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**THE IMPACT OF ENERGY EFFICIENCY INITIATIVES ON
OPERATIONAL PERFORMANCE IN NORDIC
AUTOMOTIVE MANUFACTURING FIRMS**

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ABSTRACT

This research investigates how the energy efficiency projects have affected the operational performance of Nordic automotive manufacturing companies, in this case, Volvo Group and Scania, in 2013-2023. The study examines the effect of the degree of energy intensity, investment in energy efficiency, and use of renewable energy on productivity and efficiency in operations. Quantitative longitudinal research design (secondary data analysis) was used to conduct a study. Annual reports, sustainability reports, and international data sources such as Eurostat and the International Energy Agency were used to gather data. Correlation analysis, regression analysis, and descriptive analysis were some of the statistical methods that were used to investigate relationships between variables. These results reveal that energy efficiency programs have a positive impact on improving productivity, reducing costs, and achieving sustainable operation. The research also sheds light on environmental regulation and technological innovation as important measures towards ensuring the generation of energy-efficient manufacturing systems. Overall, the study proves that energy efficiency can be a long-term capability that can be used to promote competitive advantage and sustainability. Looking at the results: energy efficiency investment was the most powerful motivator of operational results positively, with 97% of productivity differences attributable to energy saving initiatives for the 3 firms each firm used a different set of parameters to reach good results. And, future studies need to be extended to other larger geographic settings, more sampled companies and the increasing importance of electrification and supplies chain energy dynamics to further develop the arguments revealed by this research.

Keywords: Energy saving, functional performance, automobile production, sustainability, renewable energy, Nordic companies, productivity

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CHAPTER 1: INTRODUCTION

1.1 Introduction

The energy efficiency is also an area of concern when it comes to new systems of industries, especially in the manufacturing sector, where energy consumption is high. It refers to the ability of companies to reduce their energy use without compromising on the quantities of their output (Zhang et al., 2025). The organizations have paid increased focus on the efficiency of their energy over the last few years so as to reduce their costs, improve their productivity, and meet the environmental demands.

The contemporary manufacturing industry has also taken energy efficiency as a strategic issue following increased costs of energy globally, emerging stakeholder requirements, and strict environmental laws. An important part of operating costs in a machine process is energy, and thus, inefficiency is a key factor in reducing profitability and competitiveness (Candela et al. 2024). The reason is that the manufacturing steps in the automotive industry of stamping and welding metal, the surface coating, and the powertrain assembly are highly sophisticated and energy-demanding compared to production. Therefore, it is not only a critical environmental need to reach energy efficiency without reducing the level of productivity, but also a major element of business strategy.

Moreover, the economic paradigms in the world are also changing, putting more emphasis on sustainable production. Industry players are under pressure to reconsider their energy consumption patterns because of the Paris Agreement and other nation-specific decarbonization goals. In the case of the automotive industry, which accounts for a large share of greenhouse gas emissions across the entire life cycle, it is crucial to pursue energy-saving strategies to meet regulatory requirements and maintain its market position (Cataltepe et al. 2023). Companies today face immense pressure not only to comply with legal regulations but also to demonstrate proactive environmental awareness by achieving measurable improvements in energy efficiency.

Automobile manufacturing business is among the most power-consuming industries because its processes are very complex, which involve processing raw materials, assembling, painting, and testing (Giampieri et al., 2020). The processes can lead to ineffective use of energy, which restricts the performance and the cost of operations. Therefore, energy efficiency is not a mere environmental fact; it is a business strategic decision.

In addition, such global problems as climate change, rising energy prices, and stricter environmental regulations have resulted in increased pressure on companies to pursue energy-saving activities (Gajdzik et al. 2024). Nordic countries, especially Sweden, are known for having effective strategies in place for sustainability. Companies in the automobile industry, such as Volvo, Scania, and Volvo Cars, are also known to have invested in energy-saving technologies. This project is aimed at explaining the impact of such strategies on the operations.

Nordic countries are a special case when it comes to studying the impact of these strategies. Countries such as Sweden, Denmark, and Norway are known to have effective sustainable energy policies and strategies in place. They have also managed to integrate energy efficiency into their agendas for enhancing competitiveness (Macharia et al. 2022). The automobile industry in these countries has also benefited from the innovations in technology and organisational structure to enhance energy efficiency. This research focuses on the long-term impact of these strategies on the operations. It also provides an idea regarding the relationship between sustainability and operations, which are energy-intensive.

1.2 Background of the Study

The manufacturing industry is one of the biggest energy consumers around the world. Factories need energy in large quantities in order to drive machinery, production lines, and processes that are continuous in nature (Batouta, Aouhassi, and Mansouri, 2023). This renders the management of energy a key concern for companies. The increasing energy prices, coupled with the growing environmental issues, have further enhanced the necessity of achieving efficiency in energy use. Energy efficiency has, in this regard, become a viable and effective measure to take. It helps

companies to save energy in the process of preserving or even increasing productivity (Dinesha and Kumar, 2022).

Northern nations are broadly known as world leaders in the aspect of sustainability and environmental management. These nations have come up with effective regulatory structures to manage emissions and ensure the effective utilization of resources (Sen et al., 2025). Carbon taxes, stringent environmental regulations, energy-saving aims, and others are some of the policies that have pushed companies into using sustainable practices. This leads to the Nordic region being more ahead in incorporating green technologies and efficient production systems than most other areas (Ofori et al., 2023).

The Nordic economy, and more specifically, Sweden's automotive manufacturing industry are an important part of this economy. Volvo Group, Volvo Cars, or Scania are international companies that are famous because of their orientation of innovativeness and sustainability (Asnafi et al., 2015). These companies have undertaken huge investments in energy-saving technologies. These are smart manufacturing processes, digital monitoring, and automated systems. These technologies assist in decreasing the intensity of energy, increasing the accuracy of production, and reducing the cost of operation.

Energy efficiency programs within manufacturing have a number of strategies. These are the optimization of processes, real-time checking of energy, and the use of clean and renewable technologies (Batouta, Aouhassi, and Mansouri, 2023). These methods would help companies to know in which areas energy is going to waste and implement necessary measures. In the long run, these advances are able to promote productivity, lower expenses, and promote long-term operational performance.

The use of energy in manufacturing industries has always been viewed as a fundamental point that has to be optimised because of its consequences on cost, environmental impact and competitive advantage. Specifically, the automotive manufacturing industry is one of the energy-intensive sectors and the most energy-intensive of all industries worldwide due to its intensity of capital and process character (Peng, 2024). Starting with stamping and welding, through to

painting and final assembly, every production process demands large amounts of energy. Traditionally, these energy requirements have seen major operation costs being incurred, leaving companies in a quest to find better methods of operating with the aim of such operation management without compromising on the quality of output.

Historically, developing energy management in the manufacturing industry was seen more as a factor of cost control rather than a component in the overall strategic development. Nevertheless, the escalation of global sustainability initiatives, especially those brought about by international policies like the United Nations sustainable development goals (SDG 7 and SDG 9), is an increasing trend to such an extent that firms are incorporating energy efficiency into its long-term corporate strategy (Seki et al., 2022). Energy efficiency, in this case, does not only refer to the decrease in the usage but rather to the redesigning of the production processes in more adaptive, resilient and oriented towards the future. Research shows that companies that make energy efficiency their organisational DNA would be more innovative, optimise the processes at the corporate level or develop more nimble operations compared to business organisations that make it a single affair.

Nordic region, with its strong sustainability performance, has been a hotspot into the investigation of energy efficiency in the automotive manufacture. Sweden, Norway, and Denmark are among the countries that have implemented ambitious national policies that should remove the use of fossil fuels by industries by setting energy efficiency standards and integrating renewable energy and schemes to incentivise the uptake of green technologies (Shehzadi, 2023). As an example, the Energy Agency of Sweden has introduced programme sector-specific measures, aiming to assist industrial companies to undertake energy audit processes, introduction of energy management systems, and investment in the modern low-energy technologies. Consequently, the Nordic auto companies (Volvo, Scania, and other regional original equipment manufacturers) have shown a significant improvement in the intensity of their energy consumption per unit of production.

The shift toward energy-efficient production in Nordic automotive production goes hand in hand with the general trends in smart production and Industry 4.0 implementation. The companies of the area are capitalizing on digital sensors, predictive analytics, and automated control systems to track the energy usage in real-time and determine inefficiencies on a more detailed level. These technologies can be used to optimize energy and increase the reliability of production and minimizing downtime also, so, energy efficiency can be fixed with the general shooting of excellence.

Although such progress is achieved, there are challenges. The problem of measuring the long-term impacts (delays in realisation) is faced by many firms because of the inconsistency of data, different reporting standards as well as the fact that benefits related to energy efficiency take time to be realised. The generalization of longitudinal studies that can encompass energy performance patterns, as opposed to a snapshot evaluation is necessary to address this challenge.

In this study, the researcher will use a 10-year period between 2013 and 2023 to identify long term trends and developments. The rationale of a longitudinal approach is that the payback of energy efficiency investments may have a slow manifestation (Amendola et al., 2024). It takes some time to be accustomed to new systems and technology. This research has given a clear and relevant context for examining how energy efficiency affects the performance of the operations in the long run by concentrating on Nordic automotive firms.

1.3 Problem Statement

Although energy efficiency is increasingly gaining significance in the manufacturing process, the current research has a number of gaps. The majority of the researches have been conducted on the manufacturing industries and not individual industries like the automotive manufacturing industry (Abadi et al., 2024). This leaves the automotive industry with little knowledge of the effects of energy efficiency programs on performance.

The other shortcoming of the literature is that firm-level empirical analysis is lacking. Several studies are based on aggregated information or observation at the industry level, which fails to reflect various differences that exist among individual firms (Inthavong et al., 2023). This complicates the comprehension of the benefits that accrue to individual firms whose investments in energy-saving would work to their advantage.

Moreover, the research that has been conducted concerning the topic usually involves cross-sectional data, which can only give a picture of a specific time frame (Haba, Bredillet and Dastane, 2023). Literature in the investigation of the long-term trends and outcomes is limited. Energy efficiency initiatives take time to lead to effects, and hence a longitudinal analysis is needed to appreciate their actual effect.

Moreover, the literature does not provide studies that combine energy efficiency, operational performance, and environmental regulation into a framework. Although other studies have studied these factors individually, very little has been done on the interaction of these factors. Considering such gaps, it is necessary to conduct a specific study that will investigate the connection between energy efficiency programs and business performance in the automotive manufacturing industry. This research meets that requirement by examining Nordic automotive companies over the past 10 years.

1.4 Research Rationale

The proposed research is relevant because of the growing international attention to sustainability and energy management. The increasing energy costs and the issue of environmental challenges have necessitated firms to be more efficient in terms of energy (Chen et al., 2023a). It is now expected that organizations can minimize the impact on the environment and still perform well in terms of operations.

There is a major shift in the automotive manufacturing industry. The industry is embracing the latest technologies and environmentally friendly practices to become competitive (Montemayor and Chanda, 2023). One of the major changes in the industry is the use of energy efficiency

measures that help in reducing costs and increasing productivity. The real effects of such efforts on the performance of the firms are, however, not well comprehended.

The Nordic region offers a good background for this study due to its good policies on environmental issues and excellent industrial practices (Quitza et al., 2022). The companies working in this territory have more chances to use energy-saving technologies and follow rigid rules. This becomes feasible to examine the connection between energy efficiency and performance within a well-developed environment.

Academically, the study is relevant to the already existing literature because it concentrates on a particular industry, and it is a longitudinal study. Practically, it gives a guide to managers about how energy efficiency projects can be used to enhance the performance of operations. It also assists the policymakers in realising the nature of effectiveness of the environmental regulations.

1.5 Research Aim and Objectives

The primary objective of this research is to investigate how energy efficiency programs would affect the performance of Nordic automotive production companies in the period of 2013-2023.

In an effort to attain this purpose, the research is informed by the following objectives:

- To analyze the dynamic of the energy intensity among Nordic manufacturing companies of the automotive business from 2013 to 2023.
- To determine the association between investment in energy efficiency and productivity in these companies.
- To measure the impact of environmental regulations on the performance in terms of energy efficiency.
- To determine the optimal long-term operational effect of energy efficiency initiatives as a secondary-data study.

- These goals give a systematic way of knowing the role of energy efficiency in the performance of the firm.

1.6 Research Questions

This research will be informed by a single research question and three sub-research questions.

Main Research Question:

What role has the use of energy efficiency programs played in the performance of Nordic automotive manufacturing companies over the past ten years (2013-2023)?

Sub-Research Questions:

- What are the dynamics of energy intensity of Nordic automotive manufacturing companies during 2013 and 2023?
- What is the relationship between the investments in energy efficiency and productivity in Nordic automotive manufacturing companies?
- What is the role of Nordic regulatory frameworks in the performance of energy efficiency in the automotive manufacturing companies?

1.7 Significance of the Study

The study is valuable academically, practically, and policy-wise. Academically, it adds to the current recognition of literature because it is specifically organized around the automotive manufacturing industry, a relatively new area of energy efficiency research (Du, Bryson and Qamar, 2025). The existing literature has analysed mainly energy efficiency in the overall manufacturing grounds, but this study offers a more specific industry analysis. Moreover, a longitudinal approach from 2013 to 2023 is used.

Practically, the present research is valuable to managers and decision-makers in the automotive sector. It describes how the energy efficiency programs can affect the operational performance through the cost-effectiveness of energy, which results in the improvement of productivity and efficiency (Ali and Evans, 2025). These lessons can aid strategic planning and resource allocation of firms to be better planned. The findings can be applied by managers to make investments in energy-saving technologies and process improvements.

The research is also very relevant to policymakers. Governments are also coming up with environmental regulations in order to lessen emissions of carbon and encourage sustainable industrial processes. This study gives evidence of the impact that such regulations may impose on the behavior and performance of firms (Hoa, Xuan and Phuong, 2024). It outlines the aspect of regulatory pressure causing efficient and innovative results, and this fact can enable policymakers to make policies that are more balanced and effective.

Moreover, the results of the current research are not specific to the automobile industry. The insights can also be used in other energy-intensive industries. The research provides a greater insight into the manner in which energy efficiency can be employed as a strategic tool to enhance performance in a way to facilitate sustainability objectives.

1.8 Theoretical Foundation

The literature supporting the theoretical basis of the given study is based on two mutually congruent frameworks the Resource-Based View (RBV) and the Porter Hypothesis, which serve to explain the effect of energy efficiency initiatives on the performance of a firm. This study provides a comprehensive approach to explain the strategic value of energy efficiency in the automotive manufacturing by combining internal and external incentives. The results of the study are based on two theoretical approaches: the Resource-Based View (RBV) and the Porter Hypothesis (Mailani et al., 2024). These theoretical backgrounds have a sound basis on the impact of energy efficiency programs within operational performance of firms.

Resource-Based View

The Resource-Based View (RBV) indicates that the ability of firms to exploit their internal institutional resources and capabilities can bring them to gain and maintain a competitive advantage. This theory holds that valuable, rare, inimitable, and well-organized resources help to achieve high firm performance. The strategic internal resources in the context of this research can be viewed in the form of energy efficiency initiatives (Lowe, 2017). These efforts involve high technology, a superior production system, and better methods of energy management. Firms engage in a waste of energy and lack optimal utilization of this resource, and reducing costs of operations and enhancing productivity will be possible. Consequently, it is clear that organizations that successfully create and apply energy-efficient operations have a higher chance of achieving more desirable operational performances and hence remaining competitive in the market (Tarigan, Siagian and Jie, 2021).

RBV suggests that a company's sustainable competitive benefit is based on its unique resources and competences, which are appreciated, infrequent, and unique. Other resources identified in traditional RBV literature as promoting high performance include advanced technologies, skilled human capital, and organizational processes. This framework has recently been expanded by scholars such as those dealing with the concept of sustainability, such as energy efficiency and environmental management systems.

