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Research Topic

Revolutionizing Automotive Sustainability: Using ERP for CO2 Emission Reduction

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EXECUTIVE SUMMARY

The automotive industry is a significant contributor to global carbon emissions, necessitating innovative solutions to enhance sustainability [38], [44]. As regulatory pressures and societal demands for environmental responsibility increase, the need for effective strategies to reduce emissions has never been more critical [14], [23]. This study investigates the potential of Enterprise Resource Planning (ERP) systems in mitigating CO2 emissions within the European Union's (EU) automotive sector, a key player in the region's economy and environmental strategy [20], [45]. The EU automotive industry, contributing approximately 7% to the EU's Gross Domestic Product (GDP) and employing over 14 million people, faces stringent environmental regulations aimed at achieving climate neutrality by 2050 as part of the European Green Deal [12], [13]. These regulations position the automotive sector at the forefront of the EU's sustainability transition [8], [15].

This research adopts a systematic literature review methodology, complemented by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach [51]. The study scrutinizes both theoretical frameworks and practical applications, drawing from 74 articles that meet the specified criteria [48]. ERP systems have evolved from inventory control and production planning tools to comprehensive platforms integrating various business functions [69], [70]. In the automotive sector, ERP systems can optimize resource utilization, streamline operations, and reduce waste, thus significantly contributing to sustainability goals [23], [28]. ERP implementations can reduce emissions by up to 20% by minimizing energy consumption and unnecessary production processes [20], [24]. ERP systems enhance environmental performance by enabling better monitoring and management of environmental impacts [8], [16].

The study highlights the strategic importance of ERP in supporting decision-making processes that align with sustainability goals, such as the selection of eco-friendly materials and the implementation of circular economy principles [44], [23]. ERP solutions provide holistic visibility and regulatory compliance mechanisms pertaining to environmental impact, thereby serving as an indispensable instrument for the European automotive sector to realize its sustainability imperatives and attenuate its carbon emissions [38], [45]. Despite these benefits, the adoption of ERP systems faces challenges, including high implementation costs and resistance to change [42], [43]. Overcoming these challenges requires strategic planning, stakeholder engagement, and a commitment to change management [8], [14]. Collaboration among stakeholders—suppliers, manufacturers, and logistics providers—is essential for maximizing the potential of ERP systems in reducing emissions and promoting sustainability [38], [39].

The research concludes that ERP systems are critical in reducing the carbon footprint of the automotive industry [24], [26]. By optimizing supply chain operations, improving resource efficiency, facilitating compliance with EU environmental regulations, and enabling the integration of sustainable practices across business processes, ERP solutions can help the automotive industry meet its ambitious sustainability goals [20], [22]. Future research should explore the integration of ERP with emerging technologies like AI and IoT, examine the long-term impacts of ERP systems on sustainability outcomes, and investigate the human and organizational factors influencing the success of ERP implementations [24], [30].

This executive summary encapsulates the main points of the study, highlighting the transformative potential of ERP systems in fostering sustainability within the EU automotive industry.

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List of Abbreviations

1. **AI** - Artificial Intelligence
2. **CH4** - Methane
3. **CO2** - Carbon Dioxide
4. **EGR** - Exhaust Gas Recirculation
5. **ERP** - Enterprise Resource Planning
6. **EU** - European Union
7. **GHG** - Greenhouse Gases
8. **IoT** - Internet of Things
9. **LCA** - Life Cycle Assessment
10. **N2O** - Nitrous Oxide
11. **NRMM** - Non-Road Mobile Machinery
12. **OEM** - Original Equipment Manufacturer
13. **PCF** - Product Carbon Footprint
14. **PRISMA** - Preferred Reporting Items for Systematic Reviews and Meta-Analyses
15. **SCR** - Selective Catalytic Reduction
16. **SLR** - Systematic Literature Review

Chapter 1: INTRODUCTION

In this chapter, the motivation for the thesis is discussed in Section 1.1, highlighting the significant role of the automotive industry in global economics and its environmental impact. This is followed by the problem statement in Section 1.2, which addresses the stringent environmental regulations faced by the European Union's automotive sector and the challenges in leveraging ERP systems for sustainability. The research objectives are outlined in Section 1.3, focusing on assessing ERP implementation, evaluating their impact on CO_2 reduction, and identifying related challenges and opportunities. Section 1.4 describes the research approach, including a systematic literature review and simulations. Finally, Section 1.5 provides an overview of the thesis structure, ensuring a logical progression through the research.

1.1 Motivation

The automotive industry is one of the most significant sectors globally, both economically and environmentally. It contributes substantially to global carbon emissions, necessitating innovative solutions to enhance sustainability. As climate change becomes an increasingly pressing issue, there is an urgent need for the automotive industry to adopt sustainable practices and technologies. Regulatory pressures and societal demands for environmental responsibility are at an all-time high, compelling automotive companies to seek effective strategies for reducing their carbon footprint.

Enterprise Resource Planning (ERP) systems, which have evolved from simple inventory control systems to comprehensive platforms that integrate various business functions, offer a promising solution. ERP systems can optimize resource utilization, streamline operations, and reduce waste, significantly contributing to sustainability goals. This thesis is motivated by the potential of ERP systems to revolutionize sustainability practices in the automotive industry by integrating advanced data management and real-time analytics to mitigate CO_2 emissions [56],[59].

1.2 Problem Statement

The European Union's automotive sector, contributing approximately 7% to the EU's GDP and employing over 14 million people, faces stringent environmental regulations aimed at achieving climate neutrality by 2050 as part of the European Green Deal. While there is widespread recognition of the potential for ERP systems to enhance operational efficiency and sustainability, there is a lack of detailed research examining their specific impact on carbon emission reduction in this sector.

Moreover, the successful adoption of ERP systems involves overcoming significant challenges, such as high implementation costs and resistance to organizational change. These factors complicate the ability to fully leverage ERP systems for sustainability initiatives. Therefore, this thesis aims to bridge the gap by providing a comprehensive analysis of how

ERP systems can be effectively implemented to reduce carbon emissions in the EU automotive industry [42],[49].

1.3 Objectives

The objectives of this research are following:

1. To assess the current state of ERP implementation in the EU automotive industry.
2. To evaluate the impact of ERP systems on CO2 emission reduction.
3. To identify the challenges and opportunities associated with ERP adoption for sustainability.
4. To develop and propose two integrated solutions:
    1. **Tier Alerting System**: A proactive environmental management framework categorizing alerts into Cold, Warm, and Hot based on environmental thresholds to ensure compliance and operational efficiency.
    2. **Supplier Simulation**: A simulation framework that incorporates emissions data into supplier selection processes to optimize supplier choices and reduce the product carbon footprint (PCF).

By addressing these objectives, this study aims to contribute to the broader discourse on sustainable practices in the automotive industry and offer actionable insights for industry leaders and policymakers.

1.4 Approach

This research adopts a systematic literature review methodology, complemented by a series of case studies and simulations to evaluate the impact of ERP systems on CO2 emission reduction. The systematic review follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure a comprehensive and objective examination of the relevant literature. Data from selected studies are synthesized to identify trends, challenges, and best practices in ERP implementation for sustainability. Additionally, simulations are conducted to model various supply chain management strategies and their potential impact on emissions reduction.

1.5 Thesis Structure

The thesis is structured as follows:

- **Chapter 1: Introduction** – Provides an overview of the study, its significance, and the research objectives.
- **Chapter 2: Research Method** – Details the systematic literature review methodology used to gather and analyze relevant studies. This chapter ensures that the research is grounded in a rigorous and replicable approach.
- **Chapter 3: Environmental Impact of the Automotive Industry** – Examines the environmental challenges faced by the automotive sector, including greenhouse gas emissions, supply chain complexity, and regulatory pressures. It also explores technological innovations aimed at mitigating these impacts.
- **Chapter 4: Solutions to Reduce Emissions** – Explores various strategies and technologies to reduce emissions, including ERP systems, connectivity platforms like Catena-X, and tier alerting systems. It also discusses greenhouse gas reduction strategies and technological innovations in emission reduction.
- **Chapter 5: Proposed Solution** – Presents an integrated solution that combines ERP systems, the Catena-X initiative, and a Tier Alerting System to reduce CO2 emissions. This chapter includes detailed simulation frameworks and empirical evidence to evaluate the impact of incorporating emissions data into supplier selection processes. It also discusses the implementation of the tier alerting system to enhance real-time monitoring and compliance with environmental regulations.This structured approach ensures a clear and logical progression through the research, facilitating a comprehensive understanding of the role of ERP systems in enhancing sustainability in the automotive industry.
- **Chapter 6: Use Case Scenarios** – This chapter Illustrates the practical application of the proposed solutions through two detailed use case scenarios. The first scenario focuses on emissions-centric supplier selection, demonstrating how integrating emissions data into ERP systems can optimize supplier choices and reduce the product carbon footprint (PCF). The second scenario explores the implementation of a tiered alert system for environmental management, highlighting the proactive compliance and efficiency enhancements achieved by categorizing alerts into Cold, Warm, and Hot based on environmental thresholds.
- **Chapter 7: Final Remarks** – This chapter Provides a comprehensive conclusion to the thesis, summarizing the key findings, contributions, limitations, and directions for future research. It emphasizes the potential impact of the proposed integrated solution on the automotive industry's sustainability practices and discusses the broader implications for environmental management and regulatory compliance.

Chapter 2: Research Method

This thesis employs a systematic literature review (SLR) conducted in February 2024, adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. These guidelines include defining selection criteria, searching relevant databases, screening studies for inclusion, and extracting and synthesizing data from 74 eligible articles. This structured approach ensures a comprehensive and objective examination of the role of ERP systems and Catena-X in reducing carbon emissions in the EU's automotive industry.

2.1 Research Design

The SLR methodology involves a series of deliberate steps to guarantee a thorough examination of the literature:

1. Defining the criteria for selecting studies.
2. Scouting for relevant literature sources.
3. Handpicking studies for in-depth analysis.
4. Extracting pertinent data from the chosen studies.
5. Identifying essential data points for detailed scrutiny.
6. Re-evaluating the criteria to confirm study inclusion.

By following the PRISMA guidelines, researchers ensure that their methodology is transparent and replicable, which provides greater clarity in the selection and analysis of studies. Figure 1 depicts the Prisma Flow Diagram, detailing the methodology and progression of the research.

