Master’s thesis

Master's Programme in Mechanical Engineering, 60 credits

Assessing the Implementation of Sustainable Manufacturing Practices: A Comparative Analysis between the Automobile Sectors of Sweden and Select European Countries.

Master's Thesis in Mechanical Engineering, 15 credits

Halmstad 27/05/2024

Anthony Kenechukwu Orji

HALMSTAD UNIVERSITY

Preface

This Thesis was created using knowledge gained during the period of the master's program.

I want to start by appreciating God Almighty for his grace and mercy, and for making this a reality.

Special thanks and appreciation to the scientists and industrial experts that have made a significant contribution to the form and the completion of this thesis:

- Dr. Aron Chiba director examiner and supervisor of the master program in the mechanical engineering department at Halmstad University who showed support and guidance during the course of this thesis.
- Dr. Håkan Petterson professor and supervisor in the mechanical engineering department at Halmstad University.

I like to thank our Class colleagues and also to our Master thesis opponents, who during the seminars raised critical questions and propose their suggestions that helped us in improving the research quality.
Also, to thanks our families, who have been patient and support us emotionally and materially, during the entire master program, especially during the period we were focusing on writing this thesis.
Finally, I'd like to thank Sweden and Halmstad university for providing a serene, calm and stable environment to study and gain more knowledge

Abstract

This study conducts a comparative analysis of sustainable manufacturing practices within the automotive sectors of Sweden and selected European countries, emphasizing the adoption of sustainable frameworks related to CO2 emissions, Volatile Organic Compounds (VOCs) emissions, energy consumption, potable water withdrawal, and waste disposal by various manufacturers from 2019 to 2023. The dataset used was sourced from the annual sustainability report of the selected car manufacturers. Employing ANOVA and trend analysis, the research quantitatively evaluates how these countries have implemented these sustainability frameworks over the five-year period. Data collected from numerous automobile manufacturing firms reveal that, although Swedish manufacturers maintain strong performance across multiple sustainability metrics, there is notable variability among other European manufacturers. This variation underscores differences in adoption rates and operational efficiencies, emphasizing the role of regulatory frameworks, economic incentives, and corporate cultures in sustainability. The analysis not only benchmarks Sweden's performance against its European counterparts but also pinpoints areas needing enhanced adoption of sustainable practices within the automotive industry. This study serves as a valuable tool for policymakers, industry stakeholders, and researchers dedicated to advancing sustainable manufacturing practices across Europe's automotive sector.

Keywords: Comparative analysis, Sustainable manufacturing, trend lines, ANOVA.

Table of Contents

Preface 1

Abstract 2

INTRODUCTION 5

1.1 Background 6

1.1.1 Presentation of the client 6

1.2 Aim of the Study 7

1.2.1 Problem definition 7

1.3 Limitations. 8

1.4 Individual responsibility and efforts during the project. 8

1.5 Study Environment 9

METHOD 10

2.1 Alternative Methods 10

2.1.1 Case Study Research 10

2.1.2 Comparative Observational Studies. 10

2.1.3 Document Analysis 10

2.1.4 Statistical Analysis 10

2.2 Selected Method 11

2.2.1 Data Analysis 11

2.2.2 Data Validation. 12

2.2.3 Data Collection. 12

2.2.4 Selection of Countries. 12

2.2.5 Selection of Automotive Industries. 13

THEORY 15

3.1 Summary of the Literature Study and the State of the Art 15

3.1.1 Sustainable Manufacturing Processes in the European Union. 16

3.1.2 Regulatory framework: Analysis of relevant regulations and policies in Sweden. 18

3.2 Sustainable manufacturing and the Automotive Sector 18

RESULTS AND ANALYSIS 23

4.1 Analysis of Variance (ANOVA) 23

4.2. Trend Analysis. 26

CONCLUSION 29

5.1 Conclusion 29

5.1.1 Recommendation to further activities 29

CRITICAL REVIEW

REFERENCES 30
Appendices 37
Appendix i: Data Collection 37
Appendix ii: CO_2 Emission Trend 2019-2023 By Country. 38
Appendix iii: Energy Consumption Trend 2019-2023 By Country. 39
Appendix iv: Water Consumption Trend 2019-2023 By Country. 39
Appendix V : VOC emission Trend 2019-2023 By Country. 39
Appendix vi : Waste Production Trend 2019-2023 By Country. 40

1.INTRODUCTION

There is a progressive shift in manufacturing globally towards sustainability. This is primarily driven by the need to protect the environment, conserve energy, save cost and improve the overall wellbeing of people. The automotive industry, which is mainly concerned with production, sale and maintenance of motor vehicles, is a huge player in the manufacturing ecosystem globally. According to the Nova Agency report 2023, the automotive industry accounts for about 3 percent of total world output of GDP, and in emerging markets like China and India it is 7 percent. In the context of sustainability in manufacturing the automotive industry stands out with its uniqueness as well as challenges in adapting to the expectations of sustainable manufacturing.

Why Sweden? Sweden, according to business-sweden.com recognizes and actively promotes companies, solutions, and products that contribute to the goal of net-zero emissions. It is a country renowned for its push towards environmentally friendly innovation. In the Swedish automotive sector, the core policy approach to sustainable manufacturing is promoting environmental conservation, resource efficiency, and innovation. This is determined by the country's ambitious climate and energy policy, which targets reducing greenhouse gas emissions, increasing renewable energy utilization, and transitioning towards a low-carbon economy.

Meanwhile, the European automotive sector presents a diverse landscape. Since several countries are involved, each has its own regulatory framework, industry behavior and sustainability program. The European automobile sector faces a complex challenge of reconciling growth and innovation with environmental protection. Although as a unit the EU has ambitious targets towards zero carbon emission, energy efficiency and enhancing the circular economy. This unified policy exerts strong influence on the countries within the Union.

By carrying out a comparative analysis between the automobile sectors of Sweden and Europe, this research aims to shed light on the varying processes, methods, successes, and obstacles encountered in the pursuit of sustainable manufacturing in select areas within the automotive industry. Following a multifaceted examination covering environmental impact, cost benefit, energy efficiency and technological innovation, this research aims to identify the best practices, and areas for improvement. Furthermore, we hope by this comparative assessment to drive policy development, strategies, and collaborations with the aim of advancing sustainable manufacturing on both regional and global scales.

In essence, this study endeavors to contribute to the ongoing conversations around sustainable manufacturing practices within the automobile industry In Sweden and select European countries, offering deep insights that will drive further progress with respect to sustainability.

1.1 Background

In recent decades the need for sustainable manufacturing has risen to the forefront of global discourse. Awareness of the impact of traditional manufacturing practices on the climate and the environment has resulted in a shift to embrace a more sustainable approach. In 2008, there was a proposal issued by the European Union for sustainable consumer production and industry policy to improve the environmental impact of products throughout their life cycle, to increase consumer awareness and demand for sustainable goods and production technologies.
According to the 2015 report by the International Energy Agency (IEA), manufacturing industries contribute to 36% of carbon dioxide emissions and account for approximately one-third of the world's energy consumption. IEA (2018) report attributed the global transportation sector constituted one-quarter of the global carbon dioxide emissions in 2016, with road transportation alone represented 18% of this share. There is therefore an increasing pressure on the automobile industry to integrate a more sustainable approach in their manufacturing processes.
Sustainable Manufacturing involves the integration of environmentally friendly practices, resource efficiency, and ethical considerations throughout the entire product life cycle – from design and material sourcing to manufacturing, distribution, waste management and recycling.
In 1967, Sweden became the first country to pass an environmental protection act. Since then, there has been an aim on sustainability and limiting carbon emission. The government has set ambitious goals for sustainability, which include going fossil-free in the automobile sector by 2030.

1.1.1 Presentation of the client

As a master's student at Halmstad University, the primary client for this study is the automotive industry in Sweden and select European companies. These encompass a diversity of industry set up spanning the design, manufacturing, and distribution of automobiles and related components. The role the automotive industry plays are pivotal to the economic and technological landscape of both regions. It contributes significantly to employment, and global trade not excluding innovation. The considerations that led to the choice of the automotive industry in Sweden and Europe as the client for this project include,
Both regions recognize the importance of sustainable initiatives in manufacturing, this makes them ideal for this analysis.
Secondly, the automotive sector is quite complex and operates dynamically. The sector seems to cover most of the operations of interests in this research. By partnering with this sector in Sweden and Europe, we aim to add to the body of valuable knowledge and recommendations for advancing sustainable manufacturing practices.

1.2 Aim of the Study

The scope of this research will involve conducting a comparative analysis of sustainable manufacturing practices within the automobile sectors of Sweden and Europe. Key aspects of this scope are:
Countries in Europe that have similar human and economic indices as Sweden.
Automotive sectors in the chosen countries.
Sustainability practices in manufacturing like CO_2 emissions, Volatile Organic Compound (VOCs) emissions, energy consumption, portable water withdrawal and waste disposal.

The scope does not include administrative practices of the industries. It does not cover the entire European nations and other sectors beyond automobiles.
The primary purpose of this project is to assess and compare the implementation of sustainable manufacturing efforts in the automobile sectors of Sweden and Europe by extension other industrial sectors. Specifically, the work aims to:
Determine the current state of sustainability initiatives in the automotive industry.
To collate relevant data associated with key performance indicators for example energy efficiency, waste management, emissions etc. within a specified period.
To conduct a detailed validation of the data collated.
To conduct comparative analyses of the manufacturing processes among the select industries in Sweden and other European countries.

1.2.1 Problem definition

The problem at hand is the need to evaluate, compare and gain comprehensive understanding of the implementation of sustainable manufacturing practices within the automobile sectors of Sweden and Europe.
The following research questions will be answered.
RQ1. What are the key sustainable manufacturing practices implemented by selected automobile companies?
RQ2. How do the companies adapt to extant regulations in sustainability practices?
RQ3. How do the selected car manufacturers differ in their sustainability performances?
RQ4. How do they compare between Sweden and other European companies?

1.3 Limitations

This research primarily focused on some of the sustainability practices reported in the annual sustainability reports of selected car manufacturers. While this provides valuable insights into the practices of these manufacturers, it does not encompass all the sustainability initiatives that are been undertaken. As a result, the study addresses only part of the problem by focusing on some practices. The study compared practices across selected countries and manufacturers, offering a snapshot of differences and similarities. However, it did not fully explore the underlying reasons for these differences, such as cultural, economic, or regulatory factors. Therefore, the research addresses only part of the problem by identifying differences without fully explaining the causative factors behind them. The analysis was based on data available from public reports, which limited the depth of investigation into the effectiveness and implementation details of these practices.

1.4 Individual responsibility and efforts during the project.

I will undertake the following tasks in the course of this project.
Research: Conducting literature reviews, gathering data, and analyzing information related to the project topic are part of my core responsibility.
This will involve identifying relevant sources, evaluating research findings, and deriving insights to inform the project's objectives.
Coordination and Planning: Project planning and coordination efforts, participating in meetings, timelines, and defining milestones are still part of my responsibilities.
Analyses and documentation: All the necessary analyses and report preparation are defined as project tasks.

1.5 Study Environment

This project was done by Anthony Kenechukwu Orji: 19841107-T791 in fulfillment of the requirements of Masters in Mechanical Engineering Program Halmstad University, Halmstad, Sweden. The study was carried out in Halmstad University, Sweden. Secondary data from the annual sustainability report of selected car manufacturers sourced from the official website were collected, and analyzed using Microsoft Excel and Tableau.