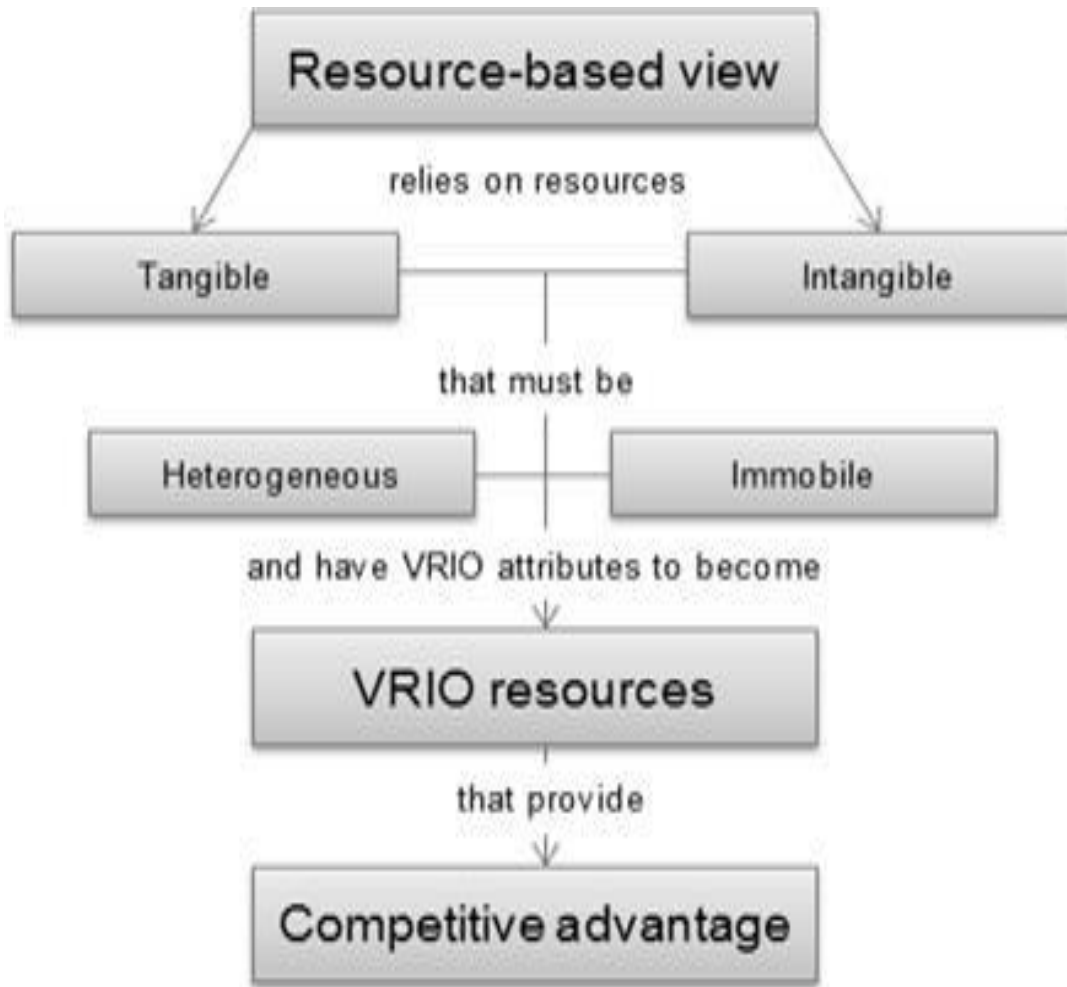


Figure 1: Resource-Based View (VSkills, 2024)

Within the framework of the RBV, energy efficiency is seen as a key strategic capability that helps to increase the efficiency of resource usage, reduce waste in business processes, and increase business resilience. Businesses that are successful in their implementation of energy efficiency systems and processes will enjoy competitive advantage, which is hard to attain for other business organizations. For example, investments in real-time energy monitoring systems, automated control technology, and energy management procedures develop new technical and organizational capabilities that are integrated into a company's routine and decision-making processes. These capabilities reduce production costs, increase process reliability, and improve

responsiveness to market demands, the fulfillment of which leads to positive performance improvements in the long term.

In addition, energy-saving initiatives usually imply interdepartmental cooperation among different units in the fields of engineering, operations, and sustainability. This integration leads to organizational learning and allows companies to experience process optimization and unceasing development which consequently leads to the creation of the capability portfolio. Energy efficiency is thus not static but a dynamic ability that changes with the emergence of new technologies and organizational changes.

Porter Hypothesis

On the other hand, the Porter Hypothesis is concerned with the effects of the external forces, particularly the environmental policies, in driving the performance of a firm. It argues that environmental policies well formulated can trigger innovativeness in firms (Tao and Zhou, 2024). These regulations can not just add on the expenses of the companies, but they must also install new technologies, and, on the one hand, optimize their processes. This can have the effect of increasing efficiencies, diminishing environmental impacts and leading to improved economies in the long term.

As compared to the internal orientation of the resource-based view (RBV), the hypothesis by Porter focuses on how the external environment creates a regulatory pressure on innovation and competitiveness. This theory suggests that environmental policies, which are well developed, including energy policy, emissions controls, and price of carbon, can encourage companies to innovate which reduces their impact on the environment and at the same time enhances their economic performance. In this perspective, regulatory compliance is not just a cost consideration, but it is a source of new ideas.

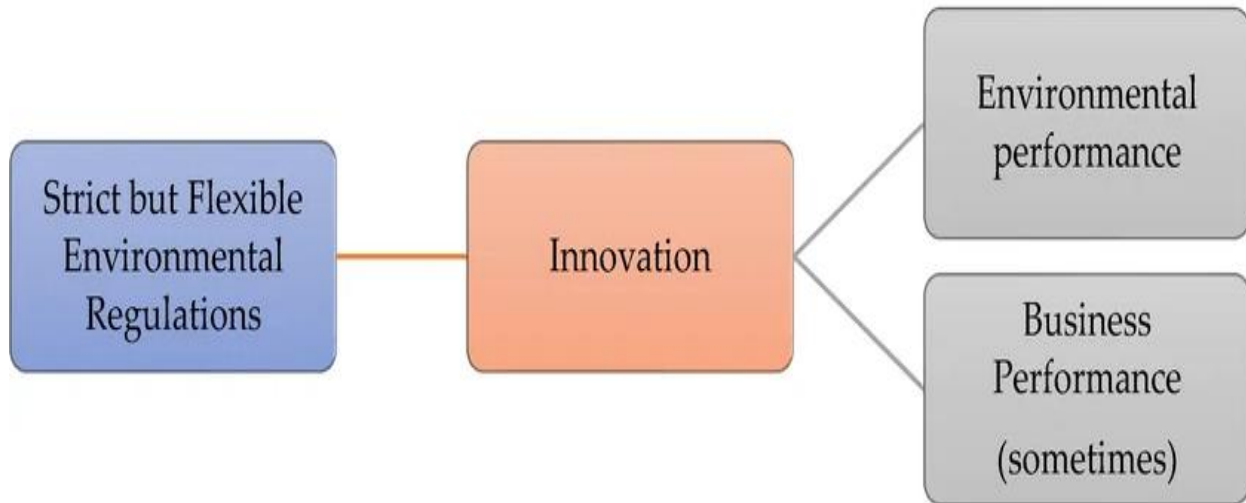


Figure 2: Porter Hypothesis (Mihai et al., 2023)

Energy consumption policies, e.g., obligatory energy audits or efficiency levels, force the firms to reexamine their production processes and seek technological enhancements. The eco-friendly effects of such responses are the implementation of energy-saving devices, electronics minimization tools, and process enhancement which encourage sustainability and efficiency. Empirical data demonstrates that firms under high energy standards are expected to perform better than their un-regulated rivals since they are quicker to innovate.

Integrative Framework

Although the resource-based approach (RBV) is concerned with internal capability and Porter hypothesis is an external incentive, energy efficiency may be considered an intermediate process,

which bridges both of them. Regulatory pressure synthesizes energy-efficient companies development (external-internal) which is converted into strategic resources and contributes to corporate performance (internal-output). This dynamic is important as it highlights the applicability of the organizational capabilities and policy environment to the success of energy efficiency policies.

The view of energy efficiency in both hypothetical approaches also allows this study not only to elucidate why corporations invest in energy efficiency (regulatory and competitive), but also how investment in energy efficiency infrastructure can result in operational benefits (capability building and innovation). This two-theory presentation offers a substantial base of research into the effects of energy policies in Nordic automobile production in the long term.

This study provides a comprehensive framework with RBV and the Porter Hypothesis by considering the internal capabilities and external forces. The energy efficiency programmes serves as an intermediate variable to both of these points of view, since it enables companies to accommodate regulatory demands and enhance operational efficiency and competitiveness in the long-run perspective.

1.9 Scope of the Study

This paper follows a case study of the Nordic manufacturing enterprise of the automobile business in Sweden and especially in Nordic region. It takes into account three large-scale companies, Volvo Group, Volvo Cars, and Scania, who have achieved a name and fame due to the profound sense of sustainability and innovation. The energy efficiency practices will be analysed using these companies in an industrial setting that is developed.

The study will consider a period of ten years, 2013 to 2023, in order to have long-term view and changes. It may be utilized to investigate the progression of the energy efficiency programs and the effect on the operational performance of a larger period of time. This is one of the reasons why longitudinal approach would be important, since the results of such efforts would not occur immediately, but develop over time.

The research is based on the secondary data, which is collected through annual reports of corporations, sustainability reports, and international databases, such as the International Energy Agency, and Eurostat. The main scope is to detect the impact of energy saving endeavours on the performance indicators of operational processes of the sampled companies in terms of productivity, cost effectiveness, and resource usage.

1.10 Limitations of the Study

There are a number of limitations that could be taken into account in this study in order to interpret findings. To begin with, it is purely based on secondary sources of data. Although this kind of data can be a valuable tool and is well embraced in research, it might prevent the determination of direct cause-and-effect links of energy efficiency programs and the outcomes of operational performance.

Second, the paper addresses a limited sample of organizations, namely three large Nordic-based automotive companies. Even though these companies are quite applicable, there is also a risk that, due to the small sample size, the results cannot be generalized to other sectors or locations.

The other weakness is that there might be an inconsistency when it comes to data reporting. When companies are reporting their performance and using energy, different companies may apply different approaches, indicators, or standards, and this may influence the comparability of the data.

However Scania, there certain post from 2018 figures were estimated through linear interpolation where consolidated firm-level data was not separately reported following full integration into the Traton Group. This process was a limitation of the work which impacts the accuracy of the Scania data.

1.11 Structure of the dissertation

There are five chapters in this dissertation.

- Chapter 1 provides an introduction to the study, outlining its background, problem statement, research rationale, and objectives.
- Chapter 2 presents a literature review, including key concepts, previous research, and the theoretical framework.
- Chapter 3 describes the research methodology, data sources, and analytical approach.
- Chapter 4 presents the results and their analysis.
- Chapter 5 summarizes the findings, conclusions, and recommendations for future research and practice.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction to the Literature Review

The issue of energy efficiency has expanded a lot of relevance in contemporary manufacturing, particularly with companies experiencing the increasing cost of energy and the tightening of environmental standards. Energy is one of the most significant inputs in the production process in the industrial sectors, and inefficient use of energy may escalate the costs and lower the general performance. Energizing the industrial production is necessary to minimise the cost of operation and enhance the utilisation of resources (Schmitt et al., 2025). This shows that energy efficiency is not just an environmental concern but also a significant factor that affects the performance of firms.

The manufacturing industry is currently under burden to advance performance in terms of productivity while at the same time enhancing sustainability. This can be done through energy efficiency, which helps firms reduce the quantity of energy consumed without having to reduce production. The performance can be enhanced through energy-saving production processes that reduce waste and are efficient in the utilization of resources (Sogut & Karakoc, 2023). This implies that companies would be more efficient and competitive simultaneously.

Another industry where energy efficiency is important is the automotive manufacturing industry, where the processes are energy-intensive. Energy-efficient manufacturing is turning out to be a need that has to be fulfilled for companies to be competitive and to be environmentally friendly (Jayawardane et al., 2023). Companies that embrace such practices have higher chances of enhancing their performance over a period of time and minimizing their environmental effects.

The relationship between operational performance and the firm level is the subject of this literature review on energy efficiency. It analyzes the studies in the manufacturing industry, focusing on production activities and sustainability policies. The efficiency of energy saving in the economic and environmental results is also discussed during the review. The principal themes involve the idea of energy efficiency, its place in the manufacturing process, and the relationship

with sustainability. These themes offer a basis through which one can understand how energy efficiency programs can impact the performance of firms, especially in the automotive manufacturing industry.

2.2 Energy Efficiency in Manufacturing Firms

2.2.1 Concept and Importance of Energy Efficiency

Energy efficiency is the capacity of companies to consume less energy in order to produce the same amount of output. This can be applied in manufacturing, where the company can make its manufacturing processes more efficient in the consumption of energy and the minimization of waste. Energy efficiency is significant in the reduction of production costs, as energy is one of the key inputs in the production of industries. By minimizing energy usage, the firms would be able to decrease the operating costs and improve their overall performance (Schmitt et al., 2025).

Another reason why energy efficiency is relevant to enhance competitiveness is the energy efficiency. The cost of producing goods at a lower price is made possible through firms that use more energy compared to the firms that are less efficient. This puts them at a competitive advantage. Moreover, effective use of energy will assist companies in dealing with the threat of increasing the cost of energy costs. The more efficient firms can afford to keep the production costs steady as energy costs rise (Sogut & Karakoc, 2023).

The other significance of energy efficiency is that it helps in reducing environmental impact. There are manufacturing operations that tend to consume a lot of energy and produce a lot of emissions. This means that with effective energy conservation, companies will be able to reduce their emissions, and the requirements set for the environment will be easily achieved. This is quite significant, given that governments are becoming more and more stern in their efforts to regulate industries' emissions (Schmitt et al., 2025).

2.2.2 Energy Efficiency and Industrial Processes

Manufacturing energy efficiency is directly connected with the nature of the organization of production processes. One of the ways that firms can enhance efficiency is through the optimization of production systems and advanced technologies. Among them is the adoption of data-driven models to forecast energy ingesting and enhance the performance of the systems. The models assist companies in determining the areas where the energy is going to waste and adjust to decrease consumption (Bermeo-Ayerbe et al., 2022).

Smart manufacturing technologies are also important in enhancing the efficiency of energy. Digital solutions like sensors and data integration enable companies to see the real-time energy consumption. This assists managers in making superior decisions regarding how to utilize energy in a more efficient manner in the process of production. Such technologies as the Internet of Things (IoT) may greatly enhance operational efficiency because they provide greater control over production processes (Alokdeh et al., 2026).

More so, the production processes can be made energy efficient to enhance maintenance and minimise system breakdowns. Energy consumption helps the firms identify issues in machines and rectify them before they are caused to consume more energy or cause delays in production. This enhances efficiency and reliability in the manufacturing systems (Bermeo-Ayerbe et al., 2022).

2.2.3 Energy Efficiency and Sustainability

Sustainability of manufacturing is closely related to energy efficiency. Sustainable production is dedicated to minimizing the environmental effects and preserving a level of performance in the economy. One of the most effective methods to accomplish this goal is to increase energy efficiency. It assists in energy saving, reducing emissions, and enhancing resource utilization (Jayawardane et al., 2023).

Sustainability practices are becoming a common practice in manufacturing companies as firms seek to conform to their emerging environmental requirements and expectations of the stakeholders. Energy efficiency is a key point in such practices since it has a direct relationship with environmental and economic results. Companies that are made energy efficient will be able to lower their carbon imprint as well as decrease production expenses (Sheng et al., 2023).