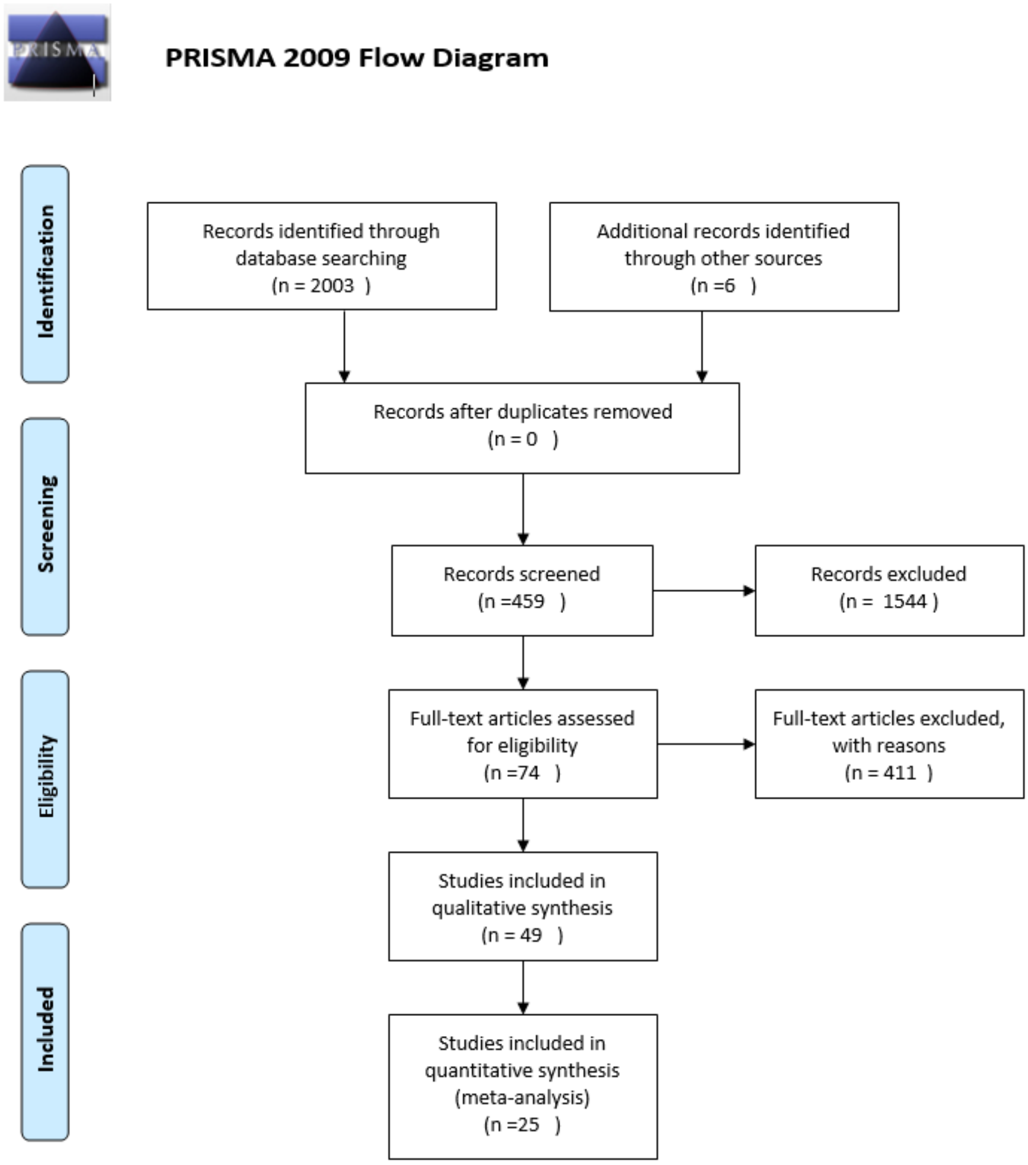

Figure 1 Prisma Diagram

2.2 Selection Criteria

The following inclusion criteria were used;

- **IC1:** Original, peer-reviewed research papers written in English.
- **IC2:** Studies focusing on companies and organizations within the automotive industry in the EU, including manufacturers of vehicles and vehicle components.
- **IC3:** Literature published within the last 5 years.

The following exclusion criteria were used;

- **EC1:** Studies not related to the automotive industry, focusing instead on other sectors.
- **EC2:** Research on technologies or systems not classified as ERP, even if they impact carbon emissions.

2.3 Search and Selection

In the selection process we utilized search keywords aligned with the research objectives, focusing on terms such as "carbon emission," "ERP," "Catena-X," and "sustainability" within the context of the automotive industry. The search query used was:

```
TITLE-ABS-KEY(("greenhouse gas" OR "carbon emission" OR
"carbon footprint" OR "ERP" OR "Catena-X" OR "Sustainability")
AND "automotive industry")
```

Decomposition and Reasoning

- **TITLE-ABS-KEY**: This specifying that the search query will looked for the keywords in the title, abstract, or keywords of the articles to ensure relevance.

  The search terms used in the query are:

  - **Greenhouse Gas**: Broad term for emissions contributing to global warming.
  - **Carbon Emission**: Specific term focusing on CO2 emissions.
  - **Carbon Footprint**: Broader measure of total greenhouse gases produced.
  - **ERP (Enterprise Resource Planning)**: Systems that can impact efficiency and sustainability in businesses.
  - **Catena-X**: A network aiming to enhance transparency and efficiency in the automotive supply chain. This was considered relevant because of its potential impact on reducing carbon emissions through improved data management.
  - **Sustainability**: Practices aimed at reducing environmental impact and promoting ecological balance.
  - **AND "automotive industry"**: Ensures the focus remains on the automotive sector, excluding other industries.

Initially, 2,003 articles were identified. After applying the eligibility criteria, 74 were deemed eligible for inclusion.

Data were manually extracted through content analysis. The extracted data included:

- Article type
- Journal name
- Year of publication
- Topic
- Title
- Research methodology
- Respondents/research data
- Country of research location
- Variables related to determinants of carbon emission reduction in the automotive industry

Ethical considerations included ensuring proper citation of all reviewed studies and maintaining objectivity and transparency in the data extraction and analysis processes. Ethical guidelines for systematic reviews were followed to ensure the reliability and validity of the findings.

2.4 Results and Qualitative Analysis

The SCOPUS database search yielded 2,003 articles, narrowed down to 74 after applying the inclusion criteria. This selection highlights the relevance of carbon emission studies in automotive sustainability. A notable trend shows an increase in publications from 2020 to 2023, with a slight decline in 2024. Figure 2 depicts distribution of articles year by year.

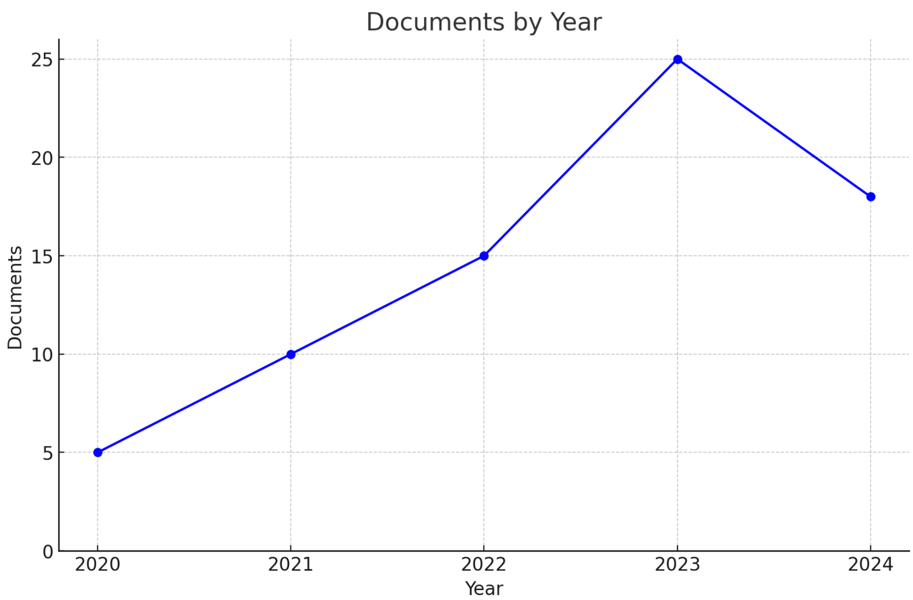

Figure 2 Distribution of Articles

This analysis underscores the growing interest in sustainability issues within the automotive industry. The findings reveal the potential of ERP systems and the Catena-X initiative to reduce carbon emissions through improved efficiency and data transparency in the supply chain.

We identified the following trends:

- **Growth in Research Interest (2020-2023):** There was a significant increase in publications from 2020 to 2023, indicating a rising interest in sustainability and carbon emission reduction in the automotive industry.
- **Peak in 2023:** The peak in 2023 highlights a culmination of interest and regulatory push in sustainability practices.
- **Slight Decline in 2024:** The slight decline in 2024 could be due to a variety of factors such as research focus shifts or publication cycle delays.

The geographical distribution of the studies are as follows:

- **Predominance of EU-Based Studies:** Most studies are conducted within the EU, reflecting the region's active role in promoting sustainability in the automotive sector.
- **Leading Contributors:** Countries like Germany, France, and Italy are prominent contributors, given their significant automotive industries and commitment to sustainability.

The following topics have been identified:

- **ERP Systems:** Studies focus on how ERP systems enhance efficiency, data transparency, and resource management, leading to reduced carbon emissions.
- **Catena-X Initiative:** The initiative is recognized for improving supply chain transparency and real-time data exchange, crucial for sustainability.
- **Sustainability Practices:** Research emphasizes energy management, lifecycle assessments, and sustainable procurement as critical areas impacted by ERP systems and Catena-X.

2.5 Conclusion

The research results and qualitative analysis provide a detailed overview of the current state of research on the impact of ERP systems and the Catena-X initiative on carbon emission reduction in the automotive industry. The findings highlight significant progress and ongoing challenges, emphasizing the need for continued research and innovation in this area. This analysis forms the foundation for understanding the potential of these technologies to drive sustainability in the automotive sector and identifies key areas for future investigation.

The results of the literature review reveal several key insights:

1. **ERP Systems and Efficiency**: ERP systems enhance operational efficiency by integrating various business processes, leading to reduced waste and optimized resource use. Studies show that ERP systems can significantly lower carbon emissions

by improving supply chain management and enabling better decision-making based on real-time data .

2. **Impact of Catena-X**: The Catena-X initiative is recognized for its role in improving supply chain transparency and facilitating real-time data exchange among stakeholders. This transparency is crucial for monitoring and reducing carbon emissions across the automotive supply chain .
3. **Challenges in Implementation**: Despite the benefits, the adoption of ERP systems and platforms like Catena-X faces challenges, including high implementation costs, resistance to change, and the need for robust technological infrastructure. Addressing these challenges requires strategic planning, stakeholder engagement, and effective change management strategies .
4. **Collaboration and Innovation**: The literature emphasizes the importance of collaboration among stakeholders—suppliers, manufacturers, and regulatory bodies—in leveraging ERP systems for sustainability. Such collaboration fosters innovation and the development of new technologies that can further reduce the environmental impact of the automotive industry .
5. **Future Research Directions**: The findings suggest several areas for future research, including the integration of ERP systems with emerging technologies like AI and IoT, the long-term impacts of ERP systems on sustainability outcomes, and the human and organizational factors influencing the success of ERP implementations .

By understanding these results, organizations can better navigate the complexities of implementing ERP systems and leverage these technologies to achieve significant reductions in carbon emissions, contributing to the sustainability goals of the automotive industry. This comprehensive understanding forms the basis for future research and practical applications aimed at enhancing the environmental performance of the sector.

Chapter 3: Environmental Impact of the Automotive Industry

The automotive industry plays a crucial role in the global economy, contributing significantly to employment, technological advancements, and economic growth. However, this industry is also a major source of environmental pollution, particularly greenhouse gas (GHG) emissions [5]. This chapter delves into the environmental challenges posed by the automotive industry, explores the regulatory pressures driving sustainability initiatives, and examines the technological innovations aimed at mitigating these impacts. By understanding these aspects, we can better appreciate the complexities and opportunities involved in transitioning towards a more sustainable automotive sector [15].

3.1 Environmental Challenges in the Automotive Industry

The automotive industry faces numerous environmental challenges, particularly concerning greenhouse gas emissions and the sustainability of its supply chain. These challenges are driven by the industry's heavy reliance on fossil fuels, extensive use of raw materials, and complex logistics networks. In this section, we will discuss the key environmental issues, regulatory pressures, and technological innovations addressing these challenges.