2. METHOD

This chapter delves into the various research methods at our disposal and the rationale behind the specific method chosen for this particular study.

2.1 Alternative Methods

2.1.1 Case Study Research

A case study is a detailed study of a specific subject, such as a person, group, place, event, organization, or phenomenon. Case studies are commonly used in social, educational, clinical, and business research (Shona M, 2023).
Robert K. Yin, (2009) a prominent researcher in case study methodology, argues that case study research is particularly adept at investigating and understanding phenomena within their real-world contexts (Yin R.K,2009). Case studies offer a comprehensive approach, providing answers to 'what,' 'why,' and 'how' questions regarding the subject of investigation.

2.1.2 Comparative Observational Studies.

Comparative studies like this fall into two categories — experimental studies and observational studies. The purpose of a comparative observational study is to determine if there is a difference in measurements between groups of individual subjects. An observational study does not impose a treatment on the subjects — it observes them as they are. (Annenberg Learner, 2024)

Observational studies are generally divided into cross-sectional, case-control, and cohort studies. (Mann, C.J.,2012) Cohort studies are also termed *follow-up* or *incidence* studies. In these studies, outcomes among two or more groups initially free of that outcome are compared. (RiffenburghR.H.,2012)

2.1.3 Document Analysis

Document analysis is a procedure for systematically reviewing documents which can be both printed and electronic material. As in other analytical methods in qualitative research, document analysis will require that data be examined and interpreted to elicit meaning, gain understanding, and develop empirical knowledge. (Corbin & Strauss, 2008) The analytic procedure entails finding, selecting, appraising (making sense of), and synthesizing data contained in documents. (Bowen, G.A.,2009) The limitations of this method include insufficient detail, low retrievability, and biased selectivity. (Yin, 1994).

2.1.4 Statistical Analysis

Statistical analysis involves carrying out a study that includes planning, designing, collecting data, analyzing, drawing meaningful interpretations, and reporting research findings. The statistical analysis gives meaning to the meaningless numbers, thereby breathing life into lifeless data. (Ali, Z., & Bhaskar, S. B. 2016)

2.2 Selected Method

The method for this study will be a combination of elements of the stated methods in (2.1). Mixed methods research requires a purposeful mixing of methods in data collection, data analysis and

interpretation of the evidence. The key word is 'mixed', as an essential step in the mixed methods approach is data linkage, or integration at an appropriate stage in the research process. (Ivankova N.V, 2006) The process of mixing methods within one study, however, can add to the complexity of conducting research. (Shorten A & Smith J, 2017). This diagram below shows the flow chart for this method so adopted.

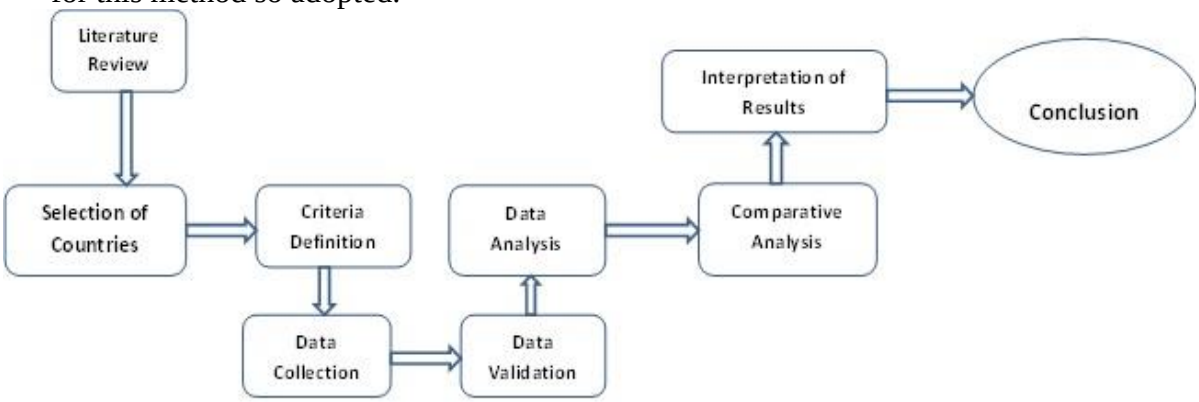


Figure 1: Flow Chart of the selected methodology

2.2.1 Literature Review

A summary of literature review surveying prior research published in books, scholarly articles, and other sources relevant to this research were studied. These studies include: Sustainability manufacturing process in the European Union, Regulatory framework: Analysis of relevant regulations and policies in Sweden, and studies of Sustainable manufacturing and the automobile sector.

2.2.2 Data Analysis

The analytical approach employed in this research comprises:
i. Analysis of Variance (ANOVA)
ii. Trend Analysis

2.2.2.1 Analysis of Variance (ANOVA)

ANOVA, or Analysis of Variance, is a statistical method used to compare the means of two or more groups to determine if there are statistically significant differences between them.

Steps for Carrying Out ANOVA

i. Formulate Hypotheses:
ii. Conduct ANOVA:
- Calculate Variability: ANOVA decomposes the total variability observed in the data into two components:
  - Between-group variability: Variability among group means.
  - Within-group variability: Variability within each group.
- F-statistic Calculation: ANOVA calculates the F-statistic by comparing the between-group variability to the within-group variability. For this research, Microsoft Excel software was used to calculate ANOVA.

iii. Interpret Result:
- Compare to Critical Value: The F-statistic is compared to a critical value from the F-distribution based on the chosen significance level (for the research, we choose 0.05 or 5%). If the calculated F-value exceeds the critical value, it suggests that there are significant differences between the group means.

Test of Significance: - If the p-value is less than the significance level (0.05), we reject the null hypothesis and conclude that there are significant differences.
- If the p-value is greater than the significance level (0.05), we fail to reject the null hypothesis, indicating no significant difference among the groups.

Hypotheses

The Hypotheses for this research for each of the sustainability practices:
Null Hypothesis (H0): There is no significant difference in (CO2 emissions, VOC emissions, portable water for disposal, waste for disposal, energy consumption) among the car manufacturers.
Alternative Hypothesis (H1): There is significant difference in (CO2 emissions, VOC emissions, portable water for disposal, waste for disposal, energy consumption) among the car manufacturers.

2.2.2.2 Trend Analysis

To further carry out comparison analysis on Sustainability practices by the selected car manufacturers we deployed trend analysis using an analytic visualization tool - Tableau. Here, the performance as per selected metrics are compared over a 5-year period (2019-2023).

2.2.3 Data Validation.

Data standardization will involve transforming data into a common format or scale, while validation focuses on ensuring the accuracy, completeness, and consistency of data through various checks and procedures.

2.2.4 Data Collection.

The dataset utilized in this research comprises CO_2 emissions per vehicle (in metric tons per vehicle), VOC emissions per vehicle (in kilograms per vehicle solvent), waste for disposal per vehicle (in kilograms per vehicle), portable water consumption per vehicle (in cubic meters per vehicle), and energy consumption per vehicle (in megawatt-hours per vehicle). Additionally, it includes the names of car manufacturers and their respective countries of operation, spanning from the years 2019 to 2023. Data were sourced from the Sustainability Reports published on the official websites of the selected car manufacturers. The following list shows the sustainability reports used.

Annual and Sustainability Report 2020 Porsche AG.(Porsche AG, 2020)
Annual and Sustainability Report 2021 Porsche AG.(Porsche AG, 2021)
Annual and Sustainability Report 2023 Porsche AG.(Porsche AG, 2023)
Aston Martin Sustainability Report 2023. (Aston Martin, 2023)
Volkswagen sustainability Report_2019. (Volkswagen, 2019)
Volkswagen_Group_Sustainability_Report 2023.(Volkswagen, 2023)
AB-Volvo-Annual-Report-2023.(AB-Volvo, 2023)
AB-Volvo-Annual-Report-2020. (AB-Volvo,2020)
Universal registration document 2020 (Renault). (Renault,2020)
Universal registration document 2023 (Renault). (Renault,2023)
Scania Annual and Sustainability Report 2023. (Scania, 2023)
Scania Annual and Sustainability Report 2019. (Scania, 2019)
Scania Annual and Sustainability Report 2020. (Scania, 2020)
Stellantis Corporate Social Responsibility Report 2023. (Stellantis, 2023)
Sustainability Report 2023, Mercedes Benz Group. (Mercedes Benz Group,2023)

BMW Group Report 2023.(BMW Group,2023)

2.2.5 Selection of Countries.

We selected countries that have similar economic indices as Sweden. Gross Domestic Product (GDP), and GDP per capita serves as an economic basis for comparing nations. (CIA,2024) The table below presents the details of the selected countries based on GDP, Real GDP per capita and Population.

Table 1: Economic indicators of Select EU countries. (source: CIA.gov)

Country	**Population(million)**	**GDP (billion USD)**	**GDP Per Capita (thousand dollar)**
Sweden	10.91	715.9995	58.89
Germany	84.22	3,860	54.00
France	68.52	2,716	45.00
Netherlands	17.7	1,009	59.20
United Kingdom	66.6	3,187	47.60

2.2.6 Selection of Automotive Industries.

The chosen criteria for selecting the automobile industries are car type, Market coverage, Revenue, Annual Sales, Workforce.

Table 2: Selected Car manufacturers (Source: Annual Reports)

Country	Company	Market Coverage	Revenue (Million usd) 2023	Annual Sales (no of cars) 2023	WorkForce
Sweden	Scania	Global	186,972	96,727	58,163
Sweden	Volvo Cars	Global	365,812	708,716	45,000
Germany	BMW	Global	168,770	2,253,835	154,950
Germany	Volkswagen	Global	335,040	9,240,000	676,000
Germany	Mercedes	Global	164,248	2,044,100	170,000

France	Renault	Global	561,576	2,235,000,000	106,000
Netherlands	Stellantis	Global`	203,166	2,119,84	208,780
United Kingdom	Aston Martin	Global	205,144	6,700	

3. THEORY

3.1 Summary of the Literature Study and the State of the Art

According to Seliger (2011), engineering encompasses the harnessing of potentials for practical applications. Manufacturing, as a specific discipline in engineering, starts from human thinking and imagination, from knowledge about natural scientific phenomena, from physical materials and shapes value creation via processes in management and technology, objectified in tangible and intangible products, in physical artifacts and services.
The Brundtland Commission, defined Sustainable development as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development (WCED), 1987).

Following the need to mitigate environmental degradation, optimize resources and improve efficiency, sustainable manufacturing has become the key phrase in industrial processes. It involves the creation of products by using processes that are economical with the aim of minimizing negative environmental impacts, conserving energy and natural resources(epa,2024). It aims primarily to develop processes that will be applied in industrial manufacturing that will optimize, materials, reusing and recycling strategies, waste management methods, software tools, pollution prevention methods, efficient industry practices, and business development that will finally yield a product used in day-to-day life maintaining eco-friendly situation around us (Narayanan & Gunasekera, 2023).
Tiffany Leung highlights the benefits of a sustainable production process. They include reduction in resources and costs, encouraging innovation, improved sales, and higher rates of hiring and retention (Tiffany Leung, 2021). It is worthy of note that traditional manufacturing methods are very vulnerable to disruptive tendencies leading to increased cost.
The approach to sustainable manufacturing is often defined on three main levels, namely: product, process, and system scales. Relationship among these three enables the achievement of the objectives of the process (Hossam, Kishawy, Hussien & Elsadig, 2018).