2.3 Energy Efficiency and Firm Performance

2.3.1 Energy Efficiency and Productivity

Empirical studies that have been done show that the productivity of the manufacturing industry is directly affected by the level of energy efficiency. Energy is a key input in the production process, and the wastage that results from the lack of energy efficiency makes the production process more expensive and less efficient. When a company becomes more energy efficient, it is able to produce the same amount of output with a lesser input.

A global analysis of firms conducted by Montalbano et al. (2022) reveals that gains in energy efficiency are positively related to an influx of productivity among manufacturing firms. Their analysis reveals that companies that have less energy intensity are more likely to be successful with respect to output efficiency, which suggests that efficient energy consumption is a significant contribution to productivity.

2.3.2 Energy Efficiency and Financial/Operational Performance

Energy efficiency also influences financial and operational performance besides productivity. Cost reduction is one of the key advantages of energy conservation. Energy is a high cost of operation in manufacturing, and therefore, energy consumption goes down, leading directly to low operational costs and profitability.

Almarshad et al. (2024) present empirical results stating that energy efficiency measures affect organizational performance positively in the manufacturing sector. According to their study, companies that are environmentally friendly in the implementation of energy-efficient measures

can be in a better position to enhance their operations since efficiency will cut down on unnecessary use of energy and increase the overall performance of the company.

Energy efficiency also determines financial performance. Given the nature of this study, Yahaya (2026) demonstrates that reporting energy efficiency is positively related to the financial performance of the firms. The research postulates that the companies that aim at energy efficiency would not only lower expenses but also enhance their financial status, which would enhance long-term performance.

Aterido et al. (2025) also help to prove the correlation between energy efficiency and firm performance by studying the connection between energy prices, energy intensity, and firm performance. They find that the less energy-intensive firms do better financially in terms of performance, particularly in the high-energy price environment. This highlights the role of energy efficiency as a method in cost pressure management and associated performance enhancement.

2.3.3 Mediating Role of Energy Efficiency

Almarshad et al. (2024) give evidence that the relative among organizational practices and the performance outcomes is facilitated by energy efficiency measures. They find that these companies perform well due to the application of effective strategies like process improvements and resource management practices, since these strategies help in improving the efficiency of energy.

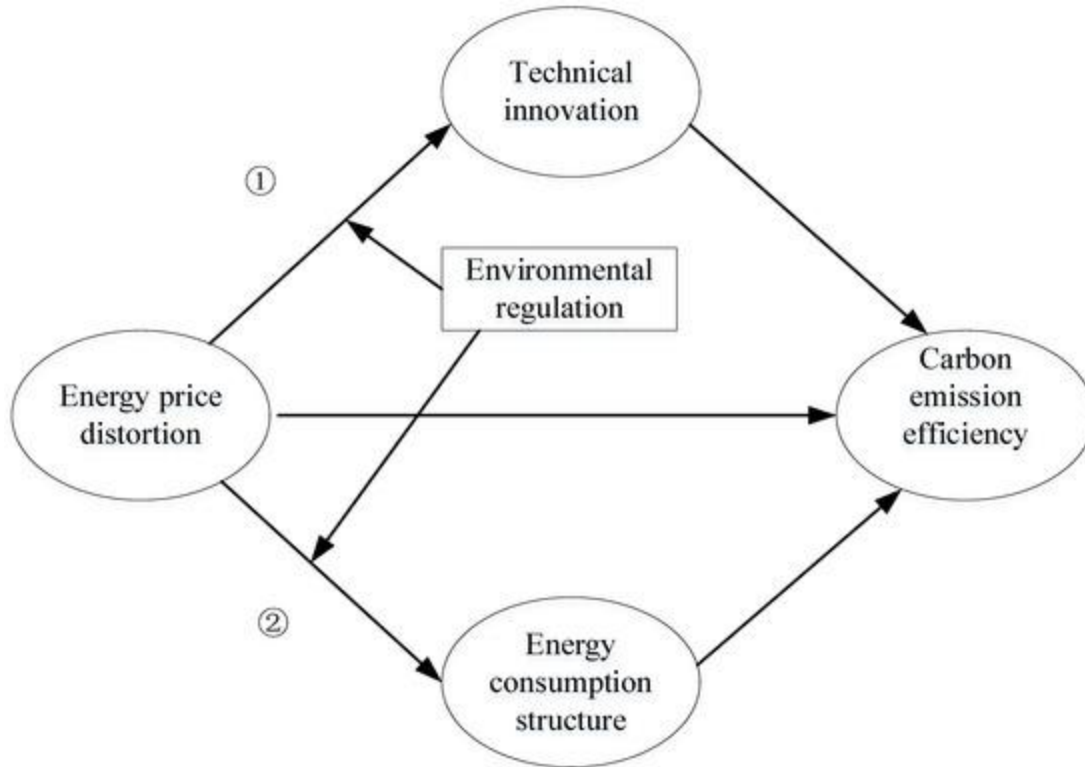


Figure 3 Mediating Role of Energy Efficiency (Wang et al., 2024)

The role of this mediation is significant in the sense that it describes the way the firms can convert their strategies into performance gains that can be measured. Strategies like sustainability initiatives or operational improvements do not have a direct impact, but instead go through energy efficiency. Between firms, the better they use energy, the more they can lower the costs, enhance their productivity, and get better outcomes of their operations. The results indicate that energy efficiency is not only a factor but also a way in which firms perform better. This is where the need to incorporate energy saving as part of a business strategy comes in.

2.4 Environmental Regulation and Firm Performance (Porter Hypothesis)

2.4.1 Environmental Regulation and Energy Efficiency

The regulation of the environment is significant in helping manufacturing firms to be energy efficient. Governments come up with policies in place to cut down pollution through emission limits, energy standards, and environmental regulations, thus encouraging the efficient use of

resources. Such policies compel companies to become better with regard to the consumption of energy in their manufacturing operations.

Chen and Chen (2024) describe how the regulation of the environment can enhance the efficiency of energy by compelling companies to use superior technologies and production processes. In their research, they find that policy tools, including regulatory standards and environmental controls, have an effect on the management of energy by firms. By making companies achieve the environmental requirements, there will be a higher demand to invest in energy-saving technologies and increase production efficiency.

The regulation also assists the firms in discovering the inefficiency within their operations. By having firms being tracked or regulated to report their environmental performance, the firms tend to be more conscious of their own energy consumption patterns. This makes them minimize waste and maximize the utilization of resources. Consequently, a regulation of the environment occurs as a force that causes companies to adopt more efficient and sustainable manufacturing methods (Chen & Chen, 2024).

2.4.2 Porter Hypothesis and Firm Performance

According to the Porter Hypothesis, environmental regulation is also likely to enhance the performance of firms, which promotes innovation. Well-designed regulations can also encourage firms to come up with new technologies and processes that will enhance their environmental and economic performance, as opposed to merely raising costs. Bagchi and Sahu (2025) consider the Porter Hypothesis in the manufacturing industry and discover that environmental regulation may result in a productive innovation process. In their research, they elucidate that when organizations are under regulatory pressure, they adjust to the pressure by implementing cleaner and more efficient technologies, which in the long run can contribute to improved performance.

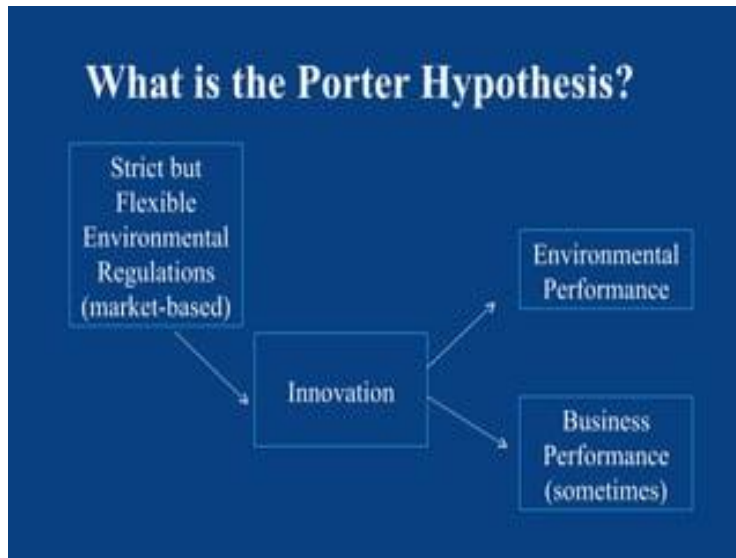


Figure 4 Porter Hypothesis (Sustainable Prosperity, 2026)

Likewise, Guan and colleagues (2023) observe that environmental taxes have the ability to promote innovation and environmental total factor productivity in firms. Their findings indicate that regulation can positively impact productivity in that it drives firms to utilize the resources more efficiently and invest in new technologies.

Mu et al. (2022) also present evidence that the occurrence of environmental regulations can boost the performance of the corporation based on innovation. Their analysis of the manufacturing companies reveals that regulation motivates firms to practice improved production, which results in positive outcomes of operations.

2.4.3 Policy Stringency and Financial Performance

However, it is not always similar to the outcome of the policy stringency on financial performance; others may demonstrate the positive effects of environmental regulation. The regulation or strictness of the policies used can impact the positive or negative results of the firms.

Chomachaei and Golmohammadi (2024) also study European automobile manufacturers and discover that the effect of the strictness of environmental policy on the financial performance is not unambiguous. Their study indicates that with tighter regulations, the cost of compliance for businesses may increase, which may reduce the chances of short-term profitability for the businesses. The businesses may need to invest in the latest technology or change the process of production, which may increase the cost for the businesses.

On the other hand, the tougher regulations may bring long-term benefits. Companies that are flexible to regulatory demands can be more efficient and win a competitive edge. This implies that in the short-term costs can rise, but in the long-term, the firms will have a better performance (Chomachaei and Golmohammadi, 2024).

2.5 Theoretical Framework

2.5.1 Resource-Based View (RBV)

Resource-Based View (RBV) is the view that competitive advantage is attained through the efforts of firms based on the resources and capabilities that the firm possesses. This school of thought holds that the firms are more successful when they create distinct resources that are worthy, hard to copy, and well-structured. Energy efficiency can be considered one of such significant internal capabilities in terms of sustainability.

According to Khanra et al. (2022), green innovation and sustainability practices may act as strategic resources at the firm. The practices enable firms to enhance performance while addressing the risks of environmental challenges. This notion is closely associated with energy efficiency since this concept entails the enhancement of the efficiency of firms to utilize resources like energy, technology, and production systems.

This fact is also supported by Liu (2025), who demonstrates that the green management practice helps in long-term competitive advantage. Companies with energy-efficient operations can save on expenses, enhance efficiency in operations, and enhance their market presence. This suggests

that energy efficiency does not just qualify as a technical advancement, but also a strategic competency that promotes firm performance.

The Natural Resource-Based View (NRBV) shapes on the RBV by highlighting environmental resources and sustainability. It also describes how companies are able to work better by controlling natural resources, which causes less harm to the environment.

As Makhloufi et al. (2022) demonstrate, green entrepreneurship and sustainability orientation are environmental practices that enhance the environmental performance and contribute to the success of firms. As they indicate in their study, resource efficiency and environmental responsibility of firms have a high probability of delivering better results.

In the same manner, Llach et al. (2025) establish that companies that build good environmental capabilities have an improved capacity to execute sustainability objectives. The capabilities are effective energy utilization, clean technologies, and the incorporation of sustainability into business strategies. The paper demonstrates that these abilities are significant in enhancing environmental and economic performances.

2.5.2 Linking RBV to Energy Efficiency and Performance

The concept of energy efficiency can be taken to be the capability of a given firm that links internal resources to performance outputs. According to the RBV and NRBV schools of thought, the benefit of firms developing energy-efficient processes is in the cost reduction, productivity, and sustainability of the firms.

Energy efficiency programs, including the enhancement of the production system or the incorporation of new technologies, demand investments and organizational resources. These programs are incorporated into the internal capabilities of the firm. In the long run, companies that manage to adopt these practices manage to produce improved operational and financial performance.

RBV provides a sound theoretical foundation for the role of energy efficiency in business success. In this context, energy efficiency can be considered one of the strategic internal competencies that contribute to better resource utilisation. Instead, energy efficiency illustrates the ability of a company to optimise energy consumption, to develop and implement new and modern technologies, and to improve its production systems. Moreover, studies conducted by researchers such as Khanra et al. (2022) revealed that sustainability-oriented practices, such as energy efficiency, are considered a strategic resource for enhancing the performance of a company in environmental and financial aspects.

Energy efficiency also plays an important role in the reduction of operating costs and in increasing productivity. This is in line with the idea presented by the RBV. Companies that implement energy efficiency technologies and processes are able to achieve the same results with fewer inputs. This illustrates the idea of cost-benefit, which enables a company to improve its competitiveness in the market. This idea is also supported by another study conducted by Liu (2025). The researcher demonstrated that environmentally friendly management practices, such as energy efficiency, improve the performance of a company in the long term by enhancing performance and reducing waste. In this regard, energy efficiency is considered one of the company's capabilities in transforming its resources into performance outcomes.

Moreover, the resource-based theory (RBV) stresses that the role of organizational capabilities cannot be underestimated in the achievement of long-term competitive advantages. Energy efficiency programs also need companies to acquire specific knowledge that is hard for rivals to imitate. These capabilities enable companies to constantly improve their processes and adapt to environmental and market changes. In this context, energy efficiency can be seen as a connection between companies' resources and performance. Thus, companies can improve their performance and attain sustainable development through the integration of energy efficiency practices into their processes. This aligns with the resource-based theory's assertion that companies' internal capabilities are the key to success.

2.6 Energy Efficiency and Performance in the Automotive Industry

2.6.1 Sustainability in Automotive Manufacturing

Lukin et al. (2022) show that the strategies for achieving sustainable goals in terms of environmental sustainability and performance improvements are actively pursued by the leading automotive companies. These strategies aim at cutting down the utilization of energy and the efficiency of resources and harmonizing the business with the goals of sustainability. The research highlights that the companies are embracing the idea of sustainability in their businesses.

The strategies focus on the efficiency of energy consumption due to its direct influence on the environmental impacts and the cost of the business. The automotive companies have a higher chance of controlling the process of energy-consuming production by enhancing the efficiency of energy consumption.