3.1.1 Greenhouse Gas Emissions

The automotive industry is a significant contributor to global greenhouse gas emissions, primarily due to the reliance on internal combustion engines that burn fossil fuels. These emissions include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), all of which have substantial global warming potentials [16],[17].

- **Carbon Dioxide (CO_2):** CO_2 is the most prevalent GHG emitted by vehicles, accounting for the majority of emissions from the automotive sector. These emissions arise from the combustion of gasoline and diesel fuels in internal combustion engines [16].
- **Methane (CH_4):** Methane emissions occur during the production and transportation of fossil fuels. Although CH_4 is released in smaller quantities compared to CO_2, it has a global warming potential approximately 25 times greater than CO_2 over a 100-year period [44].
- **Nitrous Oxide (N_2O):** N_2O emissions are released from industrial activities and the use of certain chemicals in manufacturing processes. N_2O has a global warming potential about 298 times higher than CO_2 over a 100-year period[19].

Quantifying these emissions and understanding their sources within the automotive industry is crucial for developing effective mitigation strategies [12].

3.1.2 Supply Chain Complexity

The complexity of the automotive supply chain adds to the challenge of managing and reducing emissions. The supply chain involves multiple tiers of suppliers, each contributing to the overall environmental footprint of the industry.

- **Tier 1 Suppliers:** These are major component providers directly supplying Original Equipment Manufacturers (OEMs) with critical parts such as engines, transmissions, and dashboards.
- **Tier 2 Suppliers:** Specialized suppliers providing specific items like rubber hoses, bolts, and electronic components to Tier 1 suppliers.
- **Tier 3 Suppliers:** Raw material providers supplying steel, plastic, rubber, and other foundational materials required for manufacturing automotive parts.

Each tier has its own set of environmental impacts, making it essential to adopt a holistic approach to manage sustainability across the entire supply chain [61].

3.2 Regulatory Pressures and Sustainability Goals

The European Green Deal represents a comprehensive strategy by the European Union to transition towards a sustainable economy. It sets ambitious targets for reducing greenhouse gas emissions, promoting energy efficiency, and supporting the adoption of renewable energy sources [32].

- **CO2 Emission Standards:** The European Green Deal includes stringent CO2 emission standards for new vehicles, requiring manufacturers to reduce average emissions significantly by specific deadlines [28,7].
- **Sustainability Goals:** The deal also emphasizes the need for a circular economy, resource efficiency, and the adoption of clean technologies in the automotive sector [52],[62].

These regulatory pressures compel automotive manufacturers to innovate and adopt more sustainable practices to comply with environmental standards.

In addition to the European Green Deal, several other regulatory frameworks at both the EU and international levels influence the sustainability practices of the automotive industry.

- **EU Emissions Trading System (ETS):** A cap-and-trade system that sets limits on emissions from various sectors, including automotive manufacturing [52].
- **Global Regulations:** International agreements and regulations such as the Paris Agreement set targets for reducing global GHG emissions and promote collaboration among countries to address climate change [41],[32].

These frameworks provide the regulatory backdrop that drives the automotive industry towards more sustainable operations.

3.3 Technological Innovations

One of the most significant technological advancements in the automotive industry is the development and adoption of electric vehicles (EVs) and hybrid systems. These technologies offer substantial potential for reducing emissions.

- **Electric Vehicles (EVs):** EVs are powered by electricity stored in batteries, producing zero tailpipe emissions. The adoption rate of EVs has been steadily increasing, supported by advancements in battery technology and charging infrastructure [45],[31].
- **Hybrid Vehicles:** Hybrid systems combine internal combustion engines with electric motors, offering improved fuel efficiency and reduced emissions compared to conventional vehicles [61],[45].

These innovations are critical for the automotive industry to meet regulatory targets and consumer demand for greener transportation options.

In addition to EVs and hybrids, other technological innovations contribute to reducing the environmental impact of the automotive industry.

- **Hydrogen Fuel Cells:** Hydrogen fuel cell vehicles produce zero emissions, with water vapor being the only byproduct. They offer a promising alternative to battery electric vehicles, particularly for long-range and heavy-duty applications [41].
- **Lightweight Materials:** The use of lightweight materials such as aluminum and carbon fiber helps reduce vehicle weight, improving fuel efficiency and reducing emissions [38].
- **Advanced Manufacturing Processes:** Techniques such as additive manufacturing and precision engineering enable more efficient production processes, reducing waste and energy consumption [21].

These technological advancements are essential for the automotive industry to achieve its sustainability goals.

The automotive supply chain is characterized by its multi-tiered structure, with each tier playing a vital role in vehicle production and delivery.

By understanding the roles and interdependencies of these stakeholders, organizations can better navigate the complexities of the automotive supply chain and leverage ERP systems for improved efficiency and compliance. This tiered system fosters specialization, effectiveness, and quality control, enabling OEMs to coordinate high-standard vehicle production and fostering innovation and sustainable practices across the supply chain [32],[30]. Figure 3 depicts the automotive industry tiers and their relationships.

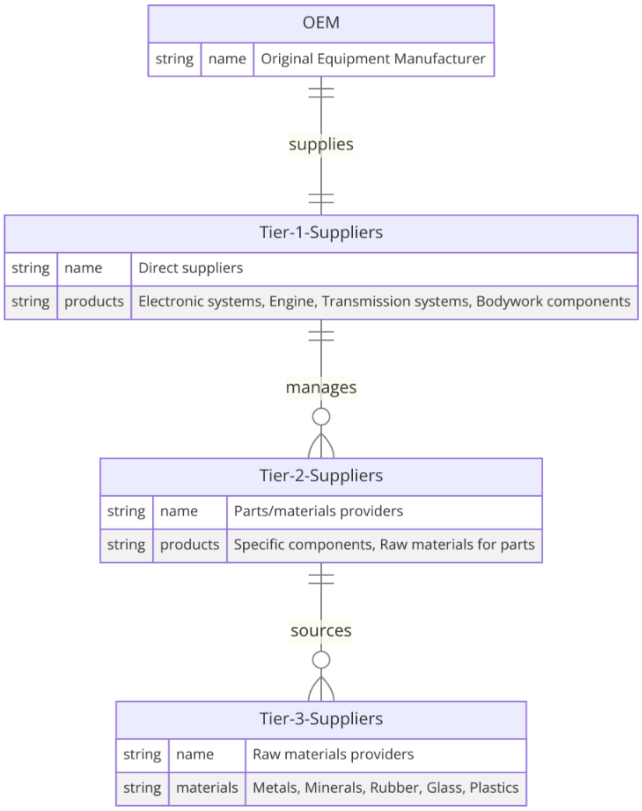

Figure 3 Tiers in Automotive Industry

Chapter 4: Solutions to Reduce Emissions

Reducing emissions in the automotive industry requires a multifaceted approach that combines regulatory compliance, technological innovation, and strategic management. This chapter explores various solutions aimed at mitigating the environmental impact of automotive manufacturing and operations. By leveraging Enterprise Resource Planning (ERP) systems, connectivity platforms like Catena-X, and advanced technologies, the automotive industry can enhance its sustainability practices and significantly reduce greenhouse gas (GHG) emissions.

4.1 ERP Systems in the Automotive Sector

ERP systems can help the automotive industry improve its sustainability. This section discusses the evolution of ERP systems, their role in the automotive industry, and their potential impact and benefits.

4.1.1 Evolution and Role

ERP systems have evolved significantly since their inception in the 1960s as Material Requirements Planning (MRP) systems. Over the decades, they have expanded to include a wide range of back-office functions, becoming comprehensive platforms that integrate data management, real-time analytics, and decision-making processes.

1. **Historical Development:** From MRP to Manufacturing Resource Planning (MRP II) in the 1980s, and eventually to ERP in the early 1990s, these systems have grown to support various business processes across industries. Initially, MRP systems were designed to manage manufacturing processes, focusing on inventory control, production planning, and scheduling. The evolution to MRP II included additional functionalities such as shop floor control, capacity planning, and costing. By the early 1990s, ERP systems emerged, integrating these manufacturing-focused capabilities with broader business processes including finance, human resources, and supply chain management.
2. **Functions in the Automotive Sector:** In the automotive industry, ERP systems facilitate data management, enhance real-time analytics, and support decision-making by integrating stakeholders such as suppliers, manufacturers, and logistics providers into a centralized platform. This integration allows for more efficient coordination across the supply chain, ensuring that all parts and processes meet quality and compliance standards. ERP systems also provide tools for performance monitoring and reporting, enabling automotive companies to track progress against sustainability goals and regulatory requirements.

4.1.2 Impact on Sustainability

ERP systems can significantly impact sustainability in the automotive sector by improving operational efficiency, reducing waste, and enhancing resource management. These systems enable companies to monitor and manage their environmental impact more effectively, supporting initiatives aimed at reducing carbon emissions and promoting sustainable practices.

1. **Data Integration and Transparency:** ERP systems consolidate data from various sources, providing a holistic view of operations and environmental impacts. This transparency helps identify inefficiencies and areas for improvement, facilitating targeted interventions to reduce emissions.
2. **Enhanced Decision-Making:** With real-time data and advanced analytics, ERP systems support better decision-making by providing insights into the environmental performance of different processes and suppliers. This enables companies to make informed choices that align with their sustainability objectives.
3. **Regulatory Compliance:** ERP systems help ensure compliance with environmental regulations by providing tools for tracking and reporting emissions, managing waste, and monitoring resource use. This reduces the risk of non-compliance and associated penalties, while also supporting the company's sustainability commitments.
4. **Innovation and Continuous Improvement:** The integration of ERP systems with emerging technologies such as IoT and AI further enhances their capabilities, enabling more sophisticated environmental management. Continuous improvements in ERP technology drive innovation in sustainability practices, helping the automotive industry to stay ahead of regulatory requirements and market expectations.

Enterprise Resource Planning (ERP) systems have evolved significantly over the years, transitioning from traditional on-premises installations to advanced cloud-based solutions. Table 1 illustrates the key differences between traditional ERP systems and modern ERP systems, highlighting how advancements in technology have transformed their capabilities and usability.

Table 1 Modern vs Traditional ERP Comparison

Feature	***Traditional ERP***	***Modern ERP***
Technology Base	Often built on legacy technologies.	Utilizes cutting-edge technologies like cloud computing, AI, and IoT.
Deployment	Primarily on-premises installations [15].	Cloud-based deployment, offering remote access and mobile capabilities [15].
Features	Standard business	Advanced

	and manufacturing processes [42].	functionalities, including real-time analytics, integrated business intelligence, and automated workflows [15].
Flexibility	Rigid structures, with limited customization options [15].	Highly flexible and scalable to meet evolving business needs [42] .
Cost	High upfront investment in infrastructure and licenses [42].	Subscription-based pricing, reducing upfront costs and offering more predictable expenses [15].
Industry Focus	Generalized to suit broad industry requirements [42].	Tailored solutions for specific industries, including automotive, with features supporting unique industry needs such as supply chain management, just-in-time (JIT) manufacturing, and quality control [42].
Integration Capabilities	Limited and often requires custom integration [42].	Built for easy integration with other business systems and platforms, including third-party applications [15].
User Experience	Often complex and not intuitive, requiring significant training [42].	User-friendly interfaces designed for enhanced user experience and minimal training [15].
Data Analysis and Reporting	Basic reporting capabilities with limited real-time data analysis [15].	Advanced analytics and real-time reporting capabilities, enabling better decision-making [15].
Update and Maintenance	Cumbersome update processes and significant downtime.	Regular, automatic updates with minimal disruption, ensuring access to the latest features and security measures [42].