At the product level, sustainable manufacturing focuses on the new 6R approach which are re-duce, re-design, re-use, re-cover, re-manufacture, and re-cycle (Joshi, Venkatachalam, & Jawahir, 2006). At the process level, the focus is on reducing energy consumption, hazards, and toxic waste is accomplished through the implementation of advanced technologies associated.
In *Sustainable Manufacturing Technologies: A Systematic Review of Latest Trends and Themes*, dealing with current challenges in manufacturing without sacrificing the future ability to repeat the process is shown to be key sustainable manufacturing and it was noted that the is increasingly becoming challenging due to rise in population rate, energy poverty, global warming, and surging demand for products and services. The literature carried out a systematic review of recent literature in the field of sustainable manufacturing technologies literature, evidencing the latest themes and trends in sustainable manufacturing (Bastas, 2021). However, the paper revealed some gaps in this research area. The focus was generic and not industry specific. It did not set out to show sustainable production trends relative to particular manufacturing sectors and specific locations.

3.1.1 Sustainable Manufacturing Processes in the European Union.

In Europe, regulatory frameworks have been developed to encourage eco-design in product development, end greenwashing and improve recycling processes. These frameworks are designed to encourage manufacturers to increase sustainability in the Eurozone.

According to the IDC Global Sustainability Readiness Survey (August 2023), about 45% of manufacturers in EMEA countries agree that sustainability related requirements from their business partners are key drivers in their operations. The priorities set by the manufacturers are:

1.
2. Design for Circularity: This focuses on product creation that can be disassembled, remanufactured and recycled at the end of their lifecycle.
3. Real-time Energy Monitoring and Optimization: Manufacturers have visibility into their energy usage patterns and optimize consumption by continuous monitoring of energy consumption level.
4. Tracking and Tracing Emissions in the Product Life Cycle: Using data analysis to monitor and track emissions in a products life cycle is used to significantly reduce its contribution to carbon emission. (Mark C. 2024).

The European Union has established comprehensive policy frameworks that directly impact manufacturing sectors, targeting objectives such as environmental preservation, waste handling, energy conservation, and the promotion of sustainable growth. **Circular Economy Action Plan** The Circular Economy Action Plan (CEAP), introduced in March 2020, stands as a pivotal component of the European Green Deal, with a primary aim of bolstering sustainable development within the EU. The new action plan provides the framework along the entire product's life cycle. It is focused on how products are designed, promotes circular economy processes, encourages sustainable consumption, and aims to ensure that waste is prevented and the resources used are kept in the EU economy for as long as possible (European Commission 2023).

Industrial Emissions Directive (IED).

The objective of this directive is to achieve a high standard of protection of human health and the environment as a whole by minimizing detrimental industrial emissions throughout the European Union (European Parliament 2023). In April 2022, the EU Commission published its proposal for a revised Industrial Emissions Directive (IED), focusing more on energy, water efficiency, product recycling, and use of safer, less or non-toxic materials in industrial processes.

Energy Efficiency Directive (EED)

Adopted in 2012 and reviewed in 2023, this legislation provides a framework for energy savings across the European Union. In the policy, we have the following,

a. Energy Efficiency Targets: The Energy Efficiency Directive (EED) mandates an 11.7% reduction target for both primary and final energy consumption.

b. Energy Efficiency in Public Sector: According to the EED, it is mandated that 3% of the total floor area of all buildings owned by public entities undergo renovation annually. These renovations must aim to attain either Nearly-Zero Energy or Nearly-Zero Emission Building standards. Overall, the directive necessitates a 1.9% reduction in the collective energy consumption of public buildings.

c. Energy Efficiency Directive Reporting: These will include all companies consuming energy above a particular threshold and the aim is to optimize energy savings.

Waste Framework Directive (WFD):

This legislation established by the European Parliament, provides guidelines on the management of waste. The core aspects of the policy include:

a. Waste Management Strategy: This compels EU member to establish and enforce waste management plans that prioritize prevention, followed by effective collection, recycling, recovery, and disposal options. (European Commission, 2023)

b. Waste Hierarchy: The directive enshrines a waste hierarchy, placing the highest priority on preventing waste generation in the first place.

Figure 2: Waste Hierarchy. Source: European Commission website

c. Extended Producer Responsibility (EPR): This holds producers financially and/or operationally accountable for the environmental impact of their products throughout the entire product lifecycle.

d. Hazardous Waste Management: To safeguard human health and the environment from the inherent dangers of hazardous waste, the WFD prescribes a cradle-to-grave approach to its management. This entails a comprehensive set of regulations governing the waste's entire lifecycle. (European Commission, 2023)

Industrial Strategy for Europe:

The groundwork for this strategy was established in 2020, with the goal of propelling the EU towards a concurrent green and digital economic transformation. This dual approach aims to not only bolster the EU's global industrial competitiveness, but also solidify Europe's position of open strategic autonomy.

3.1.2 Regulatory framework: Analysis of relevant regulations and policies in Sweden.

The European Union plays a great role in shaping Swedish national policies, therefore most Swedish regulatory frameworks in sustainable manufacturing will be influenced by the several EU directives on sustainability.

The Swedish Environmental provides a clear legal framework that guides the government's actions in safeguarding the environment. The code emphasizes the re-use and recycling, as well as other management of materials, raw materials and energy are encouraged so that natural cycles are established and maintained. (Naturvardsverket,n.d). Environmental Code regulates, among other things, the management of land and water, environmentally hazardous activities, water operations, chemical products and waste management (Patrik. M *et al* ,2024).

The Swedish energy efficiency policy is focused on tax on energy and carbon dioxide emissions. Sweden has a national energy efficiency target for a reduction of the ratio between primary energy consumption and GDP by 50% for the period 2005-2030. Already by 2017 a reduction of 20% was registered (odyssee-mure,2024).

The figure below shows the impact of this policy from 2000-2013

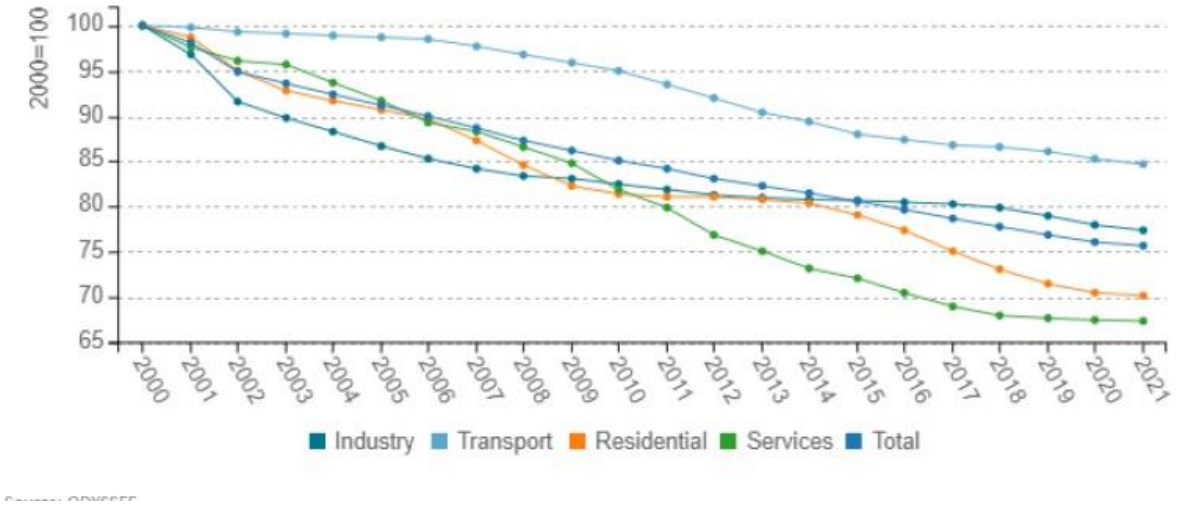


Figure 3: Technical Energy Efficiency Index. Source: ODYSSEE

3.2 Sustainable manufacturing and the Automotive Sector

As the largest single manufacturing sector among European industries, the automobile industry is often described as "the engine of Europe" in the 21st century (Claros, 2013; Jonnaert, 2014). In the study it was shown however, that consumers are increasingly getting more conscious of environmental issues and sustainability when purchasing products. Studies show that buyers are willing to pay a premium for products that engender sustainability. Additionally, recent studies also suggest that when considering full transparency of information for products, consumers are ready to pay a premium for a product (Owusu and Anifori, 2013; Xu et al.,2012). Before buying products, most consumers are already aware of green issues such as depleting natural resources, global warming, and pollution, and these inform their decisions in buying green products. (Grunert et al., 2014). The study acknowledged that the development of a configuration model for the automobile industry necessitates assigning numeric weights to attributes, reflecting stakeholders' judgments on their importance.

Accordingly in the study, corporate sustainability is a combination of economic success, environmental protection and social responsibility. The implementation of corporate sustainability can support long-term business success as well as contribute to improving living standards. (Bansal, P., 2005). Today there are many concepts and tools for sustainability implementation e.g., material and energy flow accounting, eco-audit & eco-management control, sustainability reporting, BUIS (operating environmental management information systems) or environmental management systems such as EMAS (eco management and audit scheme) and ISO 14001 (environmental management standards) (Leyh, C. *et al*, 2011). Sustainability reporting is defined by (Gray et al.,1996) as "the process of communicating the social and environmental effects of organizations' economic actions to particular interest groups within society and to society at large". The study noted that in Europe, automobile industries face certain challenges which include, the high-level competitive pressure, influenced by low-cost

manufacturers globally, posing a threat to European leadership in various sectors and challenges its export dominance. Besides, price and cost constraints, there is an increasing apprehension regarding the future availability of resources (European Commission, 2015). In addition, stakeholder requirements, especially those of consumers and political representatives are also undergoing rapid change. Here environmental acceptability, cleaner technologies, and new forms of mobility play a key role (Sukitsch, M.,2015). Regarding research methods, the authors studied the content of sustainability reports from 2012 for 14 European car manufacturers to understand how they integrate corporate sustainability and what challenges they face. Content analysis, a technique for categorizing qualitative information, was used with the help of software to analyze the large amount of data from the reports. The report concluded that with respect to the implementation of corporate sustainability, the manufacturers know about the future potential for their industry sector and confirms the importance of specific policy instruments, e.g., of management systems such as EMAS, and of ISO 14001. (Sukitsch, M.,2015)

However, the analysis did not provide a broad numerical picture of the sustainability indicators. Furthermore, in analyzing scientific literature on sustainability and innovation in the automotive sector within a time period of 13 years, the study *Sustainability and Innovation in the Automotive Sector: A Structured Content Analysis* aims to identify how the automotive sector is minimizing its environmental It identified proper classifications of eco-innovation as crucial for leveraging their characteristics effectively for sustainable industry development. (Pujari, D.,2006). These classifications were distinguished by Christensen, T.B, 2011) to explore and describe current practices in the field. In other words, this study did not involve any new experiments or data collection. This method used a protocol called ProKnow-C. This method involves four steps:(Ensslin, S.R.,2014)

5. Article selection: This involves choosing keywords and searching databases for relevant articles.
6. Filtering articles: This involves removing duplicate articles and unaligned topics.
7. Filtering articles: Here, the researchers assess the scientific quality of the articles and identify the authors.
8. Final filtering: This step involves reviewing the full text of the articles to ensure they are truly relevant to the research question.