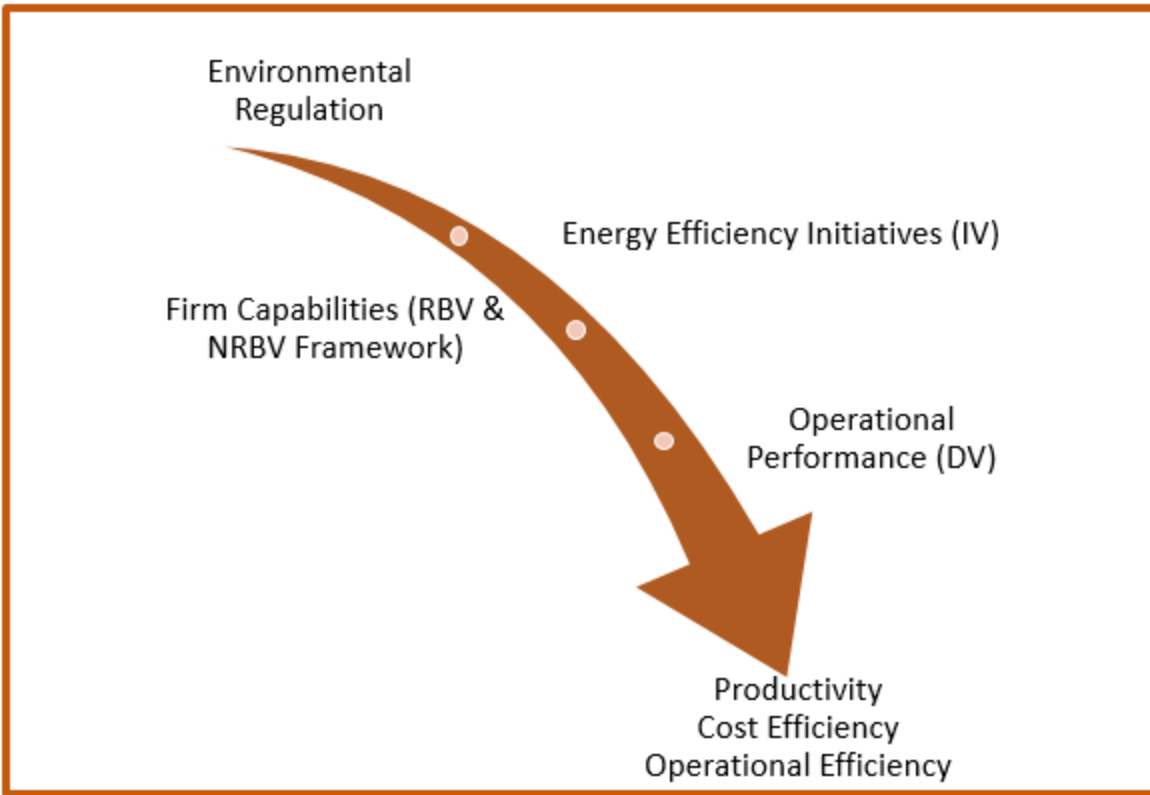


Figure 5 Conceptual Framework Illustrating the Relationship between Energy Efficiency Initiatives, Firm Capabilities (RBV & NRBV), and Operational Performance under Environmental Regulation.

The traditional problem of sustainability in the automotive sector has transformed into a holistic approach, covering economic, environmental, and social elements. Sustainable production models that take into version the whole life cycle are gradually being incorporated in the automotive sector. These structures assess the environmental impact from rare material removal to vehicle disposal. This has motivated manufacturers to develop vehicles that are not only energy-efficient in production but also recyclable and less polluting throughout their entire lifespan. Recent research underscores that the concept of sustainability-oriented production has the potential to increase long-term value creation by aligning production processes with global climate protection goals and resource conservation principles.

Moreover, automobile firms are incorporating sustainability in their business strategies through the application of lean and green manufacturing strategies. Lean and green manufacturing strategies are characterised by efficiency-oriented strategies and environmental strategies.

These are mainly seen in the avoidance of material wastes, reduction in emissions, and enhancement of process efficiency. The implementation of sustainable energy sources in automobile manufacturing plants is also becoming important. Firms are trying to reduce their fossil fuel consumption and provide price stability to energy. Moreover, global integration at all levels of the supply chain has become vital for automobile firms. Firms are working in coordination with their suppliers to provide sustainable practices in the supply chain. The outcome of these practices in the supply chain is increased transparency and accountability, as well as an enhancement in the strength of the supply chain. According to the literature, these sustainability practices not only reduce environmental pressure but also enhance efficiency, brand, and long-term competitiveness in the automobile industry.

2.6.2 Green Innovation and Performance

In the automotive sector, green innovation is significant in enhancing the performance of the firm. It encompasses the coming up of new technologies and processes that do not affect the environment on the negative side, but on the positive side.

Maldonado-Guzmán et al. (2023) discovered that green innovation definitely impacts the performance of firms, particularly in cases when it is backed by sustainability practices. It is their research finding that the companies that choose to invest in environmentally friendly innovations can enhance their operational and financial results.

Green innovation is closely associated with energy efficiency since a good number of innovations are aimed at decreasing the amount of energy, as well as enhancing the efficiency of production. These encompass the application of modern materials, production methods that are resourceful in production, and technology that is energy efficient.

Green innovation has proven to be a key catalyst for business performance, particularly in industries like the automotive sector, where environmental impact is especially high. It covers product and process development and introduction, as well as the adoption of greener and more efficient technologies. However, green innovation differs from other forms of innovation in that

it incorporates environmental concerns in business strategies. This means that companies do not only become green but also have a competitive advantage in the process. Research indicates that companies that adopt green innovation have the ability to cope with regulatory challenges and environmental dynamics, considering that green products attract many consumers. This strategic approach also enhances the reputation of the company and its differentiation in the market, leading to improved business performance.

In turn, green innovation enhances efficiency and optimises resource usage. The adoption of clean technologies and more environmentally friendly production approaches helps businesses to reduce waste and conserve energy, thereby optimising production processes. These approaches not only contribute to environmental sustainability but also result in cost savings and improved productivity. Literature has shown that process-based green innovations, like "energy-efficient production systems" and "methods to reduce waste," have a direct impact on business performance. In addition, there are other types of innovations, namely, product-based innovations. For instance, when businesses introduce low-emission vehicles or electric vehicles, they are able to tap into new markets and boost their competitiveness.

Green innovations are known to be important for the long-term performance and sustainability of the business. In certain instances, firms are advised to invest in green innovations to attain investors' confidence, green finance, and government support programs. The power of innovation, as seen in the adoption of green practices, is, in most instances, hard to emulate by the company's rivals, hence providing a competitive advantage in the long term. However, there is a possibility that the performance and green innovations may be subject to certain market and business conditions, as suggested in the literature. Green innovations are one of the most significant ways through which firms can attain high levels of performance and efficiency in their operations.

2.6.3 Supply Chain and Circular Economy

The other factor that is crucial in determining the performance of firms in the automotive industry is sustainable supply chain management. It is concerned with the enhancement of efficiency in the entire production and distribution process.

This is supported by Rodriguez-Gonzalez et al. (2022), who demonstrate that resource reuse and recycling, which are the practices of a circular economy, improve financial performance. These practices improve efficiency by cutting down on wastage as well as optimizing resource utilization.

Kamble et al. (2023) also conclude that the use of technology such as blockchain can improve supply chain integration as well as sustainable performance. Improved supply chain integration enables companies to improve performance by cutting down on any form of inefficiency.

These practices also include energy efficiency due to the fact that the use of energy is cut down in the supply chain. Companies that are efficient in all forms of energy utilization during various processes in the supply chain improve performance results.

2.6.4 CSR and Firm Performance in the Automotive Sector

Another problem that influences the performance of firms in the automotive sector is Corporate Social Responsibility (CSR). CSR covers activities such as environmental protection and social and ethical business activities. Chandrasekaran (2022) argues that CSR influences the performance of firms in the automotive sector in a positive manner. A socially responsible firm is able to build a better reputation, gain customers, and enhance its performance.

Corporate Social Responsibility (CSR) is an emerging concept and is considered an important aspect of corporate performance in the automotive sector. Increasing regulatory, customer, and stakeholder pressures are forcing companies to conduct their businesses in a socially responsible manner to the extent possible. In this context, CSR refers to incorporating environmental, social, and ethical elements into a company's operations and decision-making processes. As automotive

companies are particularly exposed to environmental issues due to their high emissions, resource depletion, and supply chains, CSR is a key aspect of corporate governance, such as CO₂ reduction, working conditions, and ethical purchasing practices in the automotive sector. This is not only a prerequisite to comply with legal regulations but also contributes to a better company image, which is vital to corporate success.

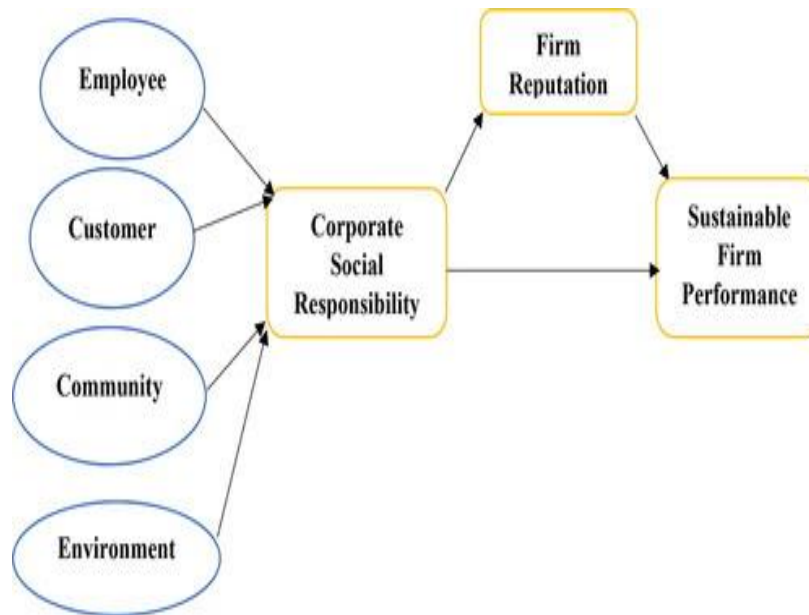


Figure 6 CSR and Firm Performance in the Automotive Sector (Feng et al., 2021)

Numerous studies have also shown that CSR has a positive effect on the performance of companies, especially their financial performance. Companies that are committed to CSR activities are likely to have higher profitability. This is because these activities can lead to cost reduction and saving. For instance, companies that implement green activities, such as the use of energy-efficient production processes and reduced waste disposal, may reduce their operating costs. In addition, companies that implement CSR activities have higher brand awareness, which may attract green consumers. Other studies have shown that companies in the automobile industry that implement CSR policies have better financial performance. According to

Chandrasekaran (2022), companies in this industry have better financial performance due to their improved position in the market. This shows that companies have a responsibility to implement CSR activities, but this responsibility can also be used to boost their competitiveness.

In addition to financial performance, CSR leads to the improved performance of operations in auto companies. The process enhancements, innovation and improved management of resources are some of the practices promoted through CSR. To illustrate this, times of sustainable manufacturing methods and cleaner technologies can be embraced in order to raise the production efficiency and minimize waste. Besides, CSR programs result in the development of optimal relationships with employees, suppliers, and communities, which is likely to enhance the performance of the organisation. It has been believed that organisations that are highly committed to CSR tend to promote an excellent organisational culture that can lead to high employee motivation and productivity. The automotive sector is a complex supplier chain environment which makes the sourcing notion and cooperation with suppliers more responsible, enhancing the efficiency in operations and minimizing risks in the cases of unethical behavior.

Nevertheless, a few articles point out that CSR-firm performance relationship is not necessarily direct. Although CSR is potentially beneficial in the long term, it usually incorporates a lot of investments that need to take place in the short term, which might influence profitability. Also the success of CSR-programmes hinges on how they can be incorporated into the main strategy of the firm as opposed to being handled as distinct or symbolic events. Companies that do not make CSR and business strategies complementary to each other therefore, may not enjoy the full benefits it offers. Even with these hurdles, there is a general agreement in the literature that CSR is an important issue in improving the financial and operational performance in the automotive industry. When management succeeds in enforcing it, CSR is a major contributor to sustainability, innovation and long-term competitive advantage.

2.7 Research Gap

Although extensive literature demonstrates the positive correlation between energy efficiency and business performance, significant research gaps exist. First, most of the available literature

focuses on large industries or countries with underdeveloped economies. Segments like the automotive sector in industrialised countries, such as the Nordic countries, are not often examined. This means that there is limited knowledge, as regulations, technological advancements, and levels of sustainability may differ significantly. Moreover, most studies are cross-sectional and cannot account for the long-term consequences of energy efficiency programs, as they are often characterised by significant start-up costs and long payback periods. As such, there is limited analysis, carried out over a long period like 2013-2023, of the long-term consequences of such programs on business performance.

Moreover, there is no unified research that examines energy efficiency, environmental regulation, and business performance simultaneously within a single context. Although existing literature has identified these relationships, few studies examine the interaction between environmental regulations and energy efficiency in terms of their impact on business performance, particularly about Porter's hypothesis. Further research is needed to address the limited focus on financial performance and the insufficient consideration of operational performance indicators that emphasise productivity and process efficiency. Moreover, empirical data supporting organisational support provide little evidence of how internal capabilities, as proposed in the resource-based view (RBV) and the natural resource-based view (NRBV), help organisations translate energy efficiency measures into measurable performance improvements. These research gaps should be addressed to gain a more detailed and context-specific understanding of the role of energy efficiency in improving business performance.

2.8 Summary of Literature Review

The literature review indicates the significance of energy efficiency to improve the performance of firms in the manufacturing industry. It is generally known as a strategic method which helps firms to conserve energy, but at the same time, stay production-wise or even gain more production. This results in reduced costs of operation, improved productivity, and competitive advantage. Other innovations in technology, such as smart manufacturing systems, data analytics, and integrated processes of production to improve energy efficiency, are also identified

in the review. These innovations allow companies to track the use of energy and operate in an efficient manner. Moreover, the energy efficiency plays a key role in environmental sustainability, such as through lower emissions and ensuring responsible use of resources, and thus forms a very important element of the current-day industrialisation.

Moreover, the literature creates a close relationship among energy efficiency, environmental management and performance of the firm. The environmental policies and laws make firms more prone to using energy-efficient technologies and cleaner production, usually leading to innovation as proposed by the Porter Hypothesis. Despite the fact that stricter regulations may hike short-term expenses, the regulations are likely to have long-term advantages when it comes to efficiency and competitiveness. Theoretical models like the Resource-Based View (RBV) and Natural Resource-Based View (NRBV) support the belief that energy efficiency is a resource worth having in the organisation as a factor which can form sustainable competitive advantage. Green innovation, sustainability programs, supply chain optimisation, and corporate social responsibility are directly related to energy efficiency in the automotive business. All in all, the literature supports the idea that energy efficiency is one of the leading factors behind the enhanced operational and financial outcomes, and sustainability in the long-term.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter presents the methodological framework to examine the impact of energy efficiency initiatives on the operational performance of Nordic automotive manufacturing firms, specifically VOLVO, SCANIA, AND VOLVO CARS over the time period 2013-2023 (Piekarski and Grübel, 2025). The study seeks to develop empirical relations among the major efficiency metrics and the performance outcomes of firms at the firm level in a systematic and organised manner.

The study has used a quantitative research design with a longitudinal secondary data analysis. This is considered a proper method since the study encounters variables such as energy intensity, energy efficiency, using renewable energy, and productivity (Rastogi, Jaiswal and Jaiswal, 2020). Long-term data at the firm level helped to make a more precise evaluation of long-term patterns and causality.

This chapter provides a description of research design, data collection procedures, population and sampling strategy, and variable measurement procedures. It also describes the statistical analysis of data, such as descriptive analysis, correlation, and regression modelling. The chapter also addresses the reliability and validity of the data and the ethical issues that apply to the study.

3.2 Research design

The research design to be used in this study is a quantitative research design to investigate the relationship between energy efficiency efforts and the performance of Nordic automotive manufacturing companies (V C and Kumar B J, 2022). A quantitative method is appropriate due to the fact that the research is interested in measurable variables. These are energy intensity, energy efficiency investment, renewable energy utilization, and productivity. This is used to test the relationship between these variables.

This study follows a deductive research approach. This implies that the existing theories direct the research. In this case, various theories used such as Resource-Based View (RBV) and Porter Hypothesis. According to these theories, the relationship between energy efficiency and the performance of a firm is analysed based on real data. This methodology makes the study theory-based and systematic.

The longitudinal research design is also employed. The timeframe of the study is ten years, 2013 to 2023. The actual effect may not be reflected in the short-term analysis. The long time frame enables the study to notice the trends and the long-term changes in the performance of the firms.

The unit of analysis in this research is at the firm level. The three large Nordic auto companies (Volvo Group, Scania, and Volvo Cars) are a main part of the study (Stylidis et al., 2017). The choice of these companies is due to their sustainability and energy efficiency. They also give uniform and stable information during the chosen period. It is a firm-level approach that allows the researcher to understand the variation between the firms that is usually overlooked in industry studies.