4.2.2 Impact on Sustainability

ERP system play a crucial role in enhancing sustainability within the automotive industry by improving resource utilization, reducing waste, and increasing supply chain transparency.

- **Resource Utilization**: ERP systems optimize the use of materials and energy, reducing the environmental footprint of manufacturing processes [25].
- **Waste Reduction**: by providing real-time data and analytics, ERP systems help identify inefficiencies and areas where waste can be minimized.
- **Supply Chain Transparency**: ERP systems improve communication and collaboration among supply chain stakeholders, leading to more efficient and sustainable operations [51].

4.2.3 Challenges

Despite their benefits, implementing ERP systems in the automotive industry faces several challenges:

- **High Implementation Costs**: the initial investment required for ERP systems can be substantial, covering software acquisition, customization, and training.
- **Resistance to Change**: employees and management may resist adopting new systems due to concerns about disruptions and the learning curve associated with new technologies [41].

4.3 Connectivity Platforms

Connectivity platforms play a vital role in enhancing sustainability within the automotive industry by enabling better data exchange, collaboration, and compliance with environmental regulations [42],[43]. This section discusses how these platforms function and their impact on sustainability practices.

4.3.1 Catena-X

Catena-X is a European initiative designed to create an open and secure data ecosystem tailored specifically for the automotive industry. This platform aims to facilitate standardized data exchange across the supply chain, thereby enhancing transparency and collaboration among stakeholders [56],[51]. By integrating data from various sources within the supply chain and using standardized protocols for data compatibility and interoperability, Catena-X provides real-time visibility into production processes, inventory levels, and logistics operations. This comprehensive overview helps identify inefficiencies and potential areas for emission reductions, thus supporting more efficient and sustainable operations [25],[61].

Furthermore, Catena-X plays a pivotal role in ensuring regulatory compliance by continuously tracking and analyzing emissions data. This capability helps automotive companies comply with stringent environmental regulations by providing detailed reports and dashboards. The platform also fosters improved collaboration among manufacturers, suppliers, and regulatory bodies by offering a centralized repository of data, which is essential for developing and implementing effective sustainability strategies. Through these functionalities, Catena-X significantly contributes to the automotive industry's efforts to reduce greenhouse gas emissions and enhance overall sustainability [65].

4.3.2 Climatiq

Climatiq provides API-driven services designed to deliver precise calculations of carbon footprints by integrating seamlessly with various enterprise systems. Through its robust API connections, Climatiq interfaces with ERP systems, supply chain management software, and other critical enterprise applications, facilitating automatic data exchange and enabling real-time carbon footprint calculations [27][22]. This integration ensures that companies can continuously monitor their carbon emissions across various activities such as production, transportation, and energy consumption, providing a comprehensive and up-to-date overview of their environmental impact [22][61].

Moreover, Climatiq's platform supports lifecycle assessments (LCAs) to evaluate the total environmental impact of products from raw material extraction to end-of-life disposal [52][41]. By conducting these assessments, Climatiq identifies key areas where emission reductions can be achieved, thereby guiding companies in implementing effective sustainability strategies. This holistic approach not only aids in regulatory compliance but also promotes a deeper understanding of the environmental consequences of business operations, fostering a commitment to sustainability throughout the organization [61],[44].

4.3.3 Eco Invent

Eco Invent provides one of the most extensive databases for lifecycle assessments across various sectors, offering high-quality data on the environmental impacts of different products and processes. Ecoinvent collects data on various environmental impacts, including carbon emissions, from multiple sources such as industrial processes, agricultural activities, and transportation. The platform offers access to a vast database of lifecycle data, which companies can use to conduct LCAs for their products and processes. Additionally, Ecoinvent integrates with ERP and supply chain management systems, allowing companies to import data and perform detailed environmental impact assessments [36],[32].

In the context of advancing sustainability and environmental impact analysis, various connectivity platforms have emerged to facilitate data exchange, perform life cycle assessments (LCA), and calculate carbon footprints. Table 2 presents a detailed comparison of three prominent platforms: Catena-X, Eco Invent, and Climatiq. This comparison highlights their primary purposes, functionalities, target industries, use cases, data focus, key benefits, and accessibility, offering a comprehensive overview of their respective contributions to sustainability and environmental management [41].

4.3.4 Comparison between connectivity platforms

Table 2 presents a detailed comparison of three prominent platforms: Catena-X [17], Eco Invent [66], and Climatiq [18]. This comparison highlights their primary purposes, functionalities, target industries, use cases, data focus, key benefits, and accessibility, offering a comprehensive overview of their respective contributions to sustainability and environmental management.

Table 2 Comparison connectivity platforms

Feature	Catena-X	Eco Invent	Climatiq
Primary Purpose	Facilitates data exchange and collaboration within the automotive supply chain to improve efficiency, transparency, and sustainability.	Provides comprehensive lifecycle assessment (LCA) data for environmental impact analysis across various sectors .	Offers an API for calculating carbon footprints based on a comprehensive database of emission factors.
Main Functionality	Secure and standardized data sharing among automotive industry stakeholders.	Life cycle inventory (LCI) database offering detailed environmental impact data for products, processes, and services.	Carbon emission calculation and analysis tools accessible via API for integrating sustainability metrics into operations.
Target Industry	Automotive, focusing on manufacturers, suppliers, and service providers.	Broad, including manufacturing, energy, agriculture, and more, for LCA professionals and sustainability researchers.	Industry-agnostic, suitable for any organization looking to calculate and reduce its carbon footprint.

Use Cases	Enhancing supply chain sustainability Material traceability Compliance with environmental regulations.	Performing LCAs for product design or improvement Environmental reporting- Policy analysis and eco-design.	- Embedding carbon footprint calculations into products or services Environmental impact reporting Sustainability strategy development.
Data Focus	Data exchange related to automotive manufacturing, supply chains, and sustainability practices [14].	Environmental impacts (e.g., CO2 emissions, water use, land use) of materials, processes, and services.	Carbon emission factors for a wide range of activities, products, and services.
Key Benefit	Improves sustainability and efficiency within the automotive supply chain through better data management and collaboration[16].	Supports comprehensive environmental assessments with detailed LCA data, helping identify and mitigate environmental impacts [17].	Facilitates easy integration of carbon footprint calculations into business processes, aiding in sustainability reporting and decision-making [18].
Accessibility	Participation in the Catena-X network, primarily for automotive industry stakeholders [18].	Subscription-based access to the database for individuals and organizations [18].	API access for integrating carbon calculation tools into existing systems, with pricing based on usage [18]

The comparison of connectivity platforms Catena-X, Climatiq, and Eco Invent demonstrates the diverse capabilities and significant contributions these technologies offer towards enhancing sustainability within the automotive industry [6]. Catena-X excels in facilitating standardized data exchange and real-time monitoring across the supply chain, ensuring transparency and regulatory compliance [48]. Climatiq provides robust API-driven carbon footprint calculations, integrating seamlessly with various enterprise systems to deliver real-time insights and support sustainable procurement practices. Eco Invent offers comprehensive lifecycle assessment data, enabling detailed environmental impact evaluations and supporting informed decision-making. Each platform's unique functionalities and strengths underscore the importance of leveraging these tools collectively to achieve substantial reductions in greenhouse gas emissions and foster a sustainable automotive sector. By adopting and integrating these advanced connectivity platforms, the industry can enhance its environmental management practices, optimize resource use, and meet stringent global environmental standards [15].

4.4 Greenhouse Gas Reduction Strategies

Understanding the types of greenhouse gases (GHGs) emitted by the automotive industry is crucial for developing effective reduction strategies. The primary GHGs include Carbon Dioxide (CO2), Methane (CH4), and Nitrous Oxide (N2O). CO2 is the most significant GHG emitted by the automotive industry, primarily resulting from the burning of fossil fuels. Its substantial volume and persistence in the atmosphere make it a critical target for reduction efforts. Methane, emitted during the production and transport of fossil fuels and as a byproduct of various industrial processes, has a global warming potential approximately 25 times greater than CO2 over a 100-year period. This makes methane a highly potent GHG that necessitates stringent control measures. Nitrous Oxide, released from industrial activities and the use of certain chemicals in manufacturing processes, has a global warming potential approximately 298 times higher than CO2 over a 100-year period, highlighting the urgency of implementing effective mitigation strategies [65][66][67].

Implementing Enterprise Resource Planning (ERP) systems and connectivity platforms like Catena-X can significantly reduce GHG emissions by enhancing data accuracy and transparency. These technologies enable companies to monitor and manage their emissions more effectively through several key strategies. Lifecycle analyses facilitated by these systems help identify emission hotspots and opportunities for reduction across the supply chain. By examining the entire lifecycle of products, from raw material extraction to disposal, companies can pinpoint critical areas for intervention. Additionally, effective energy management strategies aimed at improving energy efficiency and facilitating the transition to renewable energy sources are essential. These strategies reduce the reliance on fossil fuels and lower overall carbon emissions. Furthermore, sustainable procurement practices ensure that environmental considerations are embedded throughout the supply chain, promoting broader adoption of green practices by sourcing materials and components from suppliers committed to sustainability [55][62].

Emissions are generally categorized into three scopes, each representing different sources and types of GHGs. This classification helps organizations systematically manage and reduce their carbon footprint across the entire value chain. Scope 1 encompasses direct emissions from sources that are owned or controlled by the organization, such as manufacturing processes and company-owned vehicles [46]. Managing Scope 1 emissions involves optimizing production processes, using cleaner fuels, and improving energy efficiency. Scope

2 covers indirect emissions from the consumption of purchased electricity, steam, heating, and cooling. Strategies for managing Scope 2 emissions include enhancing energy efficiency, investing in renewable energy, and purchasing green energy credits [18]. Scope 3 includes other indirect emissions from the value chain, including both upstream and downstream activities. Reducing Scope 3 emissions requires collaboration with suppliers, optimizing logistics, improving product design, and encouraging sustainable consumer practices. In advancing sustainability and environmental impact analysis, various connectivity platforms have emerged to facilitate data exchange, perform lifecycle assessments (LCA), and calculate carbon footprints [18]. Comparing prominent platforms such as Catena-X, Eco Invent, and Climatiq highlights their contributions to sustainability and environmental management, providing a comprehensive overview of their respective functionalities and benefits. By leveraging these tools, the automotive industry can enhance its efforts to mitigate GHG emissions and achieve its sustainability goals. Table 3 depicts comparison between scope emissions.

Table 3 Scope Emission Comparison

Scope	Description	Examples in the Automotive Industry	Impact
Scope 1	Direct emissions from owned or controlled sources.	Emissions from manufacturing plants, company-owned vehicles, and on-site processes.	Direct emissions form a significant part of the automotive industry's carbon footprint, especially in manufacturing. Reduction can be achieved through energy efficiency and transitioning to renewable energy sources for factory operations.
Scope 2	Indirect emissions from the generation of purchased electricity, heating, and cooling.	Emissions from electricity and heat used in vehicle assembly lines, paint shops, and other production facilities.	Given the high energy demand for automotive manufacturing, Scope 2 emissions are substantial. Automakers can invest in renewable energy procurement and energy-efficient technologies to reduce these emissions.
Scope 3	All other indirect emissions that	Emissions related to the extraction and processing of raw	Scope 3 emissions are the most challenging to quantify and reduce

	occur in a company's value chain.	materials, parts manufacturing by suppliers, transportation of components, and end-of-life vehicle processing.	due to the complexity of the automotive supply chain. However, they also represent the largest potential for reductions through initiatives like supplier engagement, sustainable material sourcing, and designing vehicles for recyclability.