The study arrived at the conclusions that the automotive sector is well structured as regards sustainability and process innovation, that these innovations in the sector are mostly processes and incremental, since they are less expensive and less complex, and that the environmental practices used in the automotive sector are: emissions reductions, life cycle analysis, cleaner production, reverse logistics and eco-innovation (Vaz, C.,*et al*,2017). However, the research was limited to a few EU countries and relied heavily on one database (Scopus).

Additionally, case study research on the German automotive industry revealed some important challenges. The research, *Current challenges for sustainable product development in the German automotive sector: A survey-based status assessment,* reveals the following,

a. Sustainability should be systematically integrated into companies through centralized responsibility and widespread involvement of all company divisions and employees.
b. Standardization of sustainability methods is critical, applying the perspectives of both academia and industry.
c. Presently, sustainability assessment results are primarily utilized for reporting purposes. Companies should instead utilize these findings proactively to enhance product development.

d. While efficiency indicators for Sustainable Development (SD) often prioritize ecological aspects, equal consideration should be given to all three pillars: economic, ecological, and social.
e. Key drivers for SD include legislation, customer demands, and competitive pressures. These serve as effective starting points for advancing SD initiatives.
f. The primary success factor in implementing sustainability into the PD process is the company's commitment through a comprehensive corporate strategy.
g. Overcoming barriers to SD can be achieved by creating win-win solutions, transitioning from "Take-Make-Waste" (TTW) approaches to holistic "Whole-System" (WTW) analyses, and raising awareness of sustainability among both customers and manufacturers. (Held, M.,*et al*, 2018). This work employed basically expert interviews and online surveys.

However, the sample size was not sufficient to generalize the findings across the entire automotive sector.

It can be seen that sustainable manufacturing evolves through several generations, namely: traditional manufacturing; lean manufacturing; green manufacturing; and, in its most developed phase, sustainable manufacturing (Krajnik, P.,2011: Hartini, S.,2015). The 6R approach has replaced the classic 3R approach and the elements are Remanufacture, Redesign, Recover, Recycle, Reuse and Reduce. (Kishawy, H.,2018).

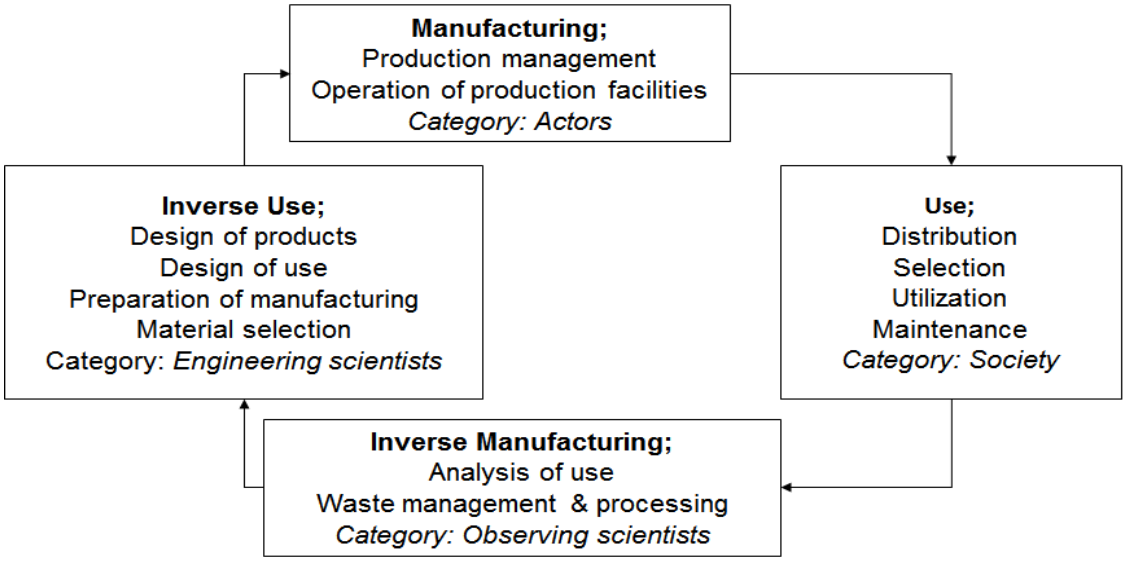


Figure 4: Design for sustainable manufacturing: cycle and elements (Jovane, F.,et al,2008)

To achieve a sustainable manufacturing system, defining and implementing some practical aspects through the product, process, and system levels are required.
Furthermore, Rosen. M.A, *et al,* (2012) emphasizes the needs for enhanced design for sustainability. It was stated that many feel that methodologies for design for sustainability are not advanced, and that numerous improvements are needed which include:

Engineering approach: This approach helps evaluate the costs and benefits of designing for sustainability. (Morgan, J.M,2006)

Necessity of better tools: Johnson, D.D., *et al* (2008) noted that the current engineering tools applied in sustainable design need improvement. These tools should be able to make a compromise between factors like production, customer needs, and environmental impact.

Increasing design options: There is a need for more sophisticated ways to include sustainability factor to allow for a wider range of sustainable design options and a more comprehensive evaluation of how sustainability affects product cost, project complexity, and process design. (Johnson, D.D., *et al* 2008)

Limitations of existing tools: There is the argument that the current engineering design tools or their variations (like design for manufacturing/assembly or Six Sigma) are inadequate for incorporating sustainability effectively. (Johnson, D.D., *et al* 2008)

In the automotive sector, the research, Jasinski, D., *et al,* (2021) describes the development process for an innovative model, named the Automotive Sustainability Assessment Model (A-SAM), to drive sustainable decision-making in the automotive sector. First, the sustainability-related business model innovation requires the measurement and assessment of economic, environmental, and societal impact and values (Boons & Lüdeke-Freund, 2013; Evans et al., 2017; Geissdoerfer, Vladimirova, & Evans, 2018).
In 2012, Short, T., *et al,* (2012) stated there is a portrayal of the Nordic countries being ahead of the UK when it comes to environmental credentials. The emphasis is often on renewable energy, wide environmental awareness and a lifestyle that might promote harmony with nature. For example, the World Bank's data on CO2 emissions show that total CO2 emissions have remained roughly constant in both countries over the period 1960-2006 (The World Bank, 2010a). From this data both countries Uk and Sweden have reduced their emissions per capita the UK has dropped from 11.7 tonnes per capita in 1970 to 8.8 in 2007, but Sweden's have dropped from 11.5 to 5.4 tonnes per capita over the same period (The World Bank, 2010b). However, the study was carried out, investigating the situation in Sweden and discussing it in the light of the existing research on the UK. The method applied for the UK research employed the use of questionnaires which followed 5 basic considerations: consideration of the research objectives; determination of the survey administration; questionnaire construction, including wording, sequence and response choice; extensive pretesting; data collection and analysis. While for Sweden two populations were addressed, based on manufacturing industry contacts from two universities: Kungliga Tekniska Högskolan, Stockholm (KTH Royal Institute of Technology, Stockholm) and the School of Engineering, Jönköping University (Short, T., *et al,* 2012) The survey gathered information on a companies' basic profile, its overall processes in design and production, and its approach to sustainability, which includes how sustainable practices are considered during design and implemented in daily operations. The result showed a contrast in the initial assumption of Sweden being ahead of the UK in implementation of sustainable processes. The evidence regarding CO2 emissions, recycling and general environmentalism, eco-design and design for sustainability suggest that this is not the case. The research however limited its geographical scope to 2 countries UK and Sweden.

4. RESULTS AND ANALYSIS

This chapter presents briefly the research output obtained from the analyses of the data collated from sustainability reports of the selected companies and the review of the EU directives on sustainable development. The research employed three methods in analysis namely regulatory analysis, Analysis of Variance (ANOVA) and Trend analysis.

4.1 Analysis of Variance (ANOVA)

Table 4.1.1: ANOVA Output of CO_2 emission among car manufacturers.

Groups	Count	Sum	Average	Variance
BMW	5.00000	1.68000	0.33600	0.00193
Mercedes	5.00000	1.74000	0.34800	0.07083
Scania	5.00000	7.90000	1.58000	0.05200
Volvo Cars	5.00000	0.24232	0.04846	0.00002
Volkswagen	5.00000	1.35039	0.27008	0.00281
Renault	5.00000	1.73550	0.34710	0.00513
Porsche	5.00000	0.39700	0.07940	0.00849
Aston Martin	5.00000	15.08000	3.01600	1.34683
Stellantis	5.00000	231.60000	46.32000	1792.30700

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	9265.63145	8.00000	1158.20393	5.81105	0.00009	2.20852
Within Groups	7175.18011	36.00000	199.31056			

Table 4.1.1 shows ANOVA results for CO2 emission of car manufacturers.

Fstat = 5.81108 Fcrit = 2.20852 P-value = 0.00009
Fstat >Fcritical, this shows that the test is significant.

The Pvalue < 0.05 hence we reject the null hypothesis and conclude there is significant difference in CO2 emissions among the car manufacturers.

Table 4.1.2: ANOVA Output of VOC emission among car manufacturers

SUMMARY

Groups	Count	Sum	Average	Variance

BMW	5.00000	3.49000	0.69800	0.01877
Mercedes	5.00000	27.39000	5.47800	0.43297
Scania	5.00000	18.00000	3.60000	0.06000
Volvo Cars	5.00000	10.27765	2.05553	0.03210
Volkswagen	5.00000	7.52000	1.50400	0.02443
Renault	5.00000	17.54745	3.50949	0.02742
Porsche	5.00000	3.01000	0.60200	0.00112

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	95.68166	6.00000	15.94694	187.03995	0.00000	2.44526
Within Groups	2.38727	28.00000	0.08526			
Total	98.06893	34.00000				

From 4.1.2, Pvalue is less than the significant level (0.05), hence we reject the null hypothesis and conclude that there is a significant difference in VOC emissions among the car manufacturers.

Table 4.1.3: ANOVA Output of waste for disposal among car manufacturers

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
BMW	5.00000	15.18000	3.03600	0.53563
Mercedes	5.00000	111.40000	22.28000	59.31700
Scania	5.00000	6.97000	1.39400	0.00113
Volvo Cars	5.00000	2.14173	0.42835	0.00170
Volkswagen	5.00000	14.06000	2.81200	0.76447
Renault	5.00000	114.74680	22.94936	2.48530
Porsche	5.00000	19.27300	3.85460	9.56518
Aston Martin	5.00000	1.50840	0.30168	0.04116

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3251.74317	7.00000	464.53474	51.10986	0.00000	2.31274
Within Groups	290.84626	32.00000	9.08895			
Total	3542.58943	39.00000				

From Table 4.1.3, Pvalue is less than the significant level (0.05), hence we reject the null hypothesis and conclude that there is a significant difference in waste disposal among the car manufacturers.

Table 4.1.4: ANOVA Output of portal water consumption among car manufacturers

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
BMW	5.00000	9.76000	1.95200	0.01797
Mercedes	5.00000	42.13000	8.42600	1.84143
Scania	5.00000	33.09000	6.61800	0.52372
Volvo Cars	5.00000	13.92000	2.78400	0.01628
Volkswagen	5.00000	18.54000	3.70800	0.05147
Renault	5.00000	22.40000	4.48000	0.12700
Porsche	5.00000	15.40000	3.08000	0.03375
Aston Martin	5.00000	51.46903	10.29381	0.34583

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	309.90880	7.00000	44.27269	119.75896	0.00000	2.31274
Within Groups	11.82981	32.00000	0.36968			
Total	321.73861	39.00000				

From Table 4.1.4, Pvalue is less than the significant level (0.05), hence we reject the null hypothesis and conclude that there is a significant difference in water consumption used in manufacturing among the car manufacturers.