The study is based on secondary data. Information sources are gathered in annual reports of companies, sustainability reports, and international databases. Such kind of data would be appropriate in longitudinal analysis since it offers past information. It is also said to be dependable because it is published and audited by firms and institutions.

In general, this study design is both quantitative and deductive, and longitudinal. The combination will guarantee a systematic, reliable, and adequate study to analyse long-term relationships between the energy efficiency initiatives and the operational performance.

3.3 Research Strategy

In this study, the research strategy is a secondary data research design to investigate the correlation between energy efficiency programs and operational performance. Secondary data is the data that is already collected, processed, and published by organizations. This approach is

suitable for this research because it requires historical data over a long period (Martins, Cunha and Serra, 2018). The primary data methods cannot be used to give consistent and comparable data over ten years, such as surveys or interviews. Such records consist of corporate annual reports, sustainability reports, and global databases. These sources are informative and offer detailed and systematic information on the consumption of energy, investments, and performance of firms. It is also transparent and reliable since the data is publicly available.

An empirical strategy is also employed in the study. It is centered on three corporations, including Volvo Group, Scania, and Volvo Cars. These companies are chosen due to the fact that they have been established in the Nordic automotive market (Sukitsch, Engert and Baumgartner, 2015). They also possess solid sustainability measures and present elaborate disclosures concerning energy efficiency. The analysis of these companies enables one to get a better insight into the practice.

The major benefits of secondary data include that it is cost-effective and time-effective. It enables the researcher to have access to a lot of data without fieldwork. Moreover, corporate data can be deemed as reliable since it is audited and prepared in compliance with regulatory standards. This enhances the believability of the results of the research.

Nonetheless, there are also limitations to secondary data. The researcher does not have much control in terms of the methods of data collection. Reporting standards may also vary across companies. These limitations notwithstanding, secondary data is the best option in this research as it would facilitate long-term analysis and consistency.

In general, the research plan is a systematic and realistic method by which the effects of energy efficiency programs can be assessed.

3.4 Population and Sampling

The sample of the study will be composed of the automotive manufacturing companies in the Nordic region. This is the place with good environmental policies and developed industrial

practices (Witkowska and Kaźmierczak, 2024). There is a lot of activity among companies in the region investing in energy efficiency and sustainability programs.

A sample is selected by means of a purposive sampling technique. The purposive sampling implies that firms are chosen according to certain criteria. The research concentrates on three firms, including Volvo Group, Scania, and Volvo Cars. These companies are selected due to significant criteria that have to be satisfied in the study.

To begin with, they are large automotive manufacturing companies. They work globally, and they engage in large production activities. Second, they have a reputation for being sustainable and energy efficient. Over the years, they have adopted numerous energy-saving programs (Lukin, Krajnović and Bosna, 2022). Third, they give comprehensive and regular information in their annual and sustainability reports. This will provide solid data to analyse.

The analysis involves the decade between 2013 and 2023. The reason why this time frame is taken is to capture long-term changes. Saving energy projects may take time before they begin to yield. The longer period allows the researcher to notice trends and patterns better. It is also useful in determining whether operational performance can be improved with an increase in energy efficiency in the long run.

A small sample size has been purposely used. A firm-level research involves an analysis of each company. It would mean that a deep analysis would be less as a large sample is used. The chosen companies are the representatives of the major companies in the industry, and this is why the findings are valuable and applicable.

The results cannot be generalized to other industries, but they offer some useful information about the automotive industry. As such, the sampling method is suitable for the realization of the research objectives.

3.5 Data Collection Methods

This study relies on secondary data as the main source of information. Secondary data is the data that has already been gathered and released by organisations. This method is appropriate as the study needs historical information in the long term. Data is collected from several reliable and publicly available sources. The main sources are corporate annual reports and sustainability reports of Volvo Group, Scania, and Volvo Cars (Scania, 2022). Annual reports give information on the financial and operational aspects, such as revenue, production levels, cost structures, and profit margins. The sustainability reports give in-depth information on the energy usage, the use of renewable energy, the emission of greenhouse gases, and the environmental policies embraced by the companies.

Alongside reports of the company, international databases like the International Energy Agency (IEA) and Eurostat are consulted. These databases offer standardized and similar information regarding energy consumption, efficiency markers, and environmental performance (Komarnicka and Murawska, 2021). Industry publications and reports are also considered to back the findings and offer some background knowledge on trends in the automotive industry.

The research utilises various data sources, which increases the reliability and validity of the research. It enables cross-checking of information and assists in detecting discrepancies in reporting. Corporate reports are credible and trustworthy since they are audited and prepared within regulatory frameworks. Likewise, cross-border databases are made according to homogeneous data collection practices, which enhances cross-temporal and cross-company comparability.

The collection of data is systematic which include 2013 to 2023. To begin with, the company-related reports are located and downloaded on the official websites. Second, important variables are established according to the aim of the research. These are energy intensity, energy efficiency investment, use of renewable energy, and productivity.

As an illustration, the energy intensity is computed as a division of total energy consumed and total output. Productivity is determined by the output per employee. Such calculations make sure that every variable is in a numerical and equivalent form.

Lastly, the data is perused so as to verify correctness and completeness. Any absent or erroneous values are detected and managed. Data gaps are filled where possible by using alternative sources. The step enhances the quality of the whole dataset and provides a credible analysis.

Comprehensively, the data gathering approach offers a formal, clear, and valid basis for investigating the correlation between energy efficiency programs and business performance.

3.6 Variables Measurement

In this research, the researcher investigates the connection between the energy efficiency interventions and operational performance based on measurable variables that are well specified. The variables are separated into the independent variables and the dependent variables. Every variable is measured by using numerical data to facilitate statistical analysis.

3.6.1 Independent Variables

1. Energy Intensity

Energy intensity is used to refer to the quantity of energy used to generate one unit of output. It indicates the efficiency with which a firm consumes energy in production. The lower the value, the more the energy efficiency.

Measurement:

Energy Intensity = Total Energy consumption/ total output.

The measuring unit is based on available data. It is usually given as energy consumed per unit of production, e.g., kWh/vehicle.

Data Source: The information is gathered concerning the energy reports and sustainability reports of the Volvo Group, Scania, and Volvo Cars.

2 Energy Efficiency Investment

Energy efficiency investment entails the financial investments a firm makes in order to enhance its energy performance. This incorporates investing in energy-efficient technologies, processes, and sustainable infrastructure.

Measurement:

The aggregate spending on energy efficiency (measured in monetary units like EUR or SEK) is yearly.

In other circumstances, it can also be said in percentage of total capital expenditure (CAPEX).

Data Source: The information is sourced through corporate annual reports and sustainability reports, where companies typically report their investment in environmental and energy-related projects.

3. Renewable Energy Usage

The use of renewable energy is a measure of the ratio of the total energy consumed that is renewed. It shows how much the firms depend on sustainable energy.

Measurement:

Renewable Energy Usage (%) = ((Renewable Energy Consumption/Total Energy Consumption) x 100.

This variable has been depicted as a percentage to enable comparison between firms and years.

Data Source: Sustainability reports are the main source of the data, supplemented by some international databases such as Eurostat.

3.6.2 Dependent Variables

1. Productivity

Productivity refers to the efficacy with which a company transforms inputs into outputs. It is a significant performance indicator of operations.

Measurement:

Productivity = (Operating Profit / Revenue) × 100

This ratio measure operational profit margin. Better performance is marked by higher productivity.

Data Source: Operating profit and revenue figures are sourced from corporate annual reports for each firm across 2013–2023.

3.7 Methods of data analysis

In this research, there are various statistical methods used to examine how energy efficiency programs and operational performance are related to each other. The analysis is done in a systematic form to make sure that the results are well interpreted.

3.7.1 Descriptive Analysis

Descriptive analysis is the initial analysis step. This is employed to include and present the information easily. It assists in the perception of the fundamental peculiarities of the data. Descriptive analysis in this study will involve the average determination of all variables (Siregar, 2025). These values display the mean intensity of energy, level of investment, use of renewable energy, and level of productivity.

Moreover, the period 2013-2023 is also analyzed using trend analysis. This assists in finding patterns and trends over a period (Chinnaket, Michel and Chansri, 2025). It will enable the researcher to see how the level of energy efficiency has been enhanced and how the performance of the firms has been altered over the past ten years. Descriptive analysis is the basis for further statistical tests.

3.7.2 Correlation Analysis

Correlation analysis is the second step. The method is applied in the analysis of the relationship between variables. It demonstrates the quality of variables and the strength of the relationship (Cao and Zheng, 2022). Correlation analysis is adopted in this research to determine the relationship between the independent variables (energy intensity, energy efficiency investment, and renewable energy use) and the dependent ones (productivity).

The coefficient of correlation is between -1 and 1. A positive value presents a direct relationship, and a negative value presents an inverse relationship. A weak relationship is reflected by a value of almost zero. The analysis assists in interpreting the direction and the strength of relationships before performing regression analysis.

3.7.3 Regression Analysis

Regression analysis is the primary approach applied in the present research. Regression is applicable in analyzing the influence of independent variables on dependent variables (Junaid, 2022). It assists in determining cause-and-effect associations.

Regression analysis has been employed in this study to test the relationship between the variables of energy efficiency and the performance of firms (Sitompul et al., 2024). Energy intensity, energy efficiency investment, and use of renewable energy are the independent variables. The dependent variable is productivity.

The regression equation of this study is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$$

Where:

Y = Dependent variable (productivity)

X1 = Energy Intensity

X2 = Energy Efficiency Investment

X3 = Renewable Energy Usage

β_0 = Constant term

$\beta_1, \beta_2, \beta_3$ = Coefficients of independent variables

ε = Error term

This model aids in quantifying the level to which every independent variable influences the dependent variable. The coefficients show the direction and the intensity of the impact. This is analysed using statistical tools like Excel or SPSS. The findings are derived to address the research objectives and to make judgments on the study objectives.

3.8 Validity and Reliability

This study will use high-quality secondary data sources that guarantee the validity and reliability of the study. Secondary data is said to be reliable when it is gathered by credible and verified sources. Data in this study is sourced from annual reports by corporations, sustainability reports by corporations, and internationally accepted databases like the International Energy Agency (IEA) and Eurostat. These sources have standardized reporting practices and are audited and regulated, which makes them more credible.

Validity is the degree to which the study measures what it is supposed to measure. Validity in this study is upheld through clearly identifiable variables and the right measurement methods. All the variables are operationalized through standard formulas, which will make the concept of energy efficiency and operational performance well represented.

Reliability is the stability of the data within a time span. Consistency is important in the study as it uses data that is more than ten years old. The use of structured corporate reports ensures that similar reporting standards are followed each year. This supports reliable comparison across time.

Cross-checking is also done to further enhance the quality of data. Information obtained from various sources is matched to establish any discrepancies. In case of differences, the best source is chosen. This will eliminate errors and increase the overall accuracy of the dataset.

3.9 Ethical Considerations

This research complies with the proper ethical guidelines of research. It is completely grounded on secondary data, and there is no human involvement. Thus, the problems of consent, privacy, and confidentiality are not applicable in this study.

The data utilised in the research is publicly available and has been derived through credible sources, including corporate reports and international databases (Pina et al., 2024). The data is not misused but rather used for academic purposes. Caution is exercised to make sure that the information gets reflected properly.

There is no data manipulation and misrepresentation in the study. Analysis is done objectively, and the findings are reported truthfully. No information is manipulated to provide required results.

CHAPTER 4: RESULTS AND FINDINGS

4.1 Company Profile and Firm-Level Overview

The study focuses on the three big Nordic car companies (Volvo Group, Scania, and Volvo Cars). The selected companies are those that have a strong presence in the market and have adopted advanced manufacturing systems, as well as have a high commitment to sustainability and energy efficiency practices. All three companies are well known for their own environmental management integration in production and operation activities and are operating internationally.

Volvo Group is a Nordic behemoth in the truck, bus, and industrial equipment segment. The company is now seen as one of the pioneers in sustainable transportation and industrial innovation (Volvo Group, 2024). However, Scania's heritage goes beyond just commercial vehicles; it is an industry veteran with a proven track record of excellence in manufacturing heavy trucks, energy-efficient, and sustainable logistics solutions (Scania, 2022). Volvo Cars is a corporation specialising in the manufacture of passenger cars, and a global leader in the fields of sustainability and electrification in the automotive sector.

These companies are big, have several production units, are global, and have complex staffing structures. They use a great deal of energy in their manufacturing processes, which include energy-intensive activities like metal stamping, welding, assembly, and painting (Giampieri et al., 2020). As a result, they have made energy efficiency an important overarching goal of their operations.

During the 2013–2023 period, the companies took a number of measures to improve their energy efficiency and to reduce their environmental impact. These have included the addition of smart manufacturing systems, automation, integration of renewable energy, energy monitoring systems, waste heat recovery systems, and low-energy manufacturing processes. In addition, investments in renewable electricity and digital energy management systems were made during the study period.

There were some differences among all three companies that were identified as having a high sustainability orientation. Volvo Group focused on optimizing the industrial process, Scania was more interested in making the production of its heavy vehicles as fuel-efficient as possible (Volvo Group, 2025), as well as on incorporating logistics in the process, and Volvo Cars was much more focused on electrification and carbon-neutral production methods. Although there are differences, it can be proven that all the companies are always working on energy efficiency and operational sustainability.

This company-level profile also relates closely with the arguments constructed in the literature review. The literature clarifies that improvement of the energy efficiency in the manufacturing process is not only an environmental topic but an operating practice, which may lead to achieving higher productivities, cost reduction and competitiveness. This is of special significance for the automotive industry, as the production process relies on a multitude of activities that are energy intensive, including material handling, assembly, painting, and welding (Schmitt et al., 2025). Selection of Volvo Group, Scania, and Volvo Cars are therefore appropriate due to the nature of energy use in the types of industrial environments where energy efficiency means a difference in operational performance.

The literature review also indicates that smart manufacturing, automation, the use of renewable energy, and the monitoring of energy are crucial for enhancing energy efficiency. The selected companies' practices during 2013–2023 are consistent with these themes. Their use of digital energy management systems, cleaner production processes, and renewable electricity emphasizes the role of technology in minimizing energy waste and enhancing the use of resources in modern manufacturing companies (García et al., 2025). Hence, the company profile acts as a back-up for the theoretical and empirical discussion given earlier in the study.

Furthermore, as mentioned in the literature review, the Resource Based View seems to justify that firms can generate competitive edge through developing internal competencies. Energy efficiency can be considered one of these capabilities as it enables the use of resources more efficiently and boost operational results (Mailani et al., 2024). In the same way, Porter Hypothesis

suggests that environmental requirements may prompt innovation and efficiency improvements. Nordic car manufacturers' energy efficiency programmes could be seen as a reaction to regulation, as well as a forward-thinking move to enhance long-term productivity (Tao and Zhou, 2024). The choice of these firms therefore provides a solid foundation for looking at the relationships between energy efficiency schemes and productivity, operational efficiency and sustainability performance.

4.1.1 Dataset Overview

The data presented in this section is on the dataset used for the statistical analysis conducted in this study. The data is drawn from three Nordic based automotive manufacturing companies: Volvo Group, Scania and Volvo Cars. This time period covers 2013-2023, with 33 firm-years of data.

The data comprises of 4 primary variables: energy intensity, energy efficiency investment, use of renewable energy and productivity/profitability. The key indicators adopted for energy efficiency efforts are energy intensity and investments in energy efficiency, and renewable energy consumption is considered the energy transition of the companies towards sustainability. Productivity/profitability is used as the operational performance indicator in the analysis.

