposition 2: Strong internal sustainability governance, when strategically aligned with technology investments, can substitute for stakeholder engagement as a driver of carbon footprint reduction.

This finding also reflects broader concerns in the literature about the gap between corporate sustainability talk and actual performance. Delmas and Burbano (2011) argue that companies often over-communicate their sustainability intentions without fully operationalizing them. The present findings illustrate that high performance is more likely when companies focus inwards embedding sustainability into governance structures and every day decision making, that when they rely primarily on outward-facing commitments. Thus, internal alignment appears more critical than visibility alone.

One interesting result is that full sustainability performance across all areas was not a requirement for success. Some companies with relatively weaker renewable energy adoption still performed well because they strengthened other areas, such as energy efficiency and internal governance. This reflects the broader systems thinking in sustainability research (Baumgartner,2013), where it is not perfection of individual actions but their connection and reinforcement that creates real outcomes. This leads to the third proposition:

Proposition 3: Balanced configurations that integrate multiple sustainability elements, internal and external, can compensate for specific weakness, provided there is strategic coherence and implementation strength.

These findings align with previous studies suggesting that isolated efforts rarely offer valuable environmental outcomes unless they are part of a broader, integrated strategy (Lozano, 2015). What matters is not whether a company succeeds in every single sustainability dimension, but whether its actions are mutually reinforcing and collectively focused on long-term goals. The fsQCA method was especially effective in revealing these dynamics, as it allowed for nuanced interpretations of how condition combinations function together.

On the other hand, several unsuccessful configurations highlight what happens when sustainability efforts are fragmented, inconsistent, or treated as symbolic gestures than as embedded strategies. Companies that had sustainability initiatives on paper but failed to integrate them operationally struggled to achieve meaningful reductions. Fragmented actions, superficial initiatives, or strategies lacking internal coherence seem to be common pathways to weak environmental performance, consistent with earlier observations in the literature (Baumgartner, 2013). This leads the fourth proposition:

Proposition 4: Sustainability failure results not only from the absence of individual practices but form a lack of alignment, integration, and strategic consistency across the organization.

This supports institutional critiques of symbolic adoption and decoupling, where companies gain legitimacy through sustainability disclosure but fail to deliver in practice (Delmas & Burbano, 2011). The result underline that internal integration, not just external signalling, is critical. Sustainability must be treated as a system-level commitment, embedded strategy, operations, and governance, rather than as a checklist of separate initiatives.

In addition, the study contributes to the academic literature by demonstrating the usefulness of Qualitative Compare Analysis (QCA) in sustainability research. QCA allows researchers to move beyond linear cause-effect assumptions and instead explore how different conditions combine to produce outcomes. This configurational approach has gained attention in recent years for studying complex management phenomena, particularly where contextual variation matters (Ragin, 2008; Misangyi et al., 2017). By applying QCA to the field of industrial sustainability, this study helps illustrate how manufacturing companies can adopt different pathways to achieve similar emission reduction targets, thereby expanding the methodological and empirical base of the literature.

Overall, these findings reinforce the idea that successful sustainability strategies are less about doing more and more, and more about doing the right things in a coordinated way.

Success appears to depend not just on which actions companies take, but on how these actions fit together strategically and operationally to support long-term decarbonization.

5.2 Practical Implications

From practical perspective, the findings offer several important lessons for companies aiming to reduce their carbon footprint. Perhaps the most important takeaway is that there is no universal model for sustainability success. Companies do not need to adopt a standardized set of actions, rather, they need to build strategies that align with their own operational realities, technological capabilities, and organizational cultures. What matters is not so much the specific actions taken, but how well these actions are coordinated and integrated into coherent strategy. Success appears to come from internal alignment and strategic coherence, rather than from ticking off external expectations or sustainability frameworks.

For companies with strong technical competencies, the findings suggest that focusing on energy efficiency improvements and renewable energy adoption can be highly effective, even in the absence of broad external engagement. This supports the idea that operational depth and technology-driven actions can deliver concrete emission reductions. Therefore, companies would benefit from embedding decarbonization directly into their production processes, energy systems, and investment planning. These core improvements are likely to give stronger and more measurable outcomes than symbolic initiatives or sustainability reporting alone.

At the same time, companies that rely heavily on external engagement and stakeholder dialogues must ensure that these activities are backed by strong internal systems. External partnerships and commitments can create reputational value, but without corresponding internal reforms, their impact on actual emissions may be limited. Organizations would benefit from treating external engagement not as a substitute for internal action, but as a complement that reinforces operational sustainability efforts.

Another practical insight concerns the danger of fragmented or uncoordinated sustainability initiatives. Thu study shows that even well-intentioned actions may fall short if pursued in isolation or without strategic focus. Companies should avoid assembling scattered activities and instead aim to build integrated sustainability strategies where renewable energy use, and sustainability governance are all mutually reinforcing. A disconnected strategy can lead to missed opportunities, wasted resources, or even reputational risk if the gap between stated goals and actual results becomes too wide.

Companies seeking to reduce their emissions should shift from asking “what more can we do?” to “what fits best together for us?”. Sustainability progress depends less on adopting a long list of initiatives and more creating a focused, internally consistent system that reflects the company’s context and long-term goals. In this sense, strategic coordination, implementation capacity, and internal ownership become as important as external visibility. The results offer practical guidance for Nordic machinery manufacturing companies but also suggest broader applicability to companies navigating complex sustainability transitions.

5.3 Limitations and future research

While this study offers important insights into sustainability strategies and carbon footprint reduction in Nordic machinery manufacturing, it also has limitations that should be acknowledged. First, the number of cases included in the analysis was relatively small. The sample consisted of sixteen companies from four Nordic countries, selected to provide a cross-section of the industry. However, the limited size means that the findings cannot be generalized beyond this specific group. Future research could expand the case pool by including more companies or additional industrial sectors to explore whether the same sustainability patterns apply in different contexts.