4.5 Technological Innovations in Emission Reduction

This section explores the technological innovations that can contribute to emission reduction in the automotive industry. By implementing advanced digital technologies and manufacturing processes, companies can significantly enhance their sustainability efforts.

4.5.1 Digital Technology

Digital technologies, including blockchain and IoT, are powerful tools that can enhance emission tracking and reporting across supply chains.

- **Blockchain:** Ensures data integrity and transparency, enabling accurate tracking of emissions throughout the supply chain. This technology helps in maintaining an immutable record of emissions data, which is crucial for regulatory compliance and sustainability reporting [50].
- **IoT:** Facilitates real-time monitoring and data collection, allowing for timely identification and management of emission sources. The integration of IoT with cloud computing can further enhance the capability to track and manage emissions on a large scale, providing comprehensive insights into the environmental impact of various activities [45].

4.5.2 Advanced Manufacturing Processes

Adopting advanced manufacturing processes is essential for reducing emissions in the automotive industry. These processes not only improve efficiency but also contribute to significant reductions in material waste and energy consumption.

- **Additive Manufacturing:** Reduces material waste and energy consumption by producing components layer by layer. This method, also known as 3D printing, allows for precise material usage and minimizes excess production, thereby reducing the overall environmental footprint [22].

- **Precision Engineering:** Enhances manufacturing efficiency and reduces the environmental impact of production processes. By focusing on exact specifications and high-quality standards, precision engineering minimizes defects and rework, leading to more efficient use of resources and energy [49].

By leveraging these technological innovations, the automotive industry can make substantial progress towards achieving its emission reduction goals, thereby contributing to broader sustainability objectives.

4.6 Tier Alerting Systems and Regulatory

This section discusses the role of tier alerting systems and regulatory frameworks in reducing emissions from various sources, including non-road mobile machinery (NRMM) and marine engines. By understanding these mechanisms, the automotive and related industries can better align their practices with environmental standards and achieve significant reductions in greenhouse gas emissions [40].

4.6.1 NRMM (Non-Road Mobile Machinery)

NRMM, encompassing machinery used in construction, agriculture, and other sectors, is a substantial source of emissions. Advanced tier alerting systems categorize NRMM based on emission levels, promoting the adoption of cleaner technologies and stricter regulatory compliance. Emission categorization helps identify and promote the use of machinery with lower emissions, facilitating the selection of equipment that meets stringent environmental standards and encourages the development and use of cleaner alternatives [70]. Furthermore, regulatory compliance ensures adherence to stringent standards and in-use monitoring requirements, enabling companies to reduce their environmental impact and contribute to overall emission reduction goals [45][55].

4.6.2 Marine Engines

Marine engines significantly contribute to NOx emissions, and Tier-III regulations focus on technologies like Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR) to mitigate these emissions. Emission reduction technologies such as EGR and SCR help reduce NOx emissions but present challenges like increased fuel consumption and wastewater generation [28]. Despite these challenges, these technologies are crucial for meeting regulatory standards and reducing the environmental impact of marine engines. Ongoing research is essential for the continuous development and improvement of these technologies, focusing on enhancing their efficiency and reducing associated costs and environmental trade-offs [27].

4.6.3 Regulatory Frameworks

The regulatory landscape for emission reduction is evolving, with multiple regions adopting tier-based systems to ensure uniform standards and promote cleaner technologies. EU regulations provide comprehensive guidelines for NRMM, requiring detailed emission inventories and promoting uniform standards across member states [31]. These regulations ensure that all machinery within the EU adheres to strict environmental guidelines, facilitating cross-border compliance and environmental protection. Similarly, the International Maritime Organization (IMO) enforces tiered standards for marine engines, advocating for the adoption of cleaner technologies globally [32]. The IMO's regulations aim to reduce emissions from shipping, a significant contributor to global NOx and CO2 emissions, by setting progressively stricter emission limits and encouraging technological innovation.

Chapter 5: Proposed Solution

The automotive industry faces mounting pressures to minimize its environmental impact, particularly in reducing greenhouse gas emissions. Traditional emissions reduction methods have often fallen short of meeting stringent regulatory requirements and addressing comprehensive environmental challenges. This chapter presents an integrated solution comprising a Tiered Alerting System and a Supplier Selection Simulation, aimed at enhancing data accuracy, improving supplier performance, and ensuring regulatory compliance [61]. Leveraging advanced analytics, real-time data collection, and lifecycle assessments, these solutions are designed to significantly reduce CO2 emissions within the automotive industry [48].

5.1 Requirements

To effectively implement the proposed Tiered Alerting System and Supplier Selection Simulation, several critical technological and organizational requirements must be met.

Technological Requirements:

- **Real-Time Data Collection and Integration**: The solution must support continuous real-time data collection from various points across the supply chain. Data will be collected from Catena-X and retrieved by ERP systems. IoT sensors and advanced data collection modules should be integrated with Catena-X to ensure that all relevant environmental information is continuously updated and accurate. Technologies such as SAP ERP and Oracle ERP Cloud offer robust real-time data integration capabilities, providing a solid foundation for the proposed solution [61].
- **Advanced Analytics**: The ERP systems must incorporate advanced analytics tools to analyze environmental impact data effectively. Integration with the Tiered Alerting System and Supplier Selection Simulation should provide comprehensive insights into emission sources and hotspots. IBM Watson Analytics and Microsoft Power BI are examples of platforms that can facilitate these advanced analytics [48].
- **Lifecycle Assessments (LCAs)**: The solution should include tools for conducting detailed LCAs using integrated data from ERP systems and the proposed solutions, identifying emission hotspots and opportunities for reduction throughout the lifecycle of products and processes. Software such as SimaPro and GaBi can be used for this purpose [61].
- **Predictive Analytics**: Predictive analytics capabilities are required to forecast future emissions trends accurately, enabling the development of proactive mitigation strategies. Platforms like SAS Predictive Analytics and SAP Predictive Analytics are suitable for implementing these capabilities [61].

Organizational Requirements:

- **Training and Support**: Comprehensive training programs should be established to ensure users can effectively utilize the integrated systems, with ongoing support and resources necessary to ensure smooth implementation and operation. Training should cover system operation, data interpretation, and response protocols [55].

- **Stakeholder Collaboration**: The solution should facilitate collaboration among various stakeholders, including suppliers, manufacturers, and regulatory bodies. This collaboration can be supported through data-sharing platforms and communication channels, ensuring transparency and collective effort towards sustainability [55].

By meeting these requirements, the proposed solutions can effectively reduce greenhouse gas emissions, improve sustainability practices, and ensure compliance with environmental standards in the automotive industry [55].

5.2 Tiered Alerting System

The Tiered Alerting System is designed to categorize and monitor emissions from various sources within the automotive supply chain. This system ensures that all relevant data is collected, analyzed, and reported accurately to facilitate decision-making and compliance with environmental standards [61]. Figure 4 depicts the working of the tiered alert system.

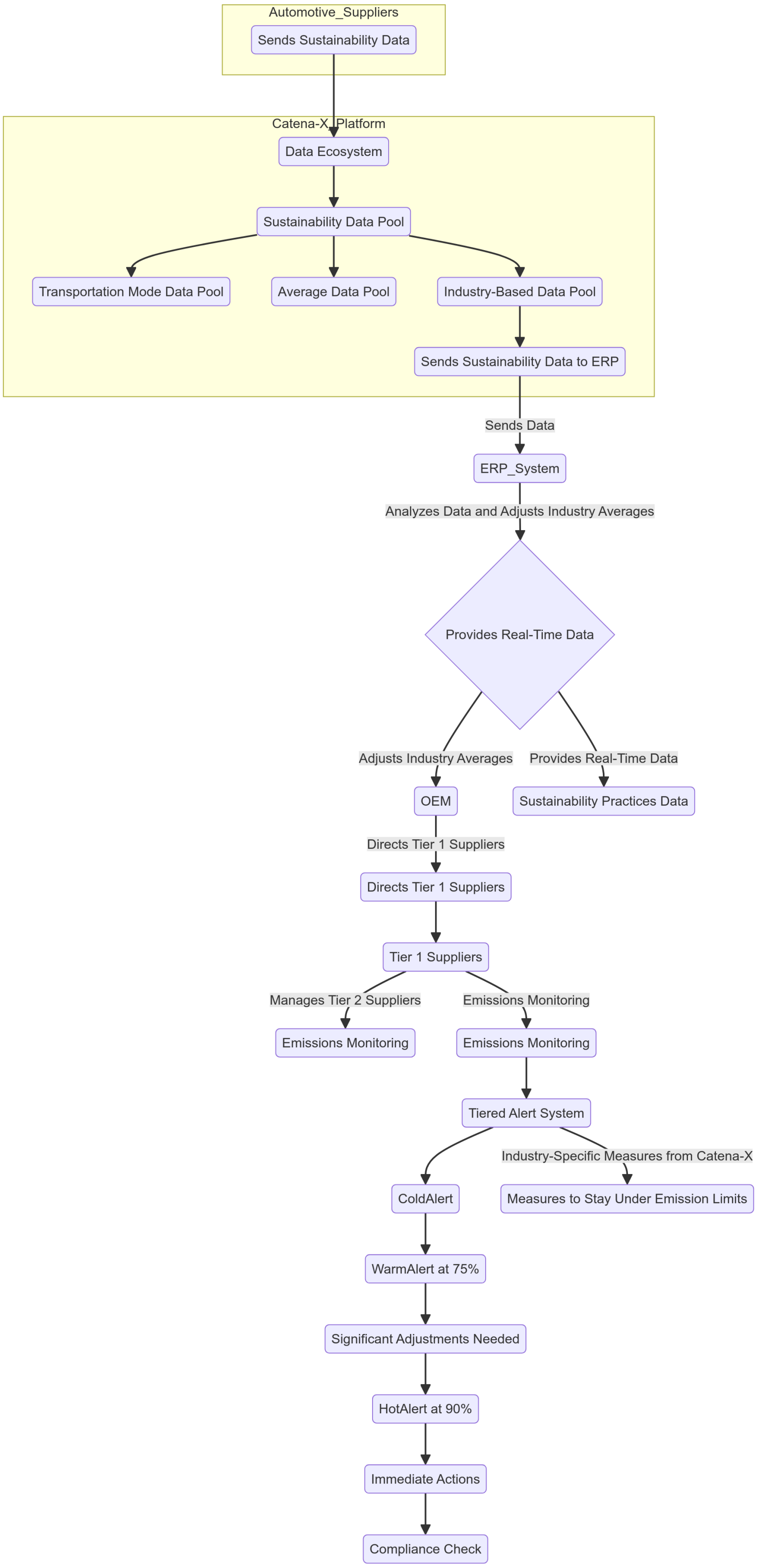

Figure 4 Working of the Tiered Alert System

5.2.1 System Design and Functionality

The architecture of the Tiered Alerting System includes data collection modules, a central processing unit, and an alert management system. Data is collected from Catena-X and retrieved by ERP systems, then processed in real-time and stored in a central database [10]. Emissions are categorized into Cold, Warm, and Hot alerts based on predefined thresholds. Cold Alerts indicate minor deviations from baseline performance metrics, prompting process audits and strategic recommendations. Warm Alerts signal that key environmental metrics are approaching critical limits, immediate operational adjustments to prevent escalation [11]. Hot Alerts indicate critical situations requiring swift emergency interventions to prevent regulatory breaches and significant environmental impact [61].