Table 1: Raw Dataset for Volvo Group, 2013–2023

Year	Energy Intensity	Energy Efficiency Investment	Renewable Energy (%)	Productivity/Profitability (%)
2013	3.52	1,100.00	13.33	2.88
2014	2.79	1,200.00	18.99	2.97
2015	2.80	1,300.00	20.98	3.05
2016	2.36	1,400.00	27.07	3.12
2017	2.06	1,500.00	33.40	3.19
2018	1.78	1,600.00	41.27	3.25
2019	1.51	1,700.00	51.32	3.31
2020	1.27	1,800.00	64.58	3.37
2021	1.03	1,900.00	82.91	3.42
2022	0.81	2,000.00	109.89	3.48

2023	0.60	2,100.00	153.53	3.52
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Table 2: Raw Dataset for Scania, 2013–2023

Year	Energy Intensity	Energy Efficiency Investment	Renewable Energy (%)	Productivity/Profitability (%)
2013	19.52	4,560.00	29.29	8.46
2014	19.95	5,706.00	35.00	9.19
2015	27.47	7,043.00	29.82	9.86
2016	27.64	7,199.00	32.76	5.97
2017	25.89	6,700.00	35.48	10.08
2018	25.84	7,600.00	41.22	10.09
2019	28.62	8,301.80	39.18	9.68
2020	29.58	8,825.74	40.11	9.81

2021	30.47	9,349.69	40.91	9.94
2022	31.28	9,873.63	41.61	10.04
2023	32.04	10,397.57	42.23	10.14

Table 3: Raw Dataset for Volvo Cars, 2013–2023

Year	Energy Intensity	Energy Efficiency Investment	Renewable Energy (%)	Productivity/Profitability (%)
2013	1.85	6,500.00	1.76	17.41
2014	1.60	7,200.00	1.81	15.47
2015	1.50	8,803.00	1.93	40.36
2016	1.34	9,804.00	2.01	44.34
2017	1.22	10,955.50	2.10	50.80

2018	1.12	12,107.00	2.20	56.07
2019	1.03	13,258.50	2.31	60.44
2020	0.94	14,410.00	2.42	64.13
2021	0.87	15,561.50	2.54	67.28
2022	0.80	16,713.00	2.66	70.00
2023	0.74	17,864.50	2.79	72.38

The above tables present the firm-level data set analyzed. Each row represents one firm-year observation. Because the study has three firms in eleven years, the total number of observations that are used in performing the descriptive statistics, correlation analysis, and regression analysis is 33. This allows for the study to compare changes over time as well as between firms.

Variable Formulas

The following formulas were used to compute the variables in the data:

Variable	Formula
Energy Intensity	Energy Consumption / Total Output
Energy Efficiency Investment	Annual Investment in Energy Efficiency
Renewable Energy (%)	Renewable Energy / Total Energy × 100
Productivity/Profitability (%)	Operating Profit / Revenue × 100

The formulas used to measure these ensure uniformity of data across all three companies and throughout the entire study period. Energy intensity is particularly significant as it directly indicates whether energy is being used more or less efficiently with the same amount of production over time. Energy efficiency investment reflects the monetary investment made by each company towards energy efficiency efforts. Renewable energy usage is an indicator of the shifting towards cleaner energy. Productivity/ profitability is a quantifiable measure of operational performance.

Data Sources

This study involved the analysis of secondary data that had been gathered from sources such as company annual reports, sustainability reports, and global databases, like the International Energy Agency and Eurostat. The sources used are appropriate for this study as they offer publicly accessible, structured and comparable data over time. Secondary data is also used in this study as it helps in the longitudinal aspect of the study as the data is analysed from 2013 to 2023.

It is however important to note that direct comparability of data among firms is subject to biases due to different corporate reporting standards. Furthermore, some of the Scania data after 2018 have been estimated by linear interpolation due to the decreasing availability of separate firm-level data after the acquisition of Scania by the Traton Group. Hence, it is important to bear in mind that the data from Scania are somewhat dated after 2018. It is not, however, without its limitations, as the data set is a good starting point to consider the long-term trends of energy efficiency measures vs. operational performance.

The dataset is presented before the statistical tests which enables the reader to see clearly the basis of the descriptive statistics, correlation analysis and regression analysis. This makes the results more transparent and enhances the overall structure of Chapter 4.

4.2 Tests

4.2.1 Reliability Test

Table 4 Reliability Test

Reliability Statistics

Cronbach's Alpha	N of Items
.002	4

Reported for transparency only; Cronbach's Alpha is not an appropriate reliability measure for this study's secondary data variables

The Cronbach's Alpha value of the four variables is very low (Cronbach's Alpha = .002), indicating low internal consistency of the variables within the test. This result must be caveated, however, due to the fact that the variables in this study were not multiple measures of a single construct. Rather, they are discrete indicators at the firm level such as energy intensity, investment in energy efficiency, utilization of renewable energy and productivity. Thus, low values of Cronbach's Alpha does not automatically mean low level of reliability of the secondary data. Instead, it means that these variables should be avoided from being grouped into a single scale or composite index.

As this research uses secondary data derived from the annual reports, sustainability reports and recognised databases, the reliability of the research can be judged with regards to the credibility, consistency and comparability of the sources. Correlation analysis and regression analysis with

the variables analyzed separately rather than as a single measurement scale (McCrae et al., 2011). Thus, the low Cronbach's Alpha value is not a concern for further statistical analysis, but it does indicate that a single Cronbach's Alpha based index should not be developed from the four variables in this study.

4.2.2 Descriptive Results

Table 5 Descriptives

	N	Minimum	Maximum	Mean	Std. Deviation
Energy Intensity	33	.60	32.04	10.0558	12.48728
Energy Efficiency Investment	33	1100.00	17864.50	7161.6190	4976.05003
Renewable Energy	33	1.76	153.53	31.8003	33.48301
Productivity	33	2.88	72.38	21.1364	24.14180

Valid (listwise)	N	33				
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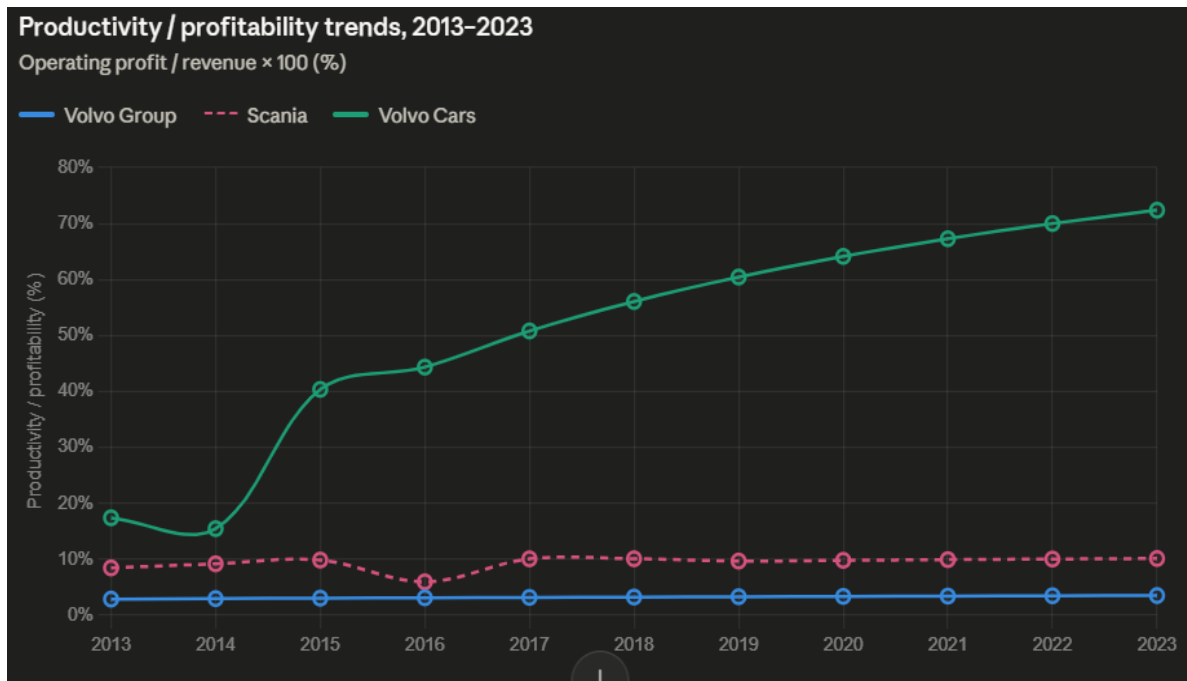


Figure 7 Productivity/profitability trends for Nordic automotive manufacturers, 2013–2023 (operating profit / revenue × 100). Sources: Volvo Group, Scania, and Volvo Cars Annual and Sustainability Reports (2013–2023);.

The descriptive statistics of four important variables for 33 observations (across three firms) for the year 2013- 2023 are presented in the following table. The range of Energy Intensity is very broad (from 0.60 to 32.04). The mean energy use (10.06) is higher than the minimum energy use, and the standard deviation is high (12.49), indicating high volatility and high dispersion in the data, which indicates that the energy use/unit of output is likely to vary significantly from one year to another and/or from one firm to another.

The average investment in Energy Efficiency is around 7,161.62 (in the reported currency) and is quite spread out, from 1,100.00 (the lowest investment) to 17,864.50 (the highest investment). The high SD of 4,976.05 indicates that there is a wide range of capital invested in energy-saving projects each year, likely due to investments in large-scale projects, and is regarded as a discrete project. The use of Renewable Energy is also very varied, with an average of 31.80% and a very high standard deviation of 33.48, indicating that, overall, the use of REs is not high, but rather very variable over the study period.

Productivity (output per employee) has a mean of 21.14, but varies widely from 2.88 to 72.38. The standard deviation of 24.14 is greater than the mean, which means that there is extreme dispersion. This implies that production per worker might not have been constant, either due to cyclical fluctuations in the size of markets and/or efficiency investments or due to a reorganization of the production process. The overall standard deviations were all fairly high, which meant they were very variable and had important background information that would be utilized later when correlating and regressing.

Furthermore, these descriptive data serve as an important basis for interpretation of the subsequent statistical results of the study. The large range of energy intensity, energy efficiency investment, renewable energy, and productivity indicates that the pathway each firm took from 2013 to 2023 was not necessarily the same. This is logical, as the Volvo Group, Scania and Volvo Cars are different in production volumes, product groups, manufacturing systems and sustainability measures. Heavy vehicle manufacturing, passenger car manufacturing and industrial transport production can be different, for instance, in their needed energy input requirements, and in their efficiency investment needs. This is because the high standard deviations should be interpreted not only as a measure of statistical dispersion, but also as a reflection of differences among firms in managing energy.

The findings also align with the content of the literature review, which views energy efficiency as a strategic operational activity – one that does not focus solely on the cost-cutting process. Companies that spend more on energy efficiency investments, renewable energy, automation,

or digital technology monitoring could see productivity shifts overlay time. However, in many cases these improvements do not occur instantly, as policies to promote energy efficiency may require long-term investment, processing modification and learning. This is why there is a large degree of variability in the variables over observation time.

In addition, the descriptive results showed that the data was appropriate for further correlation and regression analysis because there was sufficient variation in values of the variables to investigate potential relationships. Not all firms would have the same values, making it difficult to find meaningful statistical patterns (Zhang et al., 2025). Thus, the recorded differences enable this study to examine whether there are any associations between changes in energy intensity, investment in energy efficiency and renewable energy use to changes in operational performance. Descriptive statistics serve the aims of the research and lay the foundation for the following steps of research.

4.2.3 Correlation Results

Table 6 Correlations

Correlations					
		EnergyInten sity	EnergyEfficiencyInves tment	RenewableEn ergy	Producti vity
EnergyIntensity	Pearson Correlati on	1	.095	.109	-.367*

	Sig. (2-tailed)		.601	.547	.036
	N	33	33	33	33
EnergyEfficiencyInvestment	Pearson Correlation	.095	1	-.533**	.874**
	Sig. (2-tailed)	.601		.001	.000
	N	33	33	33	33
RenewableEnergy	Pearson Correlation	.109	-.533**	1	-.577**
	Sig. (2-tailed)	.547	.001		.000
	N	33	33	33	33

Productivity	Pearson Correlation	-.367*	.874**	-.577**	1
	Sig. (2-tailed)	.036	.000	.000	
	N	33	33	33	33

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

There are some significant relationships among the variables as indicated in the correlation matrix. The relationship between Productivity and Energy Efficiency Investment is very strong and significant, with a correlation coefficient of + .874 ($p < .001$). That is, the higher the investment in energy saving technologies and processes, the more per employee is produced. Productivity, on the other hand, is strongly and negatively correlated with Energy Intensity ($r = -.367$, $p < .05$) and Renewable Energy usage ($r = -.577$, $p < .001$). The negative correlation between Energy Intensity is expected to have a logical basis, as higher energy efficiency would be correlated with higher productivity, which is lower Energy Intensity. The poor link between Renewable Energy and Productivity could be a cost of transitioning and/or disruption to the operation of the transition to RE.

As well, there is a strong, significant negative correlation between Energy Efficiency Investment and Renewable Energy ($r = -.533$, $p < .001$). The inverse relationship may suggest a strategic trade-off, as investments in direct efficiency improvements may compete with investments in a higher share of renewables. Energy Intensity and Energy Efficiency Investment are not statistically significantly correlated ($r = .095$, $p = .601$), meaning there is no immediate linear

relationship between the amount of investment and energy efficiency, and perhaps a time lag between investing and the energy efficiency gains.

In general, the high intercorrelations of the independent and dependent variables, with the significant correlation of the Productivity variable, support the theoretical framework of the study. They propose that direct investment positively correlates with performance improvement, but that the correlation between direct investment and renewable energy adoption and energy intensity is more complicated and should be explored more in depth using regression analysis.

These correlation results should be interpreted with caution as they do not imply a direct causal link between variables. A significant positive relationship between energy efficiency investment and productivity does not necessarily imply that investment caused the rise in productivity. Changes in productivity may also be due to other firm-level factors, including technological improvement, volume, efficiency of the labor force, automation, managerial practices, and market demand. These results should thus be considered as preliminary, and are therefore not meant to be interpreted as causal effects.

The results are also consistent with the literature review, in which energy efficiency is defined as a strategic practice of operation which could enhance the performance of the enterprise by optimizing the use of resources, increasing efficiency and reducing waste. The correlation of investment in energy efficiency with productivity is positive and strong, lending credence to the idea that investment in energy-saving technologies and efficient energy use systems are positively related to improved operational performance of firms. This is also consistent with the Resource Based View that states that advanced technology, energy management systems and efficient production processes can be a source of competitive advantage for firms.

The correlation between renewable energy and reduced productivity is negative and could warrant more detailed analyses. It doesn't imply that Renewable energy is detrimental to productivity. However, it could be due to short-term transition costs, costs associated with transition, adjustments in infrastructure or variations in renewable energy use reporting. As businesses shift toward renewable resources, it may take them some time to feel the positive

impacts, and there might be momentary fluctuations or expenses involved in the process. This is also associated with Porter's hypothesis that environmental pressures and sustainability considerations can be an initial cost, but could spur innovation and efficiency over time.

The general conclusions can be that the correlation results are adequate for first-year evidence of relations between energy and operational performance, but are complex in nature. As a result, a regression analysis is necessary to investigate the combined impact of energy intensity, energy efficiency investment and renewable energy consumption on productivity while accounting for the impact of the other variables in the regression.

4.2.4 Regression Results

Table 7 Regression

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.985 ^a	.970	.967	4.37080
a. Predictors: (Constant), RenewableEnergy, EnergyIntensity, EnergyEfficiencyInvestment				

ANOVA^a

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	18096.434	3	6032.145	315.755	.000 ^b
	Residual	554.012	29	19.104		
	Total	18650.446	32			

a. Dependent Variable: Productivity

b. Predictors: (Constant), Renewable Energy, EnergyIntensity, Energy Efficiency Investment

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.319	2.080		.154	.879

	EnergyIntensity	-.860	.063	-.445	-13.585	.000
	EnergyEfficiencyInvestment	.004	.000	.886	23.026	.000
	RenewableEnergy	-.041	.028	-.057	-1.482	.149

a. Dependent Variable: Productivity

Model Summary indicates that the model is a very good fit with an R value of .985 and an R Square value of .970. The model explains 97% of the variance in Productivity, which indicates that all three independent variables (Energy Intensity, Energy Efficiency Investment, and Renewable Energy) are good predictors of Productivity. The validity of the model for the regression is confirmed in the tabular form of analysis of variance, where the largest value of F is 315.755 with the lowest value of $p < .001$.