Table 4.1.5: ANOVA Output of energy consumption among car manufacturers

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
BMW	5.00000	10.36000	2.07200	0.00447
Mercedes	5.00000	30.60000	6.12000	0.44340
Scania	5.00000	35.40000	7.08000	0.47700
Volvo Cars	5.00000	8.80000	1.76000	0.01300
Volkswagen	5.00000	10.80200	2.16040	0.03181
Renault	5.00000	9.70000	1.94000	0.03845
Porsche	5.00000	13.04300	2.60860	0.08220
Aston Martin	5.00000	72.89651	14.57930	27.12023

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	696.03824	7.00000	99.43403	28.19767	0.00000	2.31274
Within Groups	112.84227	32.00000	3.52632			
Total	808.88052	39.00000				

From Table 4.1.5, Pvalue is less than the significant level (0.05), hence we reject the null hypothesis and conclude that there is a significant difference in energy consumption used in manufacturing among the car manufacturers

4.2. Trend Analysis.

This analysis employed the use of trend charts implemented using Tableau Software. It plots the average values of each of the chosen metrics as per country against the years in consideration. Note Stellantis does not have data for 2019 and 2020. See Appendix ii-vi

The Tables below show the change (in percent) as per manufacturers over the period in review. The base year of 2019 was chosen and performance in each of the metrics relative to the value in 2019 evaluated.

Table 4.2.1: CO_2 emissions

CO2 Emission Trends						
		Base Year 2019	% Change 2020	% Change 2021	% Change 2022	% Change 2023
Germany	BMW	0	-12.5	-17.5	-20	-30
	Mercedes	0	-2.5	-24.4	-88.8	-89.8
	Volkswagen	0	-10.06	-14.20	-30.18	-39.64
	Porsche	0	-71.13	-95.82	-89.12	-77.82
Sweden	Scania	0	11.76	-11.76	-11.76	-23.53
	Volvo Cars	0	-4.97	-8.47	-14.00	-19.15
France	Renault	0.00	7.34	0.39	-27.93	-33.08
Netherlands	Stellantis	0.00	0.00	0.00	-3.87	-7.36
UK	Aston Martin	0.00	75.17	-2.80	-17.13	-27.97

Table 4.2.2: VOC emissions

VOC Emission Trends						
		Base Year 2019	% Change 2020	% Change 2021	% Change 2022	% Change 2023
Germany	BMW	0	-4.71	-17.65	-28.24	-38.82
	Mercedes	0	-5.69	14.68	9.36	-15.78
	Volkswagen	0	-5.95	-6.55	-16.67	-23.21
	Porsche	0	-10.61	-12.12	-12.12	-9.09
Sweden	Scania	0	-5.26	-15.79	-5.26	0.00
	Volvo Cars	0	-12.30	-11.52	7.75	-4.34
France	Renault	0	-0.70	3.81	-4.33	-8.39
Netherlands	Stellantis	0	0	0	-3.82	-4.81

UK	Aston Martin	0	0	0	0	0

Table 4.2.3: Waste Production

Waste Production						
		Base Year 2019	% Change 2020	% Change 2021	% Change 2022	% Change 2023
Germany	BMW	0	-18.58	-29.10	-33.01	-48.17
	Mercedes	0	-16.46	-30.75	-45.96	-60.87
	Volkswagen	0	-2.49	-13.54	-41.99	-53.59
	Porsche	0	-11.87	-37.12	-90.10	-92.19
Sweden	Scania	0	4.44	2.22	6.67	2.96
	Volvo Cars	0	-0.64	-2.98	-18.69	-15.71
France	Renault	0.00	-1.97	-0.37	-9.46	-14.71
Netherlands	Stellantis	0.00	0.00	0.00	-1.50	-0.44
UK	Aston Martin	0.00	-53.48	-41.40	45.70	143.99

Table 4.2.4: Water Withdrawal

Water Production						
		Base Year 2019	% Change 2020	% Change 2021	% Change 2022	% Change 2023
Germany	BMW	0	-3.30	-9.91	-10.38	-16.04
	Mercedes	0	37.45	39.69	10.66	3.09
	Volkswagen	0	5.60	12.61	5.32	-4.20
	Porsche	0	5.73	-2.87	-1.91	-10.51
Sweden	Scania	0	11.48	-3.13	2.83	-18.03
	Volvo Cars	0	-10.00	-9.33	-6.67	-10.00
France	Renault	0.00	17.50	20.00	17.50	5.00
Netherlands	Stellantis	0.00	0.00	0.00	-4.40	-18.24
UK	Aston Martin	0.00	7.53	16.72	7.91	4.48

Table 4.2.5: Energy Consumption

Energy Consumption						
		Base Year 2019	% Change 2020	% Change 2021	% Change 2022	% Change 2023
Germany	BMW	0	3.92	2.94	4.41	-3.43
	Mercedes	0	7.10	15.35	-3.80	-13.70
	Volkswagen	0	9.80	21.00	7.56	-0.95
	Porsche	0	-6.40	-9.45	-17.38	-24.93
Sweden	Scania	0	17.14	-1.43	0.00	-10.00
	Volvo Cars	0	-5.56	5.56	0.00	-11.11
France	Renault	0.00	15.25	25.42	8.47	-1.13
Netherlands	Stellantis	0.00	0.00	0.00	-3.57	-17.86
UK	Aston Martin	0.00	80.01	7.34	-9.69	-20.75

5. CONCLUSION

5.1 Conclusion

From the research, we can conclude by answering our research questions:
RQ1. What are the key sustainable manufacturing practices implemented by selected automobile companies?
The key sustainable manufacturing practices identified across the selected automobile companies include the reduction of CO_2 emissions, control of Volatile Organic Compound (VOC) emissions, efficient energy consumption, reduction in potable water usage, and effective waste disposal. These practices are essential components of the companies' efforts to enhance sustainability in their manufacturing processes.

RQ2. How do the companies adapt to extant regulations in sustainability practices?
The selected European automobile companies generally report their sustainability practices in accordance with the regulatory frameworks that govern such disclosures. They demonstrate compliance with national and the European Union environmental regulations by implementing and reporting on these key sustainable practices. This compliance reflects their adaptation to existing regulations and their commitment to environmental stewardship.

RQ3. How do the selected car manufacturers differ in their sustainability performances?
Based on the results of the ANOVA analysis, significant differences were found in the implementation of sustainable manufacturing practices among the automobile sectors of Sweden and the selected European countries. This indicates that the extent and effectiveness of sustainability efforts—such as CO_2 emission reductions, water consumption, waste disposal, VOC emission control, and energy consumption—vary significantly across the car manufacturers studied. Some manufacturers show higher efficiency and better performance in these areas, while others are less advanced.

RQ4. How do they compare between Sweden and other European companies?
Comparatively, Swedish automobile manufacturers exhibit different levels of sustainability performance when juxtaposed with their counterparts in other European countries. The variability in environmental performance across the car manufacturers indicates that some Swedish companies may excel in certain sustainable practices, such as lower CO_2 emissions and better waste management, while others may not perform as well in comparison to leading companies in countries like Germany, the Netherlands, the UK, and France. This highlights the diverse approaches and outcomes in sustainability practices within the European automobile sector.

In conclusion, the study reveals that while all selected European automobile companies engage in key sustainable manufacturing practices, there are significant differences in the extent and effectiveness of these practices. These differences reflect variability in environmental

performance and adaptation to regulatory requirements, underscoring the need for continuous improvement and harmonization of sustainability efforts across the sector.

5.1.1 Recommendation to further activities

1. Need for continuous improvement: While significant differences were observed in the current study, there is room for further improvement in sustainable manufacturing practices across the automobile sector. Continuous efforts are needed to reduce environmental impacts, enhance resource efficiency, and advance towards more sustainable production methods**.**
2. There is the need for a more centralized sustainability report management system and standardized reporting methods.

6. CRITICAL REVIEW

This research project provides an insightful comparative analysis of sustainable manufacturing practices within the automobile sectors of Sweden and selected European countries. By employing data from annual sustainability reports of selected car manufacturers, the study presents a comprehensive evaluation of how these practices differ across countries.

From an ethical standpoint, the research highlights the commitment of automobile manufacturers to transparency in reporting their sustainability efforts. However, relying on self-reported data from companies introduces potential bias, as manufacturers may selectively disclose information that portrays them in a favorable light. Future studies could benefit from incorporating third-party audits or independent assessments to enhance the credibility of the findings. The study underscores the social responsibility of car manufacturers in promoting sustainable practices. However, it primarily focuses on corporate actions and lacks a detailed analysis of the social impacts of these practices on local communities and labor forces. Further research could integrate surveys or interviews with stakeholders such as employees, local residents, and environmental groups to provide a more holistic view of the social implications. The study could explore the effectiveness of these practices in mitigating climate change and preserving natural resources.

The research does not deeply delve into the occupational health and safety aspects of sustainable manufacturing practices. Future studies should consider evaluating how these practices affect worker safety and health, particularly in manufacturing processes that involve hazardous materials or conditions. This could be achieved by reviewing OSH reports or conducting field studies in manufacturing plants.

The chosen methodology of using ANOVA and trend analysis provides a statistical framework for comparing sustainability practices. However, the study could have been enhanced by triangulating these quantitative methods with qualitative approaches, such as case studies or expert interviews, to provide a more understanding of the practices and their impacts. The literature review and selection of data sources are appropriate for the scope of the study. However, there is room for improvement in terms of diversity and depth. Including a wider range of academic sources and industry reports could provide a more comprehensive theoretical foundation. Furthermore, the research would benefit from accessing data beyond what is publicly reported by manufacturers, potentially through industry collaborations or partnerships.