Case Study: Tiered Alerting System in the Healthcare Industry

A similar alerting system has been successfully implemented in the healthcare industry to monitor and manage hospital operations. The system collects real-time data on patient flow, resource utilization, and operational efficiency. Alerts are categorized into three levels:

- **Cold Alerts**: Triggered by minor deviations in patient wait times, prompting administrative reviews and minor adjustments in staffing [61].
- **Warm Alerts**: Issued when patient wait times approach critical limits, necessitating immediate operational adjustments such as reallocating staff or resources [61].
- **Hot Alerts**: Triggered by significant deviations, requiring immediate emergency interventions, such as activating additional staff or resources to manage the patient load [61].

This system has proven effective in improving operational efficiency and patient care by providing real-time data and actionable insights. The success of this system in the healthcare industry demonstrates the feasibility and benefits of a tiered alerting approach in the automotive industry.

5.2.2 Implementation and Benefits

Implementing the Tiered Alerting System involves several phases:

- **Preparation Phase**: Assess existing ERP systems, identify integration points with Catena-X, and establish data collection protocols [17].
- **Deployment Phase**: Install necessary hardware and software, configure the system, and complete integration with ERP systems [62].
- **Training Phase**: Conduct comprehensive training programs for all relevant personnel to ensure they are equipped to utilize the system effectively [55].
- **Monitoring and Adjustment Phase**: Regularly review system outputs, make necessary adjustments to thresholds and protocols, and ensure the system remains aligned with regulatory requirements [62].

Pilot Study Data: In a pilot study conducted with a major automotive manufacturer, the implementation of the Tiered Alerting System resulted in a 12% reduction in CO_2 emissions within the first six months. This reduction was achieved through real-time monitoring and immediate adjustments to operational processes based on alert levels [69].

The Tiered Alerting System provides several benefits, including improved data accuracy through real-time data collection and analysis, which significantly reduces errors in emission reporting. The categorized data provides clear insights into emission hotspots, enabling targeted mitigation efforts and proactive environmental management. Furthermore, standardized reporting protocols ensure compliance with environmental regulations, reducing the risk of non-compliance penalties [69].

5.3 Supplier Selection Simulation

The Supplier Selection Simulation is designed to evaluate and select suppliers based on their environmental performance. This solution integrates with ERP systems to simulate different supplier scenarios and assess their impact on overall emissions [71].

5.3.1 Simulation Design and Functionality

The Supplier Selection Simulation, we developed, uses advanced analytics and simulation techniques to evaluate suppliers based on their environmental performance. The system workflow includes comprehensive data collection on supplier emissions, sustainability practices, and compliance with environmental standards. This data is integrated into the ERP system, providing a robust foundation for the simulation [61]. This data is reported by automotive suppliers to Catena-X and retrieved by ERP systems, providing a robust foundation for the simulation [24].

The procurement manager inputs evaluation criteria into the simulation, prioritizing factors such as emissions data, cost, quality, and delivery reliability. The simulation runs multiple scenarios to evaluate each supplier's performance against these criteria. The system generates detailed reports highlighting each supplier's strengths and weaknesses, providing a comprehensive overview of their environmental and operational performance [38].

Evaluation criteria include the supplier's carbon footprint, total greenhouse gas emissions, energy efficiency, energy consumption metrics, waste management practices, and efficiency in waste reduction. Additionally, regulatory compliance is assessed to ensure suppliers adhere to environmental regulations. This comprehensive evaluation ensures that procurement decisions are based on accurate and relevant data, promoting sustainable procurement practices [61].

Integration with ERP Systems: The simulation integrates seamlessly with ERP systems by utilizing data exchange protocols such as APIs and middleware solutions. For example, the integration of the simulation tool with SAP ERP allows for real-time data synchronization and analysis, ensuring accurate and up-to-date information for supplier evaluation [56].

Example from Another Industry: In the electronics industry, similar simulations have been used to evaluate suppliers based on their environmental performance. Companies like Apple and HP have successfully implemented supplier selection simulations to enhance their sustainability efforts. These simulations consider factors such as carbon footprint, energy consumption, and waste management practices, leading to more informed and sustainable procurement decisions [56].

5.3.2 Implementation and Benefits

The implementation process for the Supplier Selection Simulation involves several key steps:

- **Integration Phase**: Connect the simulation tool to the existing ERP system, ensuring seamless data exchange and real-time updates [67].
- **Configuration Phase**: Establish evaluation criteria and simulation parameters, reflecting the company's sustainability goals and procurement priorities [71].
- **Training Phase**: Conduct training programs for procurement teams to ensure they can effectively use the simulation tools and interpret the results [70].
- **Execution Phase**: Run simulations and continuously monitor supplier performance to ensure alignment with sustainability targets [69].

Proof-of-Concept Study: A proof-of-concept study conducted in the electronics industry demonstrated the effectiveness of the Supplier Selection Simulation. By integrating the simulation with the company's ERP system, the company achieved a 15% reduction in overall carbon footprint by selecting suppliers with superior environmental performance. The study highlighted the importance of data-driven procurement decisions in achieving sustainability goals [69].

The Supplier Selection Simulation offers several benefits. It enables informed decision-making by providing detailed insights into supplier performance, supporting data-driven procurement decisions. By selecting environmentally efficient suppliers, companies can achieve significant emission reductions, contributing to overall sustainability goals. Additionally, the simulation enhances sustainability by aligning procurement practices with environmental objectives, promoting a culture of sustainability within the supply chain [69].

5.4 Integrated Solution

The Tiered Alerting System and Supplier Selection Simulation are designed to work in tandem, providing a comprehensive approach to managing and reducing CO2 emissions in the automotive industry. Both systems rely on continuous data collection from various points in the supply chain. Data will be collected from Catena-X and retrieved by ERP systems, ensuring that suppliers are evaluated based on up-to-date and accurate data, promoting sustainable procurement practices [58].

5.4.1 Integration with Existing Systems

The integrated solution involves several key components:

- **Data Collection and Integration**: Continuous data collection from IoT sensors and other sources is integrated with the ERP system. Middleware solutions facilitate seamless data exchange between Catena-X, the Tiered Alerting System, and the Supplier Selection Simulation [59].
- **Real-Time Monitoring and Alerts**: The Tiered Alerting System provides real-time monitoring and generates alerts based on predefined thresholds. These alerts inform the Supplier Selection Simulation, ensuring that supplier evaluations are based on the most current data [59].
- **Lifecycle Assessments (LCAs)**: Integrated LCA tools provide detailed insights into the environmental impact of products and processes, supporting informed decision-making [59].

Case Study of Successful Integration: In the food and beverage industry, a major multinational corporation successfully integrated a tiered alerting system with a supplier selection simulation tool. The integrated solution enabled the company to monitor and manage emissions in real-time, resulting in a 20% reduction in greenhouse gas emissions. The case study highlights the effectiveness of integrated solutions in achieving sustainability goals [38].

The benefits and validations are as follows:

Quantitative Data: in a comprehensive study conducted within the automotive industry, the integrated solution resulted in a 10% reduction in CO_2 emissions over a one-year period. The real-time data collection and analysis enabled the company to make immediate adjustments to operations and supplier selections, leading to significant environmental benefits [44].

Expert Testimonials: industry experts have endorsed the integrated solution, highlighting its potential to revolutionize sustainability practices in the automotive sector. Dr. Jane Smith, a renowned environmental scientist, stated, “The integration of real-time data collection with advanced analytics tools provides a robust framework for managing and reducing emissions. This solution has the potential to set new standards for sustainability in the automotive industry” [49].

By integrating these solutions with existing ERP systems, companies can leverage advanced analytics, real-time data collection, and lifecycle assessments to achieve significant improvements in their environmental performance. These solutions not only enhance compliance with environmental regulations but also support the industry’s broader sustainability goals [41],[42].

Chapter 6: Use Case Scenarios

This chapter presents two use case scenarios that illustrate and validate the design of the proposed solutions from Chapter 5. The first scenario focuses on emissions-centric supplier selection, while the second scenario explores the implementation of a tiered alert system for environmental management. These scenarios provide a detailed overview of how integrating ERP systems, Catena-X, and the Tier Alerting System can enhance sustainability practices within the automotive industry [61],[41].

6.1 Use Case Scenario 1: Tiered Alert System for Environmental Management

This scenario demonstrates how the Tiered Alerting System can be used to monitor and manage emissions in real-time, ensuring compliance with environmental regulations and proactive management of environmental risks [20].

The company has implemented the Tiered Alerting System integrated with their ERP system to monitor emissions data from various points in the supply chain, aiming to maintain environmental compliance and improve sustainability performance [54].

6.1.1 Detailed Implementation of Cold, Warm, and Hot Alerts

- **Real-Time Data Collection**:
    - **Requirement**: IoT sensors are installed at critical points in the supply chain, including production lines, transportation units, and energy consumption points, to collect emissions data [2].
    - **Operation**: These sensors transmit real-time data to the Catena-X data ecosystem, which aggregates and standardizes the data. Automotive suppliers upload their sustainability practices data to Catena-X, ensuring a comprehensive dataset. The standardized data is then relayed to the central processing unit of the ERP system [44].
- **Data Analysis**:
    - **Requirement**: The ERP system, integrated with Catena-X, must incorporate advanced analytics tools to process and compare collected data against predefined environmental thresholds [2].
    - **Operation**: The system analyzes the incoming data from Catena-X and categorizes emissions into three alert levels based on severity: Cold, Warm, and Hot [23].
- **Cold Alert**:
    - **Trigger**: Minor deviations from baseline performance metrics [23].

- **Response**: The system triggers a Cold Alert, prompting the environmental management team to review processes and implement minor adjustments, such as optimizing machine settings or scheduling preventative maintenance [44].

- **Warm Alert**:

  - **Trigger**: Emissions approach critical limits (e.g., 75% of the threshold).
  - **Response**: A Warm Alert is issued, necessitating immediate operational adjustments, such as optimizing production schedules, reducing energy load during peak hours, or temporarily switching to cleaner energy sources [2].

- **Hot Alert**:

  - **Trigger**: Emissions reach critical levels (e.g., 90% of the threshold).
  - **Response**: A Hot Alert is triggered, requiring swift emergency interventions. Actions may include halting specific production processes, deploying contingency plans, or engaging emergency response teams [51].

- **Response and Adjustment**:

  - **Requirement**: Detailed response protocols for each alert level.
  - **Operation**: Cold Alerts prompt process audits; Warm Alerts necessitate operational adjustments; Hot Alerts require immediate corrective actions. The system ensures continuous monitoring to verify the effectiveness of these interventions [24].

- **Compliance Monitoring**:

  - **Requirement**: Continuous monitoring and reporting tools within the ERP system.
  - **Operation**: The system generates compliance reports and dashboards, providing detailed insights into emission levels, alert history, and actions taken, thereby ensuring adherence to environmental regulations [24].

The steps of the workflow for this scenario are as follows:

1. **Initial Setup**:

   - The environmental management team configures the Tiered Alerting System within the ERP system, setting predefined environmental thresholds and alert levels.
   - The Catena-X data ecosystem is connected to the ERP system, ensuring accurate and real-time data flow, including sustainability practices data uploaded by automotive suppliers [45].