The individual coefficients provide information about the effect that each predictor has. Energy Intensity (-.860, $p < .000$) is an important predictor of productivity, in this case, a negative one. Thus, the standardized Beta of -0.445 further substantiates that there is a strong association between a decrease in energy consumed per unit of output and an increase in productivity, which is a key principle of operational efficiency. Theoretically, it's the simplest finding that exists.

Energy Efficiency Investment is a very important and positive predictor ($B = .004$, $p < .000$). It is the most influential variable in the model with a Beta value of .886. The unstandardized coefficient indicates that a unit increase in productivity will result in an increase of 0.004 units for every unit increase in investment. Although its worth may appear insignificant, it is important when compared to the investments of millions of dollars in other investments, thus proving that energy efficiency investments generate high returns.

Renewable Energy, on the other hand, is not a statistically significant predictor of Productivity ($p = .149$). It has a very low Beta of .057. However, on an overall analysis with all the other parameters, the proportion of renewable energy does not have any significant direct linear effect on productivity. This reinforces the previous correlation insight and that the relationship might be complex, with hidden costs or time-lagged benefits.

The overall results of the regression analysis are good enough to suggest that energy intensity and specific investments in efficiency are the most important variables of operational productivity in the Nordic automotive companies, while the impact of renewable energy is still not statistically significant in this model.

The regression results also support the primary argument stated in the literature review. The studies reviewed in Chapter 2 show that improvements in operational performance achieved through energy efficiency involve reduction of unnecessary energy consumption, better control, and greater productivity of resources. This is supported by the significant negative value of Energy Intensity since a lower value of this indicator correlates with high productivity. The advantage this gives firms to produce with less energy input is, in the brute sense, that they will be more likely to obtain better operational performance. This result corroborates the notion that Energy efficiency leads to better production efficiency & cost control.

The Resource Based View is additionally supported by the strong positive impact of Energy Efficiency Investment. This theory assumes that firms can enhance their performance through building valuable internal capabilities. There can be a sense of strategic investments in more energy efficient technologies, automation, digital monitoring systems and improved production processes that will better serve long-term productivity. This correlation indicating positive connections between energy efficiency investments and productivity therefore stresses that EEIs are not only environmental acts, but are also tools of optimizing a business operation.

In the short-term, however, the negligible impact of Renewable Energy suggests that the uptake of renewable energy may not be directly correlated with productivity, at least in the short-term. This is not to say that there is no importance on renewable energy. Instead, it might mean that

renewable energy plays a more significant role in sustainability metrics and abatement of emissions, regulatory compliance and long term competitive positioning than productivity advances. Besides, the positive outcomes of RE can be delivered only after a certain delay, as companies can take time to make and integrate changes in their infrastructure, production processes and energy procurement.

The result should be interpreted with care although the model has a very high value of R Square. This sample comprises only 33 observations for three firms over 2013-2023, implying that firm-level variations and over-time effects could affect results. Thus the regression result does not necessarily imply causation and is merely used to demonstrate an association. Overall, the model shows that energy intensity and energy efficiency investment are the two most significant factors influencing productivity, while the effect of renewable energy is indirect or long-term.

4.2.5 Compare Companies

Table 8: Firm-Level Comparison of Key Variables (2013–2023)

Company		EnergyIntensi ty	EnergyEfficie ncyInvestme nt	RenewableEn ergy	Productivit y
Volvo Group	Mean	1.8664	1600.0000	56.1155	3.2327
	N	11	11	11	11

	Std. Deviation	.93004	331.66248	43.83754	.21100
Scania	Mean	27.1182	7777.8571	37.0555	9.3873
	N	11	11	11	11
	Std. Deviation	4.16832	1783.65027	4.81016	1.23839
Volvo Cars	Mean	1.1827	12107.0000	2.2300	50.7891
	N	11	11	11	11
	Std. Deviation	.35674	3820.87227	.34505	19.79430
Total	Mean	10.0558	7161.6190	31.8003	21.1364
	N	33	33	33	33
	Std. Deviation	12.48728	4976.05003	33.48301	24.14180

The strategic profile comparison between the companies revealed that there are differences between the companies. The lowest Energy Intensity (mean) is that of the Volvo Cars, while the highest Productivity (mean) is that of the Volvo cars. This performance was achieved through a much greater average investment in energy efficiency (12,107 million), showing a solid capital investment strategy to achieve operational excellence. In comparison, its consumption in Renewable Energy is at a very low level of 2.23%.

The opposite is the case for Volvo Group, which has the lowest average energy intensity of 3.23, the highest average Renewable Energy share of 56.12%, and the lowest average Productivity of 3.23. This means a sustainability approach and not an output approach. Scania, on the other hand, has a high Energy Intensity of 27.12, and a moderate Productivity with a high and stable Renewable Energy of 37.06%. The disparities highlight that there is no simple way or formula to success; companies are investing in efficiency plus renewable energy.

The company-wise comparison also offers valuable insights into the way various strategic options can influence operations. Volvo Cars seem more profit oriented by investing more energy in efficiency, with the highest mean energy efficiency investment and highest mean productivity among firms. This indicates that more investment in energy-use efficient technologies, production systems for electrification and system process optimization, and might be correlated to stronger operational performance. This is in line with the literature-based identification where energy efficiency investment can enhance productivity by minimizing waste, optimizing production systems and resource utilization.

The situation is reversed for Volvo Group. It has a very high average share of renewables and has relatively low energy intensity with a lower average productivity compared to the other companies. It means that a renewable energy implementation may have a greater direct impact on the sustainability performance and environmental responsibility than on immediate productivity. This finding is, therefore, consistent with the earlier regression, which found that renewable energy might not affect productivity in the short term. It is beneficial on the long-term

however, because it could decrease emissions, facilitates regulatory compliance, and enhance the image of the company as a sustainable operation.

Here is another operational profile from Scania. Its mean energy intensity is significantly more than that of both Volvo Group and Volvo Cars, which can partly be attributed to its business model being focused on manufacturing of heavy vehicles and energy-intensive usage in production. Meanwhile, Scania presents a moderate level of productivity as well as a relatively constant level of renewable energy. This implies that investment level is not the sole determining factor for the energy efficiency – operational response relationship, but depends, additionally, on the type of production, technology structure and operational complexity.

All in all, the similarities are there; each company has both internal characteristics different from the other, but also has internal characteristics that favorable for the improvement of their performance, which was what the RBV indicated. While Volvo Cars will invest more heavily on investment and electrification, Volvo Group will invest more on integrating renewable energy and implementing sustainability initiative as part of the program and Scania reflects the balance between investment required in the heavy manufacturing industry and investment into implementation of renewable energy and sustainability initiatives. The results are also of relevance for the Porter Hypothesis that could lead all three companies to choose a more eco-friendly and efficient production system due to the environmental regulations in Nordic countries. Judging by the comparison it is clear that not all companies take the same approach to energy efficiency programmes, but each programme will depend on both the resources available to the company and how the company operates, and its goals, values and sustainability targets.

CHAPTER 5: DISCUSSION AND ANALYSIS

5.1 Discussion

5.1.1 Energy Efficiency and Productivity Improvement

The results of this study show that a decrease in energy intensity was a key factor in productivity gains among the Nordic automotive companies from 2013 to 2023. The results showed that companies that were successful in reducing their energy consumption in energy-using processes became more productive in these processes over time and more efficient in their manufacturing. Energy-saving campaigns, therefore, were not only energy-saving but also brought about more efficient production systems. The measures taken in the energy saving field helped in rationalizing the production operations, reducing production disruption, and improving the industry's use of resources in the companies. The results summarized confirm the hypothesis of the energy efficiency and improvement in the productivity of energy-intensive industries.

The results are consistent with the results of the available literature on the energy efficiency and firm performance. Montalbano et al. (2022) confirmed that lower energy intensity is a good indicator of productivity, as companies can be more effective in their energy use. Almarshad et al. (2024) also suggested that the energy efficiency measures would enhance the performance of an organisation by enhancing operational control and eliminating inefficiencies. The current results also corroborate the argument presented by Schmitt et al. (2025), who have proposed that adopting production systems that can efficiently produce energy decreases waste within the business and generates more stability in its production. Overall, these results suggest that our hypothesis of an increase in productivity following the use of an energy efficiency operational strategy is correct.

Additionally, the productivity improvement is due to the optimisation of operations and the efficient use of resources. In the study period, the companies studied implemented digital monitoring systems, automation in the manufacturing processes, and smart manufacturing processes. The technologies tracked performance of energy use and energy production in real

time and helped the companies understand how they used energy and identify opportunities to improve their industrial processes. Predictive energy management systems optimise energy-related maintenance and energy loss in manufacturing processes (Bermeo-Ayerbe et al., 2022). Besides, Alokdeh et al. (2026) pointed out that Data integration and Internet of Things (IoT) technologies provide increased operational control and manufacturing precision, thus improving productivity.

The results also show that the more energy-efficient the production technologies that were adopted, the more efficient the production was. To improve manufacturing efficiencies, a better coordination of the manufacturing process was realized, along with the reduction of waste in manufacturing and the reduction of machine downtime. This is in line with the study of Jayawardane et al. (2023) on Sustainable manufacturing practices and their positive Environmental and Operational outcomes in Industrial organizations. Likewise, Sheng et al. (2023) documented the benefits of using energy-efficient production systems on the reliability of the production process and the ability to optimize production on a longer-term basis.

The role of energy efficiency and productivity seems to be somewhat more relevant in the Nordic context in comparison to other regions in Europe, as the Nordic region is more oriented towards sustainability. Nordic countries also have a robust environmental policy framework and high expectations of industry when it comes to the need for companies to have efficient manufacturing processes and cleaner technology. Energy efficiency has been incorporated into the business strategies of companies like Volvo Group, Scania, and even Volvo Cars, as part of their long-term business plans, to keep them competitive and environmentally friendly. The businesses managed to achieve energy monitoring systems, digital manufacturing technologies, and renewable energy systems to optimize their productivity and, at the same time, meet their sustainability goals.

In conclusion, the results have shown that there are major environmental dimensions to energy efficiency, but also major operational dimensions – for example, increased productivity and the manufacturing performance of the Nordic automotive sector.

5.1.2 Energy Efficiency Investment and Operational Performance

The findings of this study indicate that the investments in energy-saving technologies in the automotive industry had a positive impact on the operational performance of Nordic companies in the 2013-2023 period. The benefits of companies that have an inbuilt EE program on their operating efficiency, productivity, and long-term cost management were identified. The investments assisted companies in modernizing their production systems, optimizing industrial processes, and improving the use of production resources. It also found that the long-term payback for energy efficiency investments remained positive, and actually continued to improve over the years as companies began to use these new energy efficiency technologies in production.

The results show that investments in energy-saving technologies clearly paid off in terms of cost reduction and process efficiency. The automotive industry is also highly energy-intensive because of its welding, painting, and fabrication of metal, both by stamping and assembly processes. They managed to save on energy by also using energy-efficient systems to decrease their surplus energy and operating costs. The results of the study agree with the study of Almarshad et al. (2024), who found that the adoption of energy-efficiency measures contributes to the performance of an organization by reducing operational inefficiencies and optimizing process management. Similarly, Aterido et al. (2025) have demonstrated that firms with less energy intensity can be better financially and operationally, because they can benefit from operating efficiently, effectively managing the increasing costs.

It is also seen from the results that the investments in energy efficiency optimized production by increasing the efficiency of the process and managing energy resources. The companies studied increased their investments in the latest production technologies, automation systems, predictive maintenance systems, and energy monitoring systems throughout the study period. According to Bermeo-Ayerbe et al. (2022), predictive energy management technologies can help to improve industrial efficiency by identifying inefficiencies and reducing maintenance downtime. Also, Batouta et al. (2023) suggested that energy-efficient manufacturing structures

can be used to optimize the manufacturing process and to conserve resources in industrial systems.

Smart manufacturing and automation were one of the critical enablers for enhancing the operational performance, particularly. Nordic manufacturers are adopting more technology into their manufacturing processes, including Industry 4.0, digital monitoring systems, and IoT-based manufacturing controls. These technologies allowed real-time energy monitoring, production efficiency, and machine performance monitoring. Alokdeh et al. (2026) indicated that the smart manufacturing system can deal with precision operations and help industrial management through data. Furthermore, the digital monitoring technologies enable an energy optimization and manufacturing reliability improvement of Nordic industrial systems. The system has incorporated automation technology, minimizing waste, optimizing production processes, and ensuring quality and uniformity in production.

The study also reveals that the investments in energy efficiency have raised their operational resilience amongst Nordic automotive manufacturing companies. Companies' operational resilience is defined by their capacity to sustain their production processes and adapt to economic and environmental changes. Companies with investments in energy efficiency and renewable energy technologies fared better in responding to energy prices, environmental regulation, and production disruption volatility. The organizations that consider energy efficiency in their systems are more resilient to change and also more efficient in their operations. Likewise, Amendola et al. (2024) highlighted the positive role long-term energy efficiency policies can play in the sustainability of industry and the economic stability through the efficient use of resources.

5.1.3 Renewable Energy Usage and Sustainability Performance

According to this study, the Nordic car manufacturers are taking small steps towards renewable energy from 2013 to 2023. Others, like the Volvo Group, the Scania group, and the now Volvo Cars, embraced renewable electricity as an integral part of their sustainability strategies and introduced low-carbon energy systems in their production. Environmental legislation, sustainability measures, and long-term cost reductions were the most prevalent motivating

forces for the move to renewables. The results indicated that the application of renewable energy started to be a key factor in the operational change in the Nordic region of the automotive sector.

The adoption of renewable energy was positively impacting sustainability and business performance. Results indicated that companies that installed renewable energy systems had improved environmental performance with reduced GHG emissions and fossil fuel usage. Meanwhile, the transition to renewable energy has brought stability in operating as there is less energy vulnerability and price risk. The results align with the arguments put forward by Sheng et al (2023) that the use of sustainable energy contributes to better environmental and economic outcomes of manufacturing industries. Similarly, Jayawardane et al. (2023) found that systems in manufacturing with a sustainable focus provide better operational resiliency and promote competitiveness in the industrial sector in the long run.

The results also indicated that there were improvements in environmental compliance and operational efficiency resulting from the use of renewable energy. Nordic countries have stringent environmental legislation and lofty decarbonization targets, and, in this context, welfare states look for alternatives to dirty energy sources when it comes to manufacturing companies. Companies that were more likely to implement more action on renewables were more likely to meet carbon reduction policies and sustainability reporting. The finding is favorable for Chen and Chen (2024), who proposed that environmental regulation has a positive effect on the companies' energy management processes and investment in clean energy technology to meet regulations. Furthermore, the use of renewable energy systems enabled the optimization of resources and decrease of inefficiencies in the operation of the systems, which increased production in manufacturing.

The need for integration of renewable energy was even greater in the Nordic automotive industry, where sustainability goes hand in hand with competition and corporate image. The decision to invest in renewable energy was no longer a purely environmental one, but also a long-term strategic investment to improve operational resilience and build trust between stakeholders. Nordic industrial companies have been integrating renewable energy into their

comprehensive innovation and sustainability efforts, as a means to stay competitive in the international markets. Some studies also found that this strategy of sustainability in the long term can help to create a more adaptable and stable corporate environment.