REFERENCES

1. Accelgrid (2023). Sustainable Manufacturing Processes: 5 Key Elements. https://accelgrid.com/sustainable-manufacturing/
2. Ajay S.S, & Micah M.B, sampling techniques & determination of sample size in applied statistics research: an overview, International Journal of Economics, Commerce and Management United Kingdom, Vol. II, Issue 11, Nov 2014,ISSN 2348 0386.
3. Alfar Rodrigues, André, Action Plan for the Circular Economy in the European Union (February 24, 2023). Available at SSRN:https://ssrn.com/abstract=4368732 or http://dx.doi.org/10.2139/ssrn.4368732
4. Ali, Z., & Bhaskar, S. B. (2016). Basic statistical tools in research and data analysis. Indian journal of anaesthesia, 60(9), 662–669. https://doi.org/10.4103/0019-5049.190623
5. Al-Yousfi, A.B. (2004). Cleaner production for sustainable industrial development: Concept and applications. Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, Vol. 8. No. 4, pp. 265-273.
6. Annenberg Learner (2024). Private: Learning Math: Data Analysis, Statistics, and Probability,https://www.learner.org/series/learning-math-data-analysis-statistics-and-probability/designing-experiments/comparative-studies-15-minutes.
7 Annual and Sustainability Report 2020 Porsche AG https://www.porsche-se.com/fileadmin/downloads/investorrelations/mandatorypublications/annualreport-20/PSE2020_Annual_Report_en.pdf.
8. Annual and Sustainability Report 2021 Porsche AG https://www.volkswagen-group.com/en/publications/corporate/annual-and-sustainability-report-2021-porsche-ag-1906
9. Annual and Sustainability Report 2023 Porsche AG https://www.volkswagen-group.com/en/publications/more/annual-and-sustainability-report-2023-of-porsche-ag-2670
10. Aston Martin Sustainability Report 2023 https://www.astonmartinlagonda.com/sustainability/sustainability-reports
11. Ball, P. n.d. Sustainable-manufacturing-starting-the-journey. Retrieved from www.theiet.org on April 27, 2024
12. Bansal, P. Evolving sustainability: A longitudinal study of corporate sustainable development. Strat. Manag. J. 2005, 26, 197–218.
13. Bastas, A. (2021). Sustainable manufacturing technologies: A systematic review of latest trends and themes. Sustainability 13, 4271. https://doi.org/10.3390/ su13084271.
14. Bebbington, J., Gray, R., Hibbitt, C. & Kirk, E. (2001). Full cost accounting: An agenda for action, Certified Accountants Educational Trust London.
15. Bmw Group Report 2023. https://www.bmwgroup.com/en/report/2023/downloads/index.html
16. Boons, F., & Lüdeke-Freund, F. (2013). Business models for sustainable innovation: State-of-the-art and steps towards a research agenda. Journal of Cleaner Production, 45,
17. Borbasi, S., & Jackson, D. (2012). Navigating the Maze of Research. Chatswood, Sydney: Mosby Elsevier.
18. Bowen, G. A. (2009). Document Analysis as a Qualitative Research Method, Qualitative Research Journal, vol. 9, no. 2, 2009
19. Burns, N., & Grove, S. K. (2005). The Practice of Nursing Research, Conduct, Critique, and Utilization (5th Ed.). St Louis: Elsevier.

20. Carrera, D. G., & Mack, A. (2010). Sustainability assessment of energy technologies via social indicators: Results of a survey among European energy experts. Energy Policy, 38, 1030–1039.
21. Chao, Y. S., Wu, C. J., Wu, H. C., & Chen, W. C. (2018). Trend analysis for national surveys: Application to all variables from the Canadian Health Measures Survey cycle 1 to 4. PloS one, 13(8), e0200127. https://doi.org/10.1371/journal.pone.0200127
22. Cooper, C. R., & Schindler, P. S. (2008). Business Research Methods (10th Ed.). Boston: McGraw-Hill.Tableau, (2024). What Is Data Visualization? Definition, Examples, And Learning Resources. https://www.tableau.com/learn/articles/data-visualization. THE WORLD FACTBOOK, 2024. Real GDP per capita. https://www.cia.gov/the-world-factbook/field/real-gdp-per-capita/country-comparison/
23. Chen, L.; Olhager, J.; Tang, O. Manufacturing facility location and sustainability: A literature review and research agenda. Int. J. Prod. Econ. 2014, 149, 154–163.
24. Chari, A. & Vogt, D., Johan & Lindahl, Emma & Stahre, Johan & Despeisse, Mélanie & Sundin, Erik & Johansson, Björn & Wiktorsson, Magnus. (2021). Swedish manufacturing practices towards a sustainability transition in industry 4.0: A Resilience Perspective. 10.1115/MSEC2021-62394.
25. Claros, E., 2013. EU Car Industry (Library of the European Parliament) source: http://libraryeuroparl.wordpress.com.
26. Cochran, WG (1963): Sampling Techniques, 2nd Ed., New York: John Wiley and Sons, Inc.
27. Corbin, J. & Strauss, A. (2008). Basics of qualitative research: Techniques and procedures for developing grounded theory (3rd ed.). Thousand Oaks, CA: Sage.
9. Deakin University Library. (2024). Quantitative study designs, https://deakin.libguides.com/quantitative-study-designs
10. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA (editors). Cochrane Handbook for Systematic Reviews of Interventions version 6.4 (updated August 2023). Cochrane, 2023. Available from www.training.cochrane.org/handbook.
11. Kudzh S A and Tsvetkov V Ya 2020 Comparative Analysis (Moscow, Russia: MAKS Press) p 144 (ISBN 978-5-317-06393-1)
12. Kumar, R. (2011). Research Methodology: A Step-by-Step Guide for Beginners. Sage Publications Ltd., London.
13. W. W. Eckerson, "Data quality and the bottom line: Achieving business success through a commitment to high quality data". Data, Warehousing Institute, 2002.
14. Ensslin, S.R.; Ensslin, L.; Lacerda, R.T.d.O.; Souza, V.H.A.d. Disclosure of the State of the Art of Performance Evaluation Applied to Project Management. Am. J. Ind. Bus. Manag. 2014, 4, 677.
15. European Commission. 2015, Automotive Industry—Comprehensive Sector Analysis of New Competencies and Economic Activities within the European Union, Summary. Available online: http://ec.europa.eu/social/ (accessed on 3 March 2023).
16. European Commission. 2023, Circular economy action plan, retrieved from https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en.
17. European Environment Agency. (2022).Circular economy country profile – Sweden. https://www.eionet.europa.eu/etcs/etc-ce
18. European Parliament (2023). Circular economy: definition, importance and benefits Retrieved From https://www.europarl.europa.eu/topics/en/article/20151201STO05603/circular-economy-definition-importance-and-benefits
19. Evans, S., Vladimirova, D., Holgado, M., VAN Fossen, K., Yang, M.,Silva, E. A., & Barlow, C.Y. (2017). Business model innovation for sustainability: Towards a unified

perspective for creation of sustainable business models. Business Strategy and the Environment, 26, 597–608.
20. Geissdoerfer, M., Vladimirova, D., & Evans, S. (2018). Sustainable business model innovation: A review. Journal of Cleaner Production, 198,401–416.
21. Gray, R.; Owen, D.; Maunders, K. Accounting and Accountability: Changes and Challenges in Corporate Social and Environmental Reporting; Prentice-Hall Europe: Harlow, UK, 1996.
22. Grigorenko. Y, (2023). EU automotive sector shows good growth: how will it affect steel consumption, https://gmk.center/en/posts/eu-automotive-sector-shows-good-growth-how-will-it-affect-steel-consumption/
23. Grunert, K.G., Hieke, S., Wills, J., 2014. Sustainability labels on food products: consumer motivation, understanding and use. Food Policy 44, 177e189. http://dx.doi.org/10.1016/j.foodpol.2013.12.001.
24. Hamed G., Falah A., Jocelyn K., Sasan S. K. & Safian S. (2021). Sustainable manufacturing 4.0—Pathways and practices, Sustainability 13(24), 13956; https://doi.org/10.3390/su132413956.
25. Hartini, S.; Ciptomulyono, U. The relationship between lean and sustainable manufacturing on performance: Literature review. Procedia Manuf. 2015, 4, 38–45.
26. Held, M., Weidmann, D., Kammerl, D., Hollauer, C., Mörtl, M., Omer, M., & Lindemann, U. (2018). Current challenges for sustainable product development in the German automotive sector: A survey-based status assessment. Journal of Cleaner Production, 195, 869–889. doi:10.1016/j.jclepro.2018.05.118
27. Hess, A. S., & Abd-Elsayed, A. (2019). Observational Studies: Uses and Limitations.Pain, 123–125. doi:10.1007/978-3-319-99124-5_31
28. Hossam A. K. 1, Hussien H. & Elsadig S. (2018). Design for sustainable manufacturing: Approach, implementation, and assessment. Sustainability 10, 3604; doi:10.3390/su10103604, 1.
29. Indeed. (2022). What Is Comparative Analysis and How Is It Used. https://www.indeed.com/career-advice/career-development/comparative-analysis
30. Jasinski, D., Meredith, J., & Kirwan, K. (2015). A comprehensive review of full cost accounting methods and their applicability to the automotive industry. Journal of Cleaner Production, 108, 1123–1139.
31. Jasiński, D., Meredith, J., & Kirwan, K. (2021). Sustainable development model for measuring and managing sustainability in the automotive sector. Sustainable Development. doi:10.1002/sd.2207
32. Jawahir, I. Beyond the 3 R's: 6R concepts for next generation manufacturing: Recent trends and case studies. In Proceedings of the Symposium on Sustainability and Product Development, Chicago, IL, USA, 7–8 August 2008.
33. Jonnaert, E., 2014. The European Automotive Industry Economic Situation & Key Challenges. OICA Round Table “THE WORLD AUTO INDUSTRY: SITUATION AND TRENDS” source.
34. Johnson, D.D.; Srivastava, R. Design for Sustainability: Product Development Tools and Life Cycle Economics. In Proceedings of the 39th Annual Meeting of the Decision Sciences Institute, Baltimore, MD, USA, 22–25 November 2008; pp. 1711–1716.
35. Joshi, K.; Venkatachalam, A. & Jawahir, I.S. (2006). A new methodology for transforming 3R concept into 6R concept for improved product sustainability. In proceedings of the IV global conference on sustainable product development and life cycle engineering, Sao Paulo, Brazil, 3–6 October 2006, 3–6.

36. Jovane, F.; Yoshikawa, H.; Alting, L.; Boër, C.R.;Westkamper, E.;Williams, D.; Tseng, M.; Seliger, G.; Paci, A.M. The incoming global technological and industrial revolution towards competitive sustainable manufacturing.CIRP Ann. 2008, 57, 641–659.
37. Kishawy, H., Hegab, H., & Saad, E. (2018). Design for Sustainable Manufacturing: Approach, Implementation, and Assessment. Sustainability, 10(10), 3604. doi:10.3390/su10103604
38. Krajnik, P.; Pusavec, F.; Rashid, A. Nanofluids: Properties, applications and sustainability aspects in materials processing technologies. In Advances in Sustainable Manufacturing; Springer: Berlin/Heidelberg, Germany,2011; pp. 107–113.
39. Larson, M. G. (2008). Analysis of Variance. Circulation, 117(1), 115–121. doi:10.1161/circulationaha.107.654335
40. Mohajan, Haradhan,(2020). Quantitative Research: A Successful Investigation in Natural and Social Sciences.Journal of Economic Development, Environment and People, Volume 9, Issue 4, 2020, pp. 52-79.
41. Sarkis, J. Manufacturing's role in corporate environmental sustainability: Concerns for the new millennium. Int. J. Oper. Prod. Manag. 2001, 21, 666–686.
42. Stobierski Tim. (2021). Top data visualization tools for business professionals Harvard Business School Online. https://online.hbs.edu/blog/post/data-visualization-tools
43. Leyh, C.; Krischke, A.; Strahringer, S. Die Herausforderungen der IT-Unterstützung des Nachhaltigkeitsmanagements in KMU—Eine vergleichende Betrachtung ausgewählter KMU und Großunternehmen. In Nachhaltigkeit in Kleinen und Mittleren Unternehmen, 1st ed.; Meyer, J.-A.,Ed.; Josef Eul Verlag: Köln, Germany, 2011; pp. 269–287. (In German)
44. Mann, C.J.. (2012). Observational research methods—Cohort studies, cross sectional studies, and case–control studies. African Journal of Emergency Medicine. 2. 38–46. 10.1016/j.afjem.2011.12.004.
45. Mark, C., Sustainable Manufacturing: Key Priorities in EMEA(2023). Retrieved from ttps://blog-idceurope.com/sustainable-manufacturing-key-priorities-in-emea
46. Mercedes Benz Group, Sustainability Report 2023. https://group.mercedes-benz.com/responsibility/sustainability/sustainability-report.html
47. Midway, S. R. (2020). Principles of Effective Data Visualization. Patterns, 1(9), 100141. doi:10.1016/j.patter.2020.100141
48. Meschut, G., Janzen, V. & Olfermann, T. Innovative and Highly Productive Joining Technologies for Multi-Material Lightweight Car Body Structures. J. of Materi Eng and Perform 23, 1515–1523 (2014). https://doi.org/10.1007/s11665-014-0962-3
49. Mills, M., van de Bunt, G. G., & de Bruijn, J. (2006). Comparative research. Persistent problems and promising solutions. International Sociology, 21(5), 619–631.
50. Morgan, J.M.; Liker, J.K. The Toyota Product Development System: Integrating People, Process, and Technology; Productivity Press: New York, NY, USA, 2006.
51. Narayanan, R.G. & Gunasekera, J.S. (2023). Sustainable manufacturing processes. 1-28, Academic Press, ISBN 9780323999908.
52. Nawrocka, Monika & Maszczyk, Adam & Gołaś, Artur & Dygacz, Agnieszka & Budzisz, Aleksandra. (2015). The advantages and limitations of the statistical approach in scientific research. 10.15503/emet 2015.58.68.
53. Naturvardsverket.(n.d).The Swedish Environmental Code. https://www.naturvardsverket.se/en/laws-and-regulations/the-swedish-environmental-code. Nurse Key. (2017). Interpreting Research Outcomes. https://nursekey.com/interpreting-research-outcomes/