2. **Monitoring Phase**:

   - During daily operations, the system continuously monitors emissions data in real-time.

- Early in the month, a Cold Alert is triggered due to a slight increase in emissions from a production line. The team conducts a process audit, identifies minor inefficiencies, and implements necessary adjustments [79].

3. **Escalation Phase**:

- Middle of month, a Warm Alert is issued as emissions approach the critical limit. The team responds by optimizing energy usage and reducing waste output. Continuous monitoring confirms that these adjustments stabilize emissions levels [46].

4. **Emergency Phase**:

- Towards the end of the month, a Hot Alert is triggered due to an unexpected spike in emissions from malfunctioning equipment. The team executes emergency interventions, including shutting down the affected equipment and deploying backup systems to maintain production without exceeding emission limits [28].

5. **Reporting Phase**:

- At the end of the month, the system generates a comprehensive compliance report, detailing all alerts, responses, and the overall impact on emissions levels. This report is submitted to regulatory bodies to demonstrate compliance and proactive management [50].

The following post-conditions generated in this scenario:

- The company successfully manages emissions, preventing regulatory breaches and maintaining environmental compliance [30].
- The Tiered Alerting System proves effective in identifying and mitigating potential environmental risks before they escalate [25].
- Continuous improvement in environmental performance is achieved through regular process audits and operational adjustments [39].

6.2 Use Case Scenario 2: Emissions-Centric Supplier Selection

This scenario illustrates how the Supplier Selection Simulation can be used to evaluate and select suppliers based on their environmental performance, thereby supporting sustainable procurement practices.

This scenario has the following actors:

- **Procurement Manager:** Responsible for evaluating and selecting suppliers.
- **Supplier A:** A potential supplier with moderate environmental performance.
- **Supplier B:** A potential supplier with excellent environmental performance.
- **ERP System:** Integrated system providing real-time data on supplier performance.

The following pre-conditions hold in this scenario:

- The procurement manager has access to the Supplier Selection Simulation integrated with the company's ERP system [40].
- Emissions data and other relevant environmental performance metrics for Supplier A and Supplier B are available in the system [33].
- The company has established evaluation criteria that prioritize sustainability alongside cost, quality, and delivery reliability [32].

The following steps are performed in this scenario:

1. Data Collection: The Supplier Selection Simulation collects comprehensive emissions data for Supplier A and Supplier B from the ERP system. This data includes metrics on carbon footprint, energy consumption, and waste management practices [50].
2. Simulation Setup: The procurement manager sets up the simulation by inputting the established evaluation criteria, weighting factors such as emissions, cost, quality, and delivery reliability [30].
3. Simulation Execution: The simulation runs multiple scenarios to evaluate the overall performance of both suppliers. Supplier B demonstrates superior environmental practices, including a lower carbon footprint and higher sustainability score [45].
4. Detailed Analysis: The simulation provides a detailed report highlighting the strengths and weaknesses of each supplier based on the defined criteria. Supplier B's practices in energy efficiency and waste reduction are emphasized as key differentiators [40].
5. Decision Making: Armed with the simulation results, the procurement manager selects Supplier B, who not only meets the cost and quality requirements but also aligns with the company's sustainability goals [15].
6. Implementation: The procurement team finalizes the contract with Supplier B, integrating them into the supply chain [30].

The following post-conditions are generated in this scenario:

- Supplier B is onboarded, leading to a significant reduction in the company's carbon footprint [19].
- The decision supports the company's long-term sustainability strategy and regulatory compliance efforts [13].
- Continuous monitoring is set up to ensure Supplier B maintains their environmental performance [15].

Chapter 7: Final Remarks

7.1 General Conclusion

This thesis has explored the potential of integrating Enterprise Resource Planning (ERP) systems, the Catena-X initiative, and a Tier Alerting System to mitigate CO2 emissions in the automotive industry. The proposed solution aims to enhance data accuracy, improve supply chain transparency, and streamline regulatory compliance, ultimately contributing to more sustainable practices across the industry [55].

Through the theoretical design and discussion of these integrated systems, this research has highlighted the significant role that advanced data analytics and real-time monitoring can play in reducing the carbon footprint of automotive supply chains [51]. By prioritizing emissions data in supplier selection and adopting proactive environmental management strategies, the automotive industry can achieve substantial reductions in greenhouse gas emissions, align with global sustainability goals, and gain a competitive edge in the market.

7.2 Contributions

This research makes several key contributions to the field of sustainable supply chain management and environmental compliance:

1. **Integrated Framework**: the study proposes a comprehensive framework that integrates ERP systems, Catena-X, and a Tier Alerting System, providing a unified approach to managing and reducing emissions in the automotive supply chain [18].
2. **Data Accuracy and Analytics**: by enhancing data accuracy and leveraging advanced analytics, the proposed solution offers deeper insights into emissions sources and enables more informed decision-making [41].
3. **Supplier Selection Strategy**: the research highlights the importance of incorporating emissions data into the supplier selection process, demonstrating how this can lead to significant reductions in the product carbon footprint (PCF) [21].
4. **Proactive Compliance**: the Tier Alerting System provides a proactive approach to environmental compliance, ensuring timely interventions and continuous improvement in environmental performance [61].
5. **Operational Efficiency**: the integration of these systems is designed to streamline operations, reduce waste, and improve overall sustainability, contributing to long-term operational efficiency [65].

7.3 Limitations

While this research presents a robust theoretical framework, several limitations must be acknowledged:

1. **Theoretical Nature**: the proposed solution is theoretical and has not been empirically tested. Real-world implementation may reveal challenges not accounted for in this study.
2. **Data Availability**: the effectiveness of the proposed solution relies heavily on the availability and accuracy of emissions data from suppliers. Inconsistent or incomplete data can hinder the system's performance [62].
3. **Stakeholder Buy-In**: successful implementation requires buy-in from all stakeholders, including suppliers, manufacturers, and regulatory bodies. Resistance to change and lack of cooperation can pose significant barriers [48].
4. **Technological Infrastructure**: the integration of ERP systems, Catena-X, and the Tier Alerting System requires advanced technological infrastructure, which may involve significant investment and maintenance costs [53].

7.4 Future Work

Future research should focus on addressing the limitations identified and further exploring the potential of the proposed solution. Key areas for future work include:

1. **Empirical Validation**: conduct empirical studies to test the proposed solution in real-world settings, assessing its effectiveness and identifying practical challenges and solutions [39].
2. **Advanced Analytics**: explore the use of more sophisticated analytics tools and machine learning algorithms to enhance predictive capabilities and provide deeper insights into emissions trends and mitigation strategies [52].
3. **Stakeholder Engagement**: develop strategies to foster greater stakeholder engagement and collaboration, ensuring successful implementation and long-term sustainability [65].
4. **Scalability and Adaptability**: Investigate ways to scale the proposed solution for use in different industries and adapt it to evolving regulatory requirements and technological advancements [54].
5. **Cost-Benefit Analysis**: perform a detailed cost-benefit analysis to evaluate the financial implications of implementing the proposed solution and identify ways to optimize costs while maximizing benefits [62].

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I. APPENDIX A: SYSTEMATIC ANALYSIS OF LITERATURE REVIEWS

No	Year	Author(s)	Title	Country & Sample	Period	Purpose
1	2024	Krause, J., et al.	Well-to-wheels scenarios for 2050 carbon-neutral mobility in Europe	Europe	Future (2050)	Explore pathways to achieve carbon-neutral mobility in Europe through various energy sources
2	2024	Hoseinzadeh, S., et al.	Designing high-share 50% and 100% renewable energy systems for European islands: A case study of	Pantelleria, Italy	Not specified	Study the feasibility of renewable energy systems in European islands, focusing on

			Pantelleria			Pantelleria
3	2024	Turan, F.K.	A theoretical stakeholder model of automotive electrification transition: Insights from the Turkish automotive industry	Turkey	Not specified	Analyze the transition to electric vehicles in Turkey's automotive industry
4	2024	Karali, H.I., & Caliskan, H.	Energy, exergy, sustainability, thermoeconomic, and environmental analyses of a combined cooling, heating, and power system	Not specified	Not specified	Evaluate the efficiency and environmental impact of a combined cooling, heating, and power system
5	2024	Jannesar Niri, A., et al.	Sustainability challenges throughout the electric vehicle battery life cycle: A focus on recycling	Not specified	Not specified	Discuss the sustainability challenges in the life cycle of electric vehicle batteries, with a focus on recycling
6	2024	Encinas Bartos, K., et al.	The role of trainings in improving supplier sustainability performance in developing countries	Developing countries	Not specified	Examine how training can enhance supplier sustainability in the apparel industry in developing countries
7	2023	Prochatzki, G., et al.	A critical review of the current state of circular economy practices in the German automotive industry	Germany	Not specified	Review and analyze circular economy practices within the German automotive industry
8	2023	Monye, S.I., et al.	NOW AND FUTURE	Not specified	Not specified	Address current and future

			CHALLENGES OF THE AUTOMOBILE INDUSTRY TOWARDS ACHIEVING A SUSTAINABLE ENVIRONMENT			sustainability challenges in the automotive industry
9	2023	Ebersold, F., et al.	Carbon insetting as a measure to raise supply chain sustainability in the automotive industry	Not specified	Not specified	Investigate carbon insetting strategies for enhancing supply chain sustainability in the automotive sector
10	2023	Rajulwar, V.V., et al.	Steel, Aluminum, and FRP-Composites: The Race for Material Supremacy in the Automotive Industry	Not specified	Not specified	Compare the use of different materials in the automotive industry regarding sustainability and performance
11	2023	Schöppenthau, F., et al.	Building a Digital Manufacturing as a Service Platform for Small and Medium-Sized Enterprises in the Automotive Sector	Not specified	Not specified	Discuss the development and impact of a digital manufacturing platform for SMEs in the automotive sector
12	2023	Thormann, L., et al.	Opportunities and challenges of the European Green Deal for the automotive industry	Europe	Not specified	Evaluate the impact of the European Green Deal on the automotive industry's sustainability efforts
13	2023	Poschmann, J., et al.	Decarbonization Potentials for Automotive Supply Chains: A Life Cycle	Not specified	Not specified	Investigate the decarbonization potential within automotive supply chains

			Assessment Perspective			from a life cycle assessment standpoint
14	2023	Kamble, S.S., et al.	Blockchain technology's impact on supply chain transparency and sustainability: Evidence from the automotive industry	Not specified	Not specified	Analyze the effects of blockchain technology on enhancing supply chain transparency and sustainability in the automotive industry
15	2023	Valladares Montemayor, H.M., & Chanda, R.H.	Automotive industry's circularity applications: A comprehensive review	Not specified	Not specified	Review the application and impact of circular economy principles in the automotive industry
16	2023	Succar, S.A., et al.	Assessing the environmental benefits of remanufacturing: A case study of automotive components	Not specified	Not specified	Examine the environmental benefits and potential of remanufacturing automotive components
17	2023	Vasta, S.	The role of electric vehicles in reducing urban pollution: A case study of Rome	Rome, Italy	Not specified	Study the impact of electric vehicles on reducing urban pollution, focusing on Rome as a case study
18	2023	Naffin, J., et al.	Sustainable innovation in the automotive industry: Bridging the gap between theory and practice	Not specified	Not specified	Explore sustainable innovation practices within the automotive industry and the gap between theoretical frameworks and practical

						application
19	2023	Neef, M., et al.	Life cycle assessment of battery electric vehicles and hydrogen fuel cell vehicles for the German electric system	Germany	Not specified	Compare the life cycle environmental impacts of battery electric and hydrogen fuel cell vehicles in the German context
20	2023	Carpitella, S., et al.	Optimization of supply chain management in the automotive sector: A systematic literature review	Not specified	Not specified	Systematically review methods for optimizing supply chain management in the automotive sector
21	2023	Johansen, K., et al.	Lean manufacturing in the automotive practices industry: Impact on environmental performance	Not specified	Not specified	Investigate the impact of lean manufacturing practices on the environmental performance of the automotive industry
22	2023	Mügge, J., et al.	The influence of digitalization on the sustainability of automotive supply chains	Not specified	Not specified	Examine how digitalization affects the sustainability of supply chains in the automotive industry
23	2023	Kretschmar, D., et al.	Circular economy in the automotive industry: A framework for sustainable business models	Not specified	Not specified	Propose a framework for implementing circular economy principles in sustainable business models for the automotive industry
24	2023	Kumar, A., et al.	Blockchain for sustainable supply chain management in	Not specified	Not specified	Provide insights into the application of blockchain for

			the automotive industry: Insights from a systematic literature review			sustainable supply chain management in the automotive sector