Secondly, the study relied on secondary data, mainly from company sustainability and annual reports, and structured data sources such as the Upright Project. While these sources have good availability and are useful and often detailed, they reflect how companies choose to report their sustainability efforts. This means that some strategic decisions, challenges, or internal trade-offs may remain hidden. To complement this type of data, future studies could use interviews or survey methods to gain deeper understanding of how sustainability strategies are planned and executed inside companies.

Another limitation is that the study focused on a specific period, from 2019 to 2023. While this allowed a focused assessment of recent sustainability efforts, it does not capture how strategies evolve over longer periods. Future research could take a longitudinal approach and examine how companies' sustainability configurations change over time – for example, in response to regulatory shifts, economic conditions, or new technologies.

In terms of scope, this study focused on four key conditions: energy efficiency improvements, renewable energy adoption, stakeholder and policy engagement, and alignment with sustainable development goals. These were chosen because of their relevance to industrial sustainability and carbon reduction. However, there are also other important factors that were not included. For example, the role of leadership, digital tools, supply chain collaboration, or investment in innovation. Future research could explore these additional dimensions to build a more complete understanding of what drives successful decarbonization.

The results indicated that diverse combinations of sustainability initiatives can lead to the same positive outcome, while others may lead to failure. This shows the significance of configuration thinking but also imply that more effort is needed to understand why some organisations succeed while others do not. Future research should focus more closely on comparing successful and failed situations or perhaps investigating specific industrial subsegments in greater depth.

In summary, this study provides a useful start for understanding how companies in Nordic machinery manufacturing companies reduce their carbon footprints, but there is still much to explore. By expanding the number of cases, incorporating other data sources, and including additional sustainability dimensions, future research can build on these findings and help companies, policymakers, and researchers navigate the complex landscape of industrial sustainability.

6 Conclusion

This study explored Nordic machinery manufacturing companies to reduce their carbon footprint through various sustainability configurations. By applying fuzzy-set Qualitative Comparative Analysis, the study examined 16 companies across Finland, Sweden, Norway, and Denmark. The research focused on four core conditions: adoption of Renewable Energy Technologies (RET), Stakeholder and Policy Engagement (SPE), Alignment with Sustainable Development Goals (SDGA), and Energy Efficiency Improvements (EEI). Thought this approach, the study aimed to identify not just a single drivers of carbon footprint reduction, but combinations of conditions that enable it.

The results demonstrated that carbon footprint reduction in Nordic machinery manufacturing does not follow a one-size-fits-all model. Instead, multiple effective pathways were identified, confirming the presence of equifinality, different combinations of sustainability strategies leading to the same positive outcome. Energy efficiency improvements and the use of renewable energy technologies appeared repeatedly in the most consistent and empirically relevant configurations. The presence of sustainable development goal alignment further strengthened these pathways. The lack of RET or SDGA was common among companies that failed to achieve major carbon reductions, pointing out the importance of both technological and strategic breadth in sustainability work.

The findings contribute to existing literature by highlighting how configurations of sustainability practices interact in manufacturing context. The study also shows that carbon reduction is best approached through an integrated effort, where technological upgrades, policy engagement, and strategic ambition reinforce each other. These insights offer valuable guidance: effective carbon reduction does not necessarily require excelling in every area but rather aligning the right mix of actions in a coherent way.

It is a fact that the study has limitations. The reliance on publicly available reports means that data completeness and consistency may vary. The relatively small sample size and the use of cross-sectional data further limit the generalizability of the findings. The threshold used in QCA also influence the results, and therefore interpretations should remain cautious and exploratory. Future research could expand on this study by including a larger scale of companies, examining other industrial sectors, or using longitudinal data to observe sustainability efforts over time. Qualitative studies could also complement the QCA approach by offering deeper insights into internal decision-making processes and contextual factors. There is also room to explore the role of external enablers such as supply chain collaboration or digital innovations in enhancing carbon reduction strategies.

In short, this thesis underscores that successful carbon footprint reduction in the Nordic machinery manufacturing sector is driven by well-aligned configurations of sustainability efforts. Rather than pursuing isolated efforts, companies benefit from integrating energy efficiency, renewable technologies, stakeholder engagement, and diverse sustainability goals into a coherent strategic whole. These findings support a more nuanced understanding of industrial sustainability, one that embraces complexity and multiple pathways to achieve impactful environmental outcomes.

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Appendix 1

Table 11. Raw data

Company	SDGA	RET	EEI	SPE	OUTCOME
Kone	77	97 %	-4.76 %	3.4	66.59 %
Metso	37	47 %	-69.24 %	3.9	91.92 %
Wärtsilä	87	60 %	-40.13 %	8.7	56.21 %
Valmet	41	24 %	-34.55 %	5.1	71.47 %
Epiroc	36	42 %	-21.43 %	4.7	56.79 %
Atlas copco	60	64 %	-4.58 %	7.6	64.05 %
Volvo	33	53 %	-15.81 %	10.5	33.34 %
Sandvik	30	34 %	-57.02 %	3.9	61.60 %
FLSmitdth	33	26 %	-52.82 %	0.7	37.77 %
Danfoss	111	50 %	-40.90 %	8.6	63.16 %
Vestas	245	100 %	-18.59 %	15.25	24.53 %
Nilfisk	38	6.3 %	-10.84 %	1.5	22.00 %
TOMRA	66	56 %	-39.99 %	2.6	61.71 %
Aker solutions	85	58 %	24.34 %	12.2	74.73 %
Yara international	69	60 %	-41.23 %	1.4	43.14 %
Kongsberg	53	56 %	-66.38 %	-1.9	82.59 %