54. Odyssee-mure.(n.d). Energy efficiency trends and policies. https://www.odyssee-mure.eu/publications/efficiency-trends-policies-profiles/swe den.html
55. Organization for Economic Co-operation and Development (OECD). The Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data, 3rd ed.; OECD Publishing: Paris, France, 2005; p. 166.
56. J. W. Osbourne, "Notes on the Use of Data Transformation", Practical Assessment, Research & Evaluation, 2002, 8(6): n6.
57. Ramos, T. B., & Caeiro, S. (2010). Meta-performance evaluation of sustainability indicators. Ecological Indicators, 10, 157–166.
58. Patrik, M., Cecilia, B., Isabel, F., Environmental, Social & Governance Law Sweden 2024,https://iclg.com/practice-areas/environmental-social-and-governance-law/sweden.
59. Pendar M.R, Rodrigues F, Páscoa JC, Lima R (2022) Review of coating and curing processes: evaluation in the automotive industry. Phys Fluids 34(10)
60. Peterson, E. W. F. (2017). The Role of Population in Economic Growth. Sage Open, 7(4). https://doi.org/10.1177/2158244017736094
61. Pickvance C. G. (2001). The methodological challenge to comparative research.
62. Journal of Housing and the Built Environment, Vol. 16, No. 1,pp. 7-28 Pujari, D. Eco-innovation and new product development: Understanding the influences on market performance. Technovation 2006, 26, 76–85.
63. Rosen, M. A., & Kishawy, H. A. (2012). Sustainable Manufacturing and Design: Concepts, Practices and Needs. Sustainability, 4(2), 154–174. doi:10.3390/su4020154
64. Rachuri, S.; Sriram, R.; Narayanan, A.; Sarkar, P.; Lee, J.; Lyons, K.; Kemmerer, S. Sustainable Manufacturing: Metrics, Standards, and Infrastructure—NIST Workshop Report; NIST Interagency/Internal Report (NISTIR);National Institute of Standards and Technology (NIST): Gaithersburg, MD, USA, 2010; p. 7683.
65. Rzezinski, R & Kochanski, L. (2018). Joining methods in car body construction. IOP Conference Series: Materials Science and Engineering. 400. 022051. 10.1088/1757-899X/400/2/022051.
66. Riffenburgh.R.H.,(2012). Statistics in Medicine (Third Edition), Academic Press,https://doi.org/10.1016/B978-0-12-384864-2.00025-1
67. Scania Annual and Sustainability Report 2023. https://www.scania.com/group/en/home/newsroom/press-releases/press-release-detail-page.html/4766129-scania-publishes-annual-and-sustainability-report-for-2023---significant-growth-in-sales-and-earning
68. Scania Annual and Sustainability Report 2019. https://www.scania.com/content/dam/group/investor-relations/financial-reports/annual-reports/Scania_AnnualReport_2019-English.pdf
69. Scania Annual and Sustainability Report 2020. https://www.scania.com/content/dam/group/investor-relations/annual-review/download-full-report/scania-annual-and-sustainability-report-2020.pdf
70. Seliger, G.: Sustainability engineering by product-service systems. In: Hesselbach, J.,Herrmann, C. (eds.) Glocalized Solutions for Sustainability in Manufacturing. Proceedingsof the 18th CIRP International Conference on Life Cycle Engineering, Braunschweig,Germany, May 2–4, pp. 22–28. Springer, Heidelberg (2011).
71. Shao, J., Taisch, M., & Ortega Mier, M. (2016). A study on a configuration model for facilitating sustainable consumption: A case involving the automobile industry in Italy. Journal of Cleaner Production, 137, 507–515. doi:10.1016/j.jclepro.2016.07.130
72. Shona, M. (2023, May 8). What Is a Case Study? | Definition, Examples & Methods.https://www.scribbr.com/methodology/case-study/

73. Short, T., Lee-Mortimer, A., Luttropp, C., & Johansson, G. (2012). Manufacturing,sustainability, ecodesign and risk: lessons learned from a study of Swedish and English companies. Journal of Cleaner Production, 37, 342–352.
74. Shorten A, Smith J, Mixed methods research: expanding the evidence base Evidence-Based Nursing 2017;20:74-75.
75. Statista (2024), Passenger Cars - Europe.https://www.statista.com/outlook/mmo/passenger-cars/europe
76. Stellantis Corporate Social Responsibility Report 2023. https://www.stellantis.com/en/news/press-releases/2024/april/stellantis-2023-corporate-social-responsibility-report-outlines-strong-results-against-ambitious-dare-forward-2030-targets
77.
78. Steve Sarsfield, "How a Small Data Error Becomes a Big Data Quality Problem", September 3, 2012. Retrievable at: https://www.linkedin.com/grp/post/ 103526-162333712.
79. Sudarsan, R.; Sriram, R.D.; Narayanan, A.; Sarkar, P.; Lee, J.H.; Lyons, K.W.; Kemmerer, S.J. Sustainable manufacturing: Metrics, standards, and infrastructure-workshop summary. In Proceedings of the 2010 IEEE Conference on Automation Science and Engineering (CASE), Toronto, ON, USA, 21–24 August 2010; pp. 144–149.
80. Sukitsch, M., Engert, S., & Baumgartner, R. (2015). The Implementation of Corporate Sustainability in the European Automotive Industry: An Analysis of Sustainability Reports. Sustainability, 7(9), 11504–11531. doi:10.3390/su70911504 Sustainable Manufacturing (2024). Retrieved from https://www.epa.gov/sustainability/sustainable-manufacturing.
81. Suresh K, Thomas SV, Suresh G. Design, data analysis and sampling techniques for clinical research. Ann Indian Acad Neurol. 2011 Oct;14(4):287-90. doi: 10.4103/0972-2327.91951.
82. Swanson, R. A., & Holton, E. F. III. (Eds.) (2005). Research in Organizations: Foundations and Methods of Inquiry. SanFrancisco: Berrett-Koehler. The World Bank, (2018).https://datatopics.worldbank.org/world-development indicators/themes/economy.html#
83. Thomas.L. (2023). Simple Random Sampling | Definition, Steps & Examples,https://www.scribbr.com/methodology/simple-random-sampling/University Health Network. (2024). Systematic Review Overview. https://guides.hsict.library.utoronto.ca/
84. Vaz, C., Rauen, T., & Lezana, Á. (2017). Sustainability and Innovation in the Automotive Sector: A Structured Content Analysis. Sustainability, 9(6), 880. doi:10.3390/su9060880
85. Vitalii Ivanov,Ivan Dehtiarov,Jozef Zajac, 2018.Flexible Fixtures for Parts Machining in Automobile Industry,DOI: 10.4108/eai.22-11-2017.2274155
86. Xiaofeng Wang, Zhenshun Cheng, Cross-Sectional Studies: Strengths, Weaknesses, and Recommendations, Volume 158, Issue 1, Supplement, 2020,Pages S65-S71, SSN 0012-3692, https://doi.org/10.1016/j.chest.2020.03.012.
87. Tiffany L. (2021).What is sustainable manufacturing and the benefits? Retrieved From https://www.winman.com/blog/what-is-sustainable-manufacturing-and-the-benefits.
88. Todescato, M., Braholli, O. & Chaltsev, D. ((2023). Sustainable manufacturing through application of reconfigurable and intelligent systems in production processes: a system perspective. Sci Rep 13, 22374. https://doi.org/10.1038/s41598-023-49727-5.
89. Universal registration document 2020 (Renault). https://www.renaultgroup.com/wp-content/uploads/2021/03/ren2020_urd_en_mel.pdf

90. Universal registration document 2023 (Renault). https://www.renaultgroup.com/wp-content/uploads/2024/03/renault_urd_2023__en__202403201552.pdf
91. Vesela Veleva, Michael Ellenbecker, Indicators of sustainable production: Framework and methodology, Journal of Cleaner Production, Volume 9, Issue 6, 2001,Pages 519-549, ISSN 0959-6526, https://doi.org/10.1016/S0959-6526(01)00010-5.
92. Volkswagen sustainability Report_2019 https://www.volkswagen-group.com/en/publications/corporate/sustainability-report-2019-1668
93. Volkswagen_Group_Sustainability_Report 2023 https://www.volkswagen-group.com/en/publications/more/group-sustainability-report-2023-2674
94. Volvo-Annual-Report-2023. https://www.volvogroup.com/en/news-and-media/events/2024/feb/annual-report-2023.html
95. Volvo-Annual-Report-2020 https://www.volvogroup.com/en/news-and-media/events/2021/feb/annual-and-sustainability-report-2020.html
96. Warfield, D. (2013). IS/IT Research: A Research Methodologies Review. Journal of Theoretical and Applied Information Technology, 3(1), 28-35.
97. White, L., & Millar, R. B. (2014). Quantitative Approaches. In V. Wright-St Clair, D. Reid, S. Shaw, & J. Ramsbotham (Eds.), Evidence-based Health Practice. South Melbourne: Oxford University Press.
98. World Commission on Environment and Development (WCED). Our Common Future; Oxford University Press: Oxford, UK, New York, NY, USA, 1987.
99. Yi-Chun K., Yo-Ming W., Yi-Xuan L., 2021. Identifying Key Factors for Sustainable Manufacturing and Development. Review of Integrative Business and Economics Research, Vol. 11, Issue 1
100. Yin, R. K. (1994). Case study research: Design and methods (2nd ed.). Thousand Oaks, CA: Sage.
101. Yin RK: Case study research, design and method. 2009, London: Sage Publications Ltd., 4.
102. Yousif M.I., Norsiah H., & Susan S.A. (2020). Assessing sustainable manufacturing practices and sustainability performance among the oil and gas industry in Iraq. International Journal of Energy Economics and Policy, 10(4), 60-67.