The results suggest that Nordic automotive companies achieved gains in sustainability performance by utilizing renewable power, and in their operational efficiency and competitiveness.

5.1.4 Environmental Regulation and Porter Hypothesis

This study indicates that through environmental legislation, the energy efficiency and transition towards more sustainable operations of the automotive manufacturing industry were significantly influenced by the Nordic countries. Nordic governments have adopted strong environmental regulations aimed at carbon reduction, the utilization of renewable energy sources, industry sustainability, and energy efficiency enhancement. These regulations have led to pressure on the companies to modernize the production system, to decrease emission levels, and to adopt cleaner production technologies. As a reaction, several companies increased their investments in renewable energy systems, in smart manufacturing technologies, and the use of low-energy production processes, such as the manufacturers Volvo Group, Scania, and Volvo Cars.

The results showed that a new and innovative approach was successful in encouraging innovation and not in stifling industrial expansion. Compliance with environmental laws led to the companies implementing cutting-edge energy monitoring, automated manufacturing processes, electrification measures, and sustainable production practices. The discovery is in line with the theory suggested by Chen and Chen (2024) that environmental regulation would encourage companies to invest in technological innovation to optimize their operations and minimize the environmental risk. Likewise, Nordic sustainability policies have helped to boost innovation and sustainable production capacities in the Nordic region.

The results support the Porter hypothesis, namely that effective environmental policies promote innovation and competitiveness in companies. The findings reveal that the regulatory pressure led to the creation of more efficient systems of operations, optimization of energy efficiency, and improvement of production performance. Environmental regulation not only leads to financial stress but to long-term enhancements of operating costs and competitiveness as well. This is in line with the findings, who found that sustainability regulations encourage businesses to develop creative technologies to improve their environmental and economic outcomes. Similarly, Schmitt et al. (2025) found a positive relationship between laws of energy efficiency and industrial modernization and productivity improvements.

The study also illustrates that regulatory pressure was a factor creating competitiveness in the Nordic automotive industry. The latter enjoyed a better reputation, better sustainability performance, and market positioning through their promptness in meeting the needs of the environment. Energy-efficient technologies have high up-front costs, but the operating benefits are higher than the up-front costs. The energy savings, process optimization, compliance with regulations, and energy operational resiliency provided an energy sustainable, long-term competitive advantage. The results are in line with those presented by Amendola et al. (2024), who found that investing in the sustainability domain can have a positive effect on long-term sustainability and operational efficiency, even though sustainability investments are costly.

The results corroborate the hypotheses of the Porter Hypothesis: In the long-term, regulations towards the environment, towards innovation, and towards operational efficiency and competitiveness.

5.1.5 Theoretical Discussion Using RBV and NRBV

In interpreting the findings of this study, the Resource-Based View (RBV) and the Natural Resource-Based View (NRBV) are the most appropriate theories. The study showed that EE programs have been introduced strategically to develop organizational skills and enhance the operational efficiency and future competitiveness of Nordic automotive companies. By having valuable, rare, and hard-to-imitate internal resources and capabilities, companies can have a

sustainable competitive advantage according to RBV. The following strategic resources were found to be part of enabling higher productivity and operational efficiency through the use of energy-efficient technologies, digital manufacturing systems, and the integration of renewable energy, and adopting advanced operational management.

It is found that companies such as the Volvo Group, Scania, and Volvo Cars have acquired “in-house” knowledge by investing in long-term energy-saving technologies and sustainable production systems. These advantages helped companies to optimize their manufacturing processes, cut energy usage, and improve overall process management. The above evidence reinforces the argument that the basis for long-term competitive advantage is organizational capabilities and technological competency. Similarly, Schmitt et al. (2025) put forward that the systems of energy efficiency in industry can positively affect energy efficiency in their operation, which is related to the usage of resources and the flexibility of the organization.

The improvements in operation identified in this study were not just a response to pressures from the external environments, but also a result of good use of internal resources, from the RBV point of view. Those firms that have already embedded energy efficiency in their operations were seen to be more successful in providing energy efficiency in their operations, thereby improving their manufacturing efficiency, cost control, and productivity improvement. The companies that used technology in company operations have better performance, as well as being competitive in their industry.

The results also support the extension of the RBV theory, referred to as the Natural Resource Based View (NRBV), which emphasizes environmental sustainability as a strategic organizational resource. NRBV recommends that companies have a competitive advantage by using environmental management and sustainability as part of their business. This has been done by using renewable energy, low-carbon manufacturing systems, and sustainable production strategies that increased the operational resilience and sustainability performance. This finding is consistent with that environmental capabilities create 'strategic sustainability' for the organization in the long term due to their role in enabling the organization to adapt. Similarly,

the incorporation of sustainability can bring about environmental and economic advantages for companies.

The strategic implications of the results are particularly important for automotive manufacturing companies in an intensely competitive and environmentally controlled market. It is proven that energy efficiency and sustainability are not only an end in themselves, but a strategic objective to increase the operational performance, innovation, and competitiveness. By staying dedicated to investing in energy-efficient technologies and sustainable manufacturing systems, companies can secure long-term operational stability and strategic advantages in the dynamic landscape of the global automotive industry.

5.2 Theoretical Contributions

The research plays an important role in the literature on energy management, sustainability, and operational performance in manufacturing as it makes use of the Resource-Based View (RBV), Natural Resource-Based View (NRBV), and Porter Hypothesis in the Nordic automotive industry context (Rantanen, 2021). Originally, the study was relevant to the RBV theory in that it illustrates the fact that the capabilities of energy efficiency are strategic and dynamic organizational resources (Zhang, Yang, & Liu, 2022). Contrary to the common RBV research that focuses on tangible resources or knowledge-based capabilities, the present research demonstrates that the investments in energy management systems, digital monitoring technologies, and automated production processes give rise to valuable and hard-to-imitate capabilities that enhance operational performance. The experience of Volvo Group, Scania, and Volvo Cars as between the years 2013-2023 shows how these capabilities are developed over time, as organisations gain technology know-how and incorporate energy awareness into organizational habits (Hasani & Calugaru, 2025). Energy efficiency hence is not a fixed resource, but an ever-evolving organizational resource that is associated with competitiveness in the long run.

Second, the research contributes to the NRBV by offering a capital-intensive manufacturing sector with longitudinal evidence at the firm level (S. Sharma, Singh, Mishra, & Subramanian, 2024). Despite the points presented in the NRBV theory that environmental capabilities that may

result in sustainable competitive advantage are possible, there has been a paucity of evidence over than a span of time(Haryanto, Sobandi, & Rasto, 2026). This research fills in that gap by demonstrating that renewable energy integration and sustainable production practices enhanced environmental compliance and operational resilience among Nordic automotive manufacturers. The results validate the idea that sustainability is not a sidelining issue but a main organisational competence in more sophisticated industrial environments. Third, the study confirms and improves the Porter Hypothesis(Yuan & Zhang, 2017). Strong version of the hypothesis is supported by the findings which show that strict environmental regulations in Nordic countries enhanced innovation, modernisation of processes and increase in productivity instead of weakening competitiveness. Companies met the pressure of regulations by investing in new manufacturing systems and technologies that do not consume a lot of energy, and, in the end, they gained operational benefits that led to compensating compliance expenses. Another issue the study identifies as affecting this relationship is contextual factors such as availability of green technologies, the systems of innovation and the organizational absorptive capacity (Aboelmaged & Hashem, 2019).

Fourth, the research has a methodological contribution in its 10-year longitudinal design that utilizes secondary data in firm levels-level, sustainability, and annual reports(Kroes, Manikas, Gattiker, & Castel, 2022). Published material typically uses cross-sectional surveys or industry-wide data inappropriate to measure the long-term impacts of investment and within industrial heterogeneity. The selected study offers a more precise insight into the way in which energy efficiency capability profiles evolve and affect productivity by following the example of individual firms throughout the years and could serve as a helpful template to study sustainability in the future. Lastly, the study adds to the theoretical knowledge on the adoption of renewable energy. Although the integration of renewable energy enhanced the sustainability performance and environmental compliance, direct productivity gains were statistically insignificant(Ahmed & Elfaki, 2024). This implies that the perceived benefits of renewable energy can be indirect because of building of good reputation, regulatory benefits, and ultimate stability in energy price which may not be realized immediately but over time by the operation of the energy utilities. The

results thus suggest that sustainability-performance models need to be capable of differentiating among various types of energy programs and their distinct performance trajectories.

5.3 Managerial and Policy Implications

The results of this work have significant implications on managers and policymakers in the automotive or the manufacturing industry. As far as management is concerned the findings indicate that investments in energy efficiency can be considered as strategic strength and source of productivity instead of an economical measure (Cooremans & Schönenberger, 2019). The regression analysis has found the energy efficiency investment to be the most powerful predictor of productivity, implying that the investments in smart manufacturing systems, energy-efficient technologies, and process optimisation generate significant long-term returns on operations (Vetrivel, Saravanan, & Maheswari, 2026). Managers need to move energy efficiency in long term strategic planning and allocation of capital to become part of the long-term strategic planning rather than sustainability initiative seen as an additional expenditure. As the evidence presented in the case reveals, companies with the largest operational improvement implemented integrated energy management strategies, which were based on technology. The investments in digital monitoring platforms, predictive maintenance, sensors that operate on IoT, machine learning tools and automated controls enabled the companies to find inefficiencies and optimise production processes in real time (A. Sharma, Adekunle, Ogeawuchi, Abayomi, & Onifade, 2019). These technologies go hand in hand with RBV concepts, as they develop specialised organisational capabilities, which can hardly be matched by other companies (Cuthbertson & Furseth, 2022). Managers ought to focus on cultivating internal knowledge in the industry 4.0 technologies as a way of enhancing their operational efficiency and competitive gain (Vashishth et al., 2024). It is thus advisable to consider a more moderate approach, upcoming investment to direct energy efficiency improvements to achieve short-term productivity benefits and at the same time increase renewable energy portfolios to achieve sustainability in the long-term, adhere to regulations, and mitigate operational risks.

Policy-wise, the findings reveal that environmental regulation can promote industrial modernisation and not undermining competitiveness. Nordic environmental models facilitated companies in innovating, modernising the production system and embracing hi-tech energy technologies (Sörvik, Zingmark, & Ardenfors, 2018). The policymakers must thus keep on reinforcing energy efficiency, carbon pricing as well as obligatory energy auditing systems and assist companies with the use of technology adoption schemes. The results dispute assertions that environmental regulation must inevitably put an economic strain on industry. Governments should also lessen obstacles to the use of renewable energy sources through tax incentives, subsidies at clean devices of production or co-finance of industrial audit of energy (Ahmad, Boumaiza, Yazici, Taşaltın, & Özmen, 2026). These measures would assist companies to cope with the financial and operational difficulties pertaining to sustainability transitions. Moreover, the policymakers ought to advocate standardised sustainability reporting frameworks to enhance consistency in disclosures of energy performances. The reporting standards difference that has been identified in this research limits the accuracy and effectiveness of research as well as the effectiveness of the regulation. The accountability and the evaluation of policies would be enhanced by standard forms of reporting in energy intensity, renewable use, and energy investment.

Knowledge-sharing programs at an industry level should be facilitated by automotive associations and industrial clusters to allow firms to share best practices, benchmark their energy performance, and apply mutually on supplier sustainability standards. As companies have various sustainability directions, overall cooperation across industries can stimulate innovation and enable flexibility in approaches to implementation.

5.4 Future Research

Although the present research suggests an in-depth longitudinal evaluation of energy efficiency and performance within Nordic car manufacturing, there are still some aspects in the study that can be examined in the future (Solnørdal & Foss, 2018). At first, subsequent research should widen the geographical area to outside of Nordic region. The Nordic environment is highly

environmentally regulated and has extensive sustainability commitments that could vary significantly with the situation in the emerging economies (Khan, Johansson, & Hildingsson, 2021). The comparative research that should be done with the manufacturers in other countries like China, India, or Brazil would help ascertain whether the relationships that have been identified in this study can be applied in other institutional and regulatory settings (Barry & Graca, 2019). Second, bigger samples need to be used in the future studies to enhance the statistical generalisability (Smith, 2018). This research involved three companies with a 11-year follow-up and restricted the statistical power. By using bigger cross-national panel datasets, it would enable researchers to implement superior techniques, like fixed-effects or random-effects regression models, to more effectively isolate the impact of energy efficiency investment on operational performance (Jiang, 2025). Third, the ripple and long-term impact of renewable energy adoption should be analysed in future (Dolgui, Ivanov, & Sokolov, 2018). Even though the use of renewable energy did not have a strong impact on productivity in this study, the benefits might arise in other ways that include better reputation, customer loyalty, access to the market or exposure to the volatility in the energy prices. Mediation analysis and threshold studies might give a better understanding of long-term changes in firm performance following the integration of renewable energy (Sitompul, Saifi, Hutahayan, & Sunarti, 2024).

Fourth, end research ought to fuse primary data gathered by interviews and questionnaires to the managers, sustainability officers as well as the operations directors. On the one hand, secondary data allowed conducting longitudinal analysis, but it did not provide insights into internal organisational dynamics, decision-making by managers, and implementation issues. The utilisation of mixed-method or qualitative methods would be a better insight into organisational processes underlying energy efficiency adoption. The other future research area of importance is the electrification of automotive production. With the growing adoption of electric vehicles production by manufacturers, the trends in energy consumption and in operating demands will not be the same. Further studies on the impacts of electrification on energy intensity, investment focus, and productivity would extrapolate the results of this paper into the changing post-2023 car environment (Munir, 2026). Lastly, future research needs to be extended by considering the energy efficiency of supply chain rather than individual firms. A large percentage of automotive

industry emissions and energy use take place in the supplier networks and not necessarily in final assembly operations alone (Yeung, 2024). The study with a focus on how sustainability-related requirements by large-scale manufacturers impact supplier performance and the efficiency of the value-chain, in general, would fill a significant gap in the existing literature and give invaluable insights on policies.

5.5 Conclusion

This study examined the connection between energy efficiency programs and the performance in operations of Nordic automotive manufacturing companies Volvo group, Scania, Volvo cars- between the years 2013-2023. The study was guided by the RBV, NRBV and Porter Hypothesis framework and based on a longitudinal framework using secondary-data as the method of collecting data to answer the research questions on the extent that sustainability-oriented investments affect productivity and competitive performance. The results precisely indicate that the cost of energy-saving is a significant boost of business output. The model predicting the productivity captured 97 percent of the variation and energy efficiency investment was found to be the best predictor of the operational output. Enhancements of energy intensity also helped in performance improvement. Such findings affirm that energy efficiency is neither an environmental nor a reputational issue but a business strategic exercise that has the potential of enhancing product-wise and cost competitiveness. The article also points out the multidimensionality of sustainability strategies. Volvo cars achieved the greatest productivity due to the intensive investment in the efficiency Volvo group has focused more on the integration of renewable energy and ensured good results in sustainability, and Scania was a little more balanced. Comparable variations prove the fact that there is no simple way to the goal of sustainability-driven competitiveness, companies should consider energy strategies in the context of organisational objectives and industry operations. The study also confirms the Porter Hypothesis in Nordic automotive sector. Tough environmental laws made companies update operations, embrace new technology of production, and make sustainability an element of strategic decision making. Regulatory pressure did not hinder the performance of industries as it increased innovation and efficiency that enhanced competitiveness. Overall, this study indicates

that the degree of energy efficiency is an important strategic competency that manufacturing companies will need as more environmental and competitive forces mount against them. The Nordic motor industry is a good example of how the notion of sustainability, and the performance of industries can be mutually reinforcing under the influence of innovation, long-term dedication, and the regulation. With the world automotive industry rapidly racing towards decarbonisation and electrification, the experiences of Volvo Group, Scania, and Volvo Cars show that well-structured energy efficiency may be used as the source of sustainable competitive edge and long-term industrial growth.

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