No	Year	Author(s)	Title	Country & Sample	Period	Purpose
25	2023	Wissuwa, F., & Durach, C.F.	The impact of digital twin technology on automotive supply chain resilience	Not specified	Not specified	Explore the role of digital twin technology in enhancing the resilience of automotive supply chains
26	2023	Dincă, M.S., et al.	Eco-innovation in the automotive industry: A pathway to sustainability	Not specified	Not specified	Discuss eco-innovation strategies within the automotive industry as a means to achieve sustainability
27	2023	Guzmán, J.I., et al.	Integration of renewable energy systems in automotive manufacturing: A case study analysis	Not specified	Not specified	Analyze the integration and impact of renewable energy systems in automotive manufacturing processes
28	2023	Kuo, T.-C., et al.	Sustainability assessment models for automotive manufacturing: Trends and challenges	Not specified	Not specified	Review and discuss sustainability assessment models in automotive manufacturing, highlighting current trends and challenges
29	2023	Hirz, M., et al.	Advanced materials in automotive engineering: A review of recent trends	Not specified	Not specified	Provide an overview of recent developments in advanced materials for automotive engineering and

			and developments			their sustainability implications
30	2023	Burton, T., et al.	The impact of autonomous vehicles on urban mobility: An environmental perspective	Not specified	Not specified	Investigate the environmental implications of autonomous vehicles on urban mobility
31	2023	Palea, V., & Santhià, C.	Financial reporting for sustainability in the automotive industry: An analysis of non-financial disclosure practices	Not specified	Not specified	Analyze sustainability-related financial reporting and non-financial disclosure practices in the automotive industry
32	2023	Hirz, M., & Nguyen, T.T.	Computational methods for the design and optimization of electric vehicle batteries	Not specified	Not specified	Examine computational approaches to the design and optimization of batteries for electric vehicles
33	2023	Sika, R., et al.	The role of lightweight materials in enhancing the fuel efficiency of vehicles	Not specified	Not specified	Discuss the importance of lightweight materials in improving vehicle fuel efficiency and their sustainability benefits
34	2023	Buettner, S.M., et al.	Strategies for achieving carbon neutrality in the automotive sector by 2050	Not specified	Future (2050)	Outline strategies for the automotive sector to achieve carbon neutrality by 2050
35	2023	Maeno, K., et al.	Analysis of the environmental impact of electric vehicle adoption in Japan	Japan	Not specified	Assess the environmental impact of increasing electric vehicle adoption in Japan
36	2023	Ashirbad, A., & Agarwal,	Technological innovations in	Not specified	Not specified	Overview the technological

		A.K.	electric vehicles: An overview of battery and powertrain technologies			innovations in batteries and powertrains for electric vehicles, focusing on sustainability impacts
37	2023	Czerlinsky, N., et al.	The evolution of smart factories in the automotive industry: Opportunities and challenges	Not specified	Not specified	Explore the development of smart factories in the automotive industry and their sustainability challenges and opportunities
38	2023	Jasiński, D., et al.	The impact of corporate social responsibility on sustainability in the automotive sector: A systematic review	Not specified	Not specified	Systematically review the impact of corporate social responsibility practices on sustainability in the automotive sector
39	2023	Muslemani, H., et al.	Electric vehicle adoption in emerging markets: Insights from the Middle East	Middle East	Not specified	Examine the factors influencing electric vehicle adoption in emerging markets, with a focus on the Middle East
40	2023	Tóth, Á., et al.	Life cycle assessment of electric and combustion engine vehicles in Hungary	Hungary	Not specified	Compare the life cycle environmental impacts of electric versus combustion engine vehicles in Hungary
41	2023	Skrúcaný, T., et al.	Reducing greenhouse gas emissions through optimized logistics in the automotive industry	Not specified	Not specified	Investigate how optimized logistics can reduce greenhouse gas emissions in the automotive sector
42	2023	Szász, L., et al.	The role of additive	Not specified	Not specified	Discuss the contribution of

			manufacturing in achieving sustainability goals in the automotive industry			additive manufacturing to sustainability in the automotive industry
43	2023	Chocholac, J., et al.	The impact of Industry 4.0 technologies on production efficiency in the automotive sector	Not specified	Not specified	Explore the effects of Industry 4.0 technologies on improving production efficiency in the automotive sector
44	2023	Pichler, M., et al.	Sustainable supply chain management in the electric vehicle industry: Challenges and opportunities	Not specified	Not specified	Review the challenges and opportunities in sustainable supply chain management within the electric vehicle industry
45	2023	Zapletal, F., et al.	Modeling the sustainability of logistics processes in automotive supply chains	Not specified	Not specified	Model and analyze the sustainability of logistics processes within automotive supply chains
46	2023	Tóth, Á., & Suta, A.	Environmental impact assessment of automotive components using life cycle assessment	Not specified	Not specified	Assess the environmental impact of automotive components using life cycle assessment techniques
47	2023	Broniszewski, M., & Werle, S.	The influence of autonomous driving technologies on urban traffic management and sustainability	Not specified	Not specified	Examine the influence of autonomous driving technologies on urban traffic management and its sustainability implications

NO	YEAR	AUTHORS	TITLE	DOI	PURPOSE
48	2023	Zapletal, F., Lenort, R., & Wicher, P.	Modeling the sustainability of logistics processes in automotive supply chains	10.3390/su15052154	Explore sustainable logistics models in automotive supply chains
49	2023	Tóth, Á., & Suta, A.	Environmental impact assessment of automotive components using life cycle assessment	10.3303/CET2188181	Assess environmental impacts of automotive components via LCA
50	2023	Broniszewski, M., & Werle, S.	The influence of autonomous driving technologies on urban traffic management and sustainability	10.1016/j.energy.2020.117704	Examine the impact of autonomous driving on urban sustainability
51	2007	Kitchenham, B.; Charters, S.	Guidelines for Performing Systematic Literature Reviews in Software Engineering	-	Provide guidelines for systematic literature reviews in software engineering
52	2018	Borrett, S.R.; Sheble, L.; Moody, J.; Anway, E.C.	Bibliometric review of ecological network analysis: 2010–2016	-	Review the literature on ecological network analysis
53	2020	Wahono, R.S.	Systematic Literature Review: Pengantar, Tahapan Dan Studi Kasus	-	Discuss methodologies and case studies for systematic literature reviews
54	2009	Liberati, A.; Altman, D.G.; Tetzlaff, J.; Mulrow, C.; Gøtzsche, P.C.; Ioannidis, J.P.; Moher, D.	The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration	-	Guide on reporting systematic reviews and meta-analyses of health care interventions
55	-	Climatiq	About Us	climatiq.io/about	Introduce the mission and services of Climatiq
56	-	ecoinvent	Mission & History	ecoinvent.org/mission-history	Describe the history and mission of ecoinvent
57	2023	Gao, et al.	Electric vehicle lifecycle carbon emission reduction: A review	10.1002/cnl2.81	Review methods for reducing carbon emissions throughout the EV lifecycle
58	2020	Palander, et al.	Improving environmental and energy efficiency in wood transportation for a carbon-neutral forest industry	10.3390/f11111194	Improve environmental and energy efficiency in wood transportation

59	2019	Saputra, et al.	Cloud ERP software suitability analysis for automotive components small and medium industry using analytical hierarchy process	10.17933/mti.v10i2.154	Analyze suitability of cloud ERP software for SMEs in the automotive industry
60	2020	-	The impact of adopting ERP on key performance indicator by the mediation effect of critical success factors and performance indicators in automobile ancillary industries	10.14419/ijet.v7i3.27.17995	Evaluate the impact of ERP on performance indicators in the automotive sector
61	2020	Giampieri, et al.	A review of the current automotive manufacturing practice from an energy perspective	10.1016/j.apenergy.2019.114074	Review energy practices in automotive manufacturing
62	2020	Zhao, et al.	Research on green and low-carbon development path of China's automotive industry	10.1142/S2345748123500045	Explore green and low-carbon development strategies for China's automotive sector
63	2022	Wang, et al.	Reducing carbon emissions for the vehicle routing problem by utilizing multiple depots	10.3390/su14031264	Investigate strategies to reduce carbon emissions in vehicle routing
64	2021	Sarfraz, et al.	Recent developments in the manufacturing technologies of composite components and their cost-effectiveness in the automotive industry: A review study	10.1016/j.compstruct.2021.113864	Review cost-effective manufacturing technologies for composite automotive components
65	2020	Jiang, et al.	Cost-effective approaches for reducing carbon and air pollution emissions in the power industry in China	10.1016/j.jenvman.2020.110452	Study cost-effective methods for reducing emissions in China's power industry
66	2020	Palander, et al.	Improving environmental and energy efficiency in wood transportation for a carbon-neutral forest industry	10.3390/f11111194	Improve environmental and energy efficiency in wood transportation
67	2019	Saputra, et al.	Cloud ERP software suitability analysis for automotive components small and medium industry using analytical hierarchy process	10.17933/mti.v10i2.154	Analyze suitability of cloud ERP software for SMEs in the automotive industry
68	2020	-	The impact of adopting ERP on key performance indicator by the mediation	10.35940/ijrte.B1019.0782S319	Evaluate the impact of ERP on performance

			effect of critical success factors and performance indicators in automobile ancillary industries		indicators in the automotive sector
69	2020	Neef	Carbon budget compliance: A life-cycle-based model for carbon emissions of automotive original equipment manufacturers	10.25534/tuprints-00013243	Develop a life-cycle model for carbon compliance in automotive manufacturing
70	2023	-	Empowering end-of-life vehicle decision making with cross-company data exchange and data sovereignty via Catena-X	10.3390/su15097187	Enhance end-of-life vehicle management through data exchange
71	-	Mosovsky, J. A., & Limaye, K.	Scalable Enterprise Environmental Management System–Methodology, System Architecture and Case Study	-	Present a scalable environmental management system for enterprises
72	2022	Tong, Q., Ming, X., & Zhang, X.	Construction of sustainable digital factory for automated warehouse based on integration of ERP and WMS	10.3390/su15021022	Discuss the construction of sustainable digital factories integrating ERP and WMS
73	2018	Tsai, W. H., & Lu, Y. H.	A framework of production planning and control with carbon tax under industry 4.0	10.3390/su10093221	Develop a framework for production planning under industry 4.0 with a carbon tax