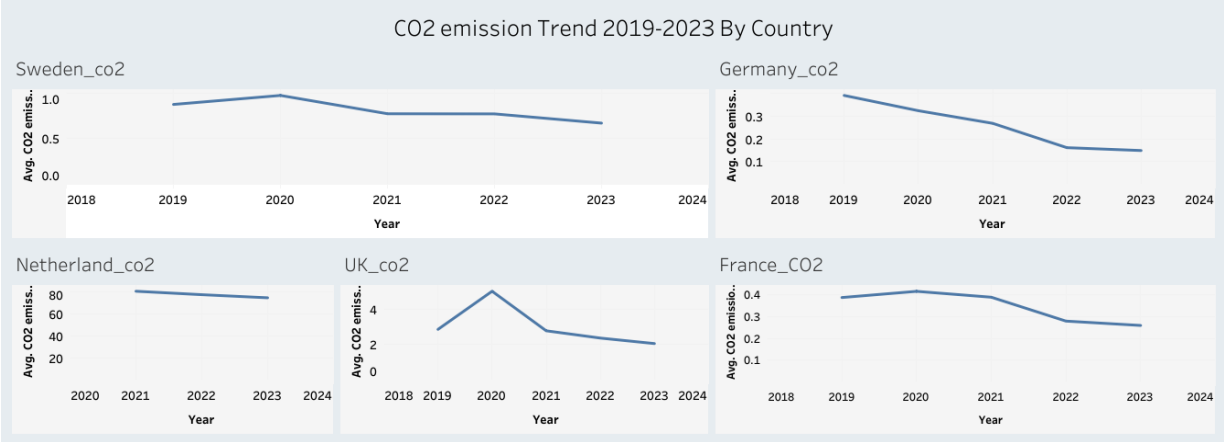
Appendices

Appendix i: Data Collection

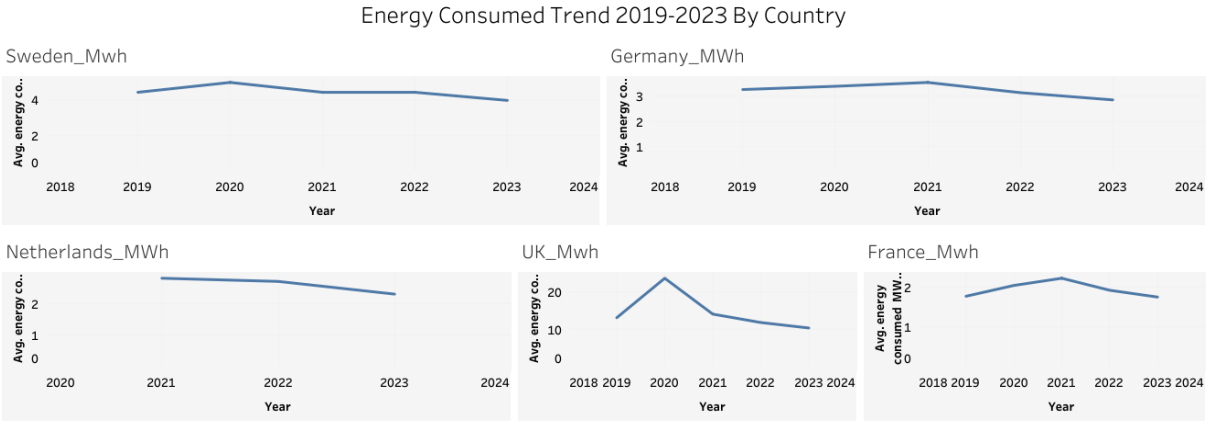
CAR	YEAR	CO2 emission per vehicle produced in metric tons/vehicle	VOC emissions per vehicle produced in kg/vehicle solvent	waste for disposal per vehicle produced in kg/vehicle	portable water consumption per vehicle produced in m3/vehicle	energy consumed per vehicle produced in MWh/vehicle	Country
BMW	2019	0.4000	0.8500	4.0900	2.1200	2.0400	Germany
BMW	2020	0.3500	0.8100	3.3300	2.0500	2.1200	Germany
BMW	2021	0.3300	0.7000	2.9000	1.9100	2.1000	Germany
BMW	2022	0.3200	0.6100	2.7400	1.9000	2.1300	Germany
BMW	2023	0.2800	0.5200	2.1200	1.7800	1.9700	Germany
Mercedes	2019	0.5910	5.4500	32.2000	7.1300	6.0600	Germany
Mercedes	2020	0.5760	5.1400	26.9000	9.8000	6.4900	Germany
Mercedes	2021	0.4470	6.2500	22.3000	9.9600	6.9900	Germany
Mercedes	2022	0.0660	5.9600	17.4000	7.8900	5.8300	Germany
Mercedes	2023	0.0600	4.5900	12.6000	7.3500	5.2300	Germany
Scania	2019	1.7000	3.8000	1.3500	6.7100	7.0000	Sweden
Scania	2020	1.9000	3.6000	1.4100	7.4800	8.2000	Sweden
Scania	2021	1.5000	3.2000	1.3800	6.5000	6.9000	Sweden
Scania	2022	1.5000	3.6000	1.4400	6.9000	7.0000	Sweden
Scania	2023	1.3000	3.8000	1.3900	5.5000	6.3000	Sweden
Volvo Cars	2019	0.0534	2.1430	0.4636	3.0000	1.8000	Sweden
Volvo Cars	2020	0.0508	1.8793	0.4606	2.7000	1.7000	Sweden
Volvo Cars	2021	0.0489	1.8962	0.4498	2.7200	1.9000	Sweden
Volvo Cars	2022	0.0460	2.3091	0.3770	2.8000	1.8000	Sweden
Volvo Cars	2023	0.0432	2.0500	0.3907	2.7000	1.6000	Sweden
Volkswagen	2019	0.3327	1.6800	3.6200	3.5700	2.0100	Germany
Volkswagen	2020	0.2992	1.5800	3.5300	3.7700	2.2070	Germany
Volkswagen	2021	0.2854	1.5700	3.1300	4.0200	2.4320	Germany
Volkswagen	2022	0.2323	1.4000	2.1000	3.7600	2.1620	Germany
Volkswagen	2023	0.2008	1.2900	1.6800	3.4200	1.9910	Germany
Renault	2019	0.3885	3.5782	24.2340	4.0000	1.7700	France
Renault	2020	0.4170	3.5533	23.7560	4.7000	2.0400	France
Renault	2021	0.3900	3.7146	24.1450	4.8000	2.2200	France
Renault	2022	0.2800	3.4233	21.9418	4.7000	1.9200	France
Renault	2023	0.2600	3.2781	20.6700	4.2000	1.7500	France
Porsche	2019	0.2390	0.6600	7.1720	3.1400	2.9520	Germany
Porsche	2020	0.0690	0.5900	6.3210	3.3200	2.7630	Germany

Porsche	2021	0.0100	0.5800	4.5100	3.0500	2.6730	Germany
Porsche	2022	0.0260	0.5800	0.7100	3.0800	2.4390	Germany
Porsche	2023	0.0530	0.6000	0.5600	2.8100	2.2160	Germany
Stellantis	2019	No data	No data	No data	No data	No data	Netherlands
Stellantis	2020	No data	No data	No data	No data	No data	Netherlands
Stellantis	2021	80.2000	2.8189	48.1500	4.7700	2.8000	Netherlands
Stellantis	2022	77.1000	2.7112	47.4300	4.5600	2.7000	Netherlands
Stellantis	2023	74.3000	2.6832	47.9400	3.9000	2.3000	Netherlands
Aston Martin	2019	2.8600	No Data	0.2536	9.5910	13.0892	UK
Aston Martin	2020	5.0100	No Data	0.1180	10.3134	23.5618	UK
Aston Martin	2021	2.7800	No Data	0.1486	11.1944	14.0505	UK
Aston Martin	2022	2.3700	No Data	0.3695	10.3498	11.8215	UK
Aston Martin	2023	2.0600	No Data	0.6188	10.0205	10.3734	UK

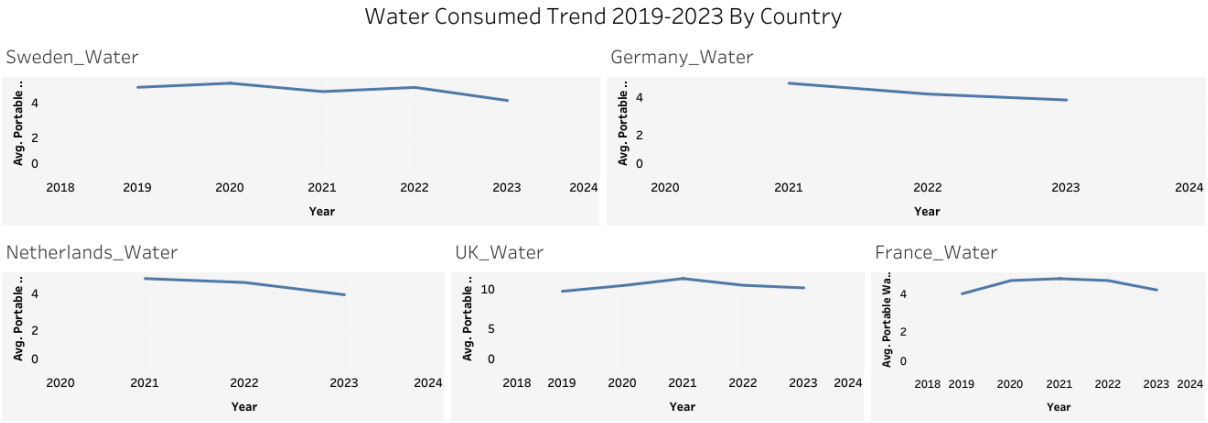
Appendix ii: CO_2 Emission Trend 2019-2023 By Country.



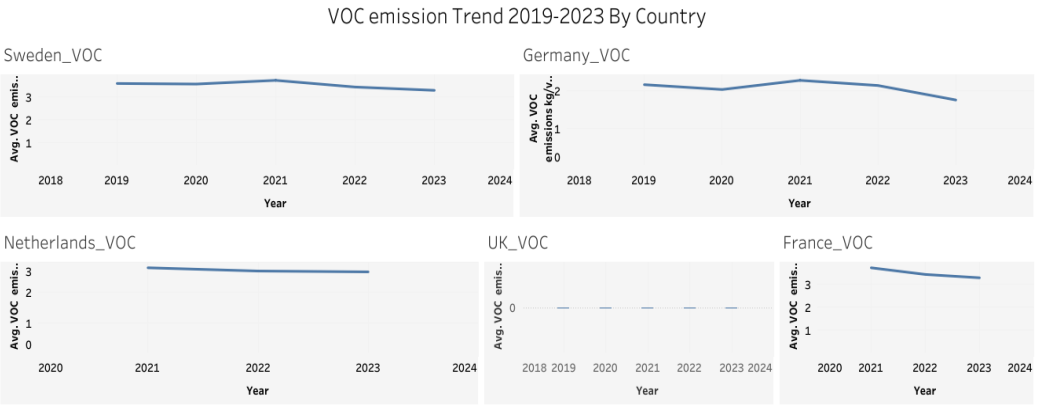
Appendix iii: Energy Consumption Trend 2019-2023 By Country.



Appendix iv: Water Consumption Trend 2019-2023 By Country.



Appendix V : VOC emission Trend 2019-2023 By Country.



Appendix vi : Waste Production Trend 2019-2023 By Country.