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SUSTAINABILITY AND TRANSPARENCY IN THE ELECTRIC VEHICLE SUPPLY CHAIN: ANALYSIS OF THE CURRENT SITUATION AND STRATEGIES FOR THE FUTURE

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Abstract:

This study examines the sustainability challenges faced by automotive companies within the electric vehicle (EV) supply chain, focusing on transparency and the environmental impacts of sourcing critical battery materials such as lithium, cobalt, and nickel. Through a survey of automotive companies, the research explores how company size influences the adoption of sustainable practices and transparency with suppliers. Findings reveal significant barriers, including high implementation costs, lack of technology, and limited influence over suppliers, especially for smaller companies. The study underscores the need for enhanced collaboration, regulatory support, and technological innovation to improve sustainability across the EV supply chain.

Keywords: Electric Vehicles Supply Chain, Transparency, Sustainability, Sustainable Project Management.

1. Introduction

In recent years, the automotive industry has undergone a profound transformation driven by the need to reduce greenhouse gas emissions and address the challenges posed by climate change, a topic increasingly prevalent across all industrial sectors. In this context, propelled by global regulatory pressure and the rising demand for sustainable mobility solutions, electric vehicles (EVs) have become the centerpiece of environmental strategies for many car manufacturers. These companies have had to adapt their production and supply lines to align with this growing market trend. Recent studies predict that the global market share for electric vehicles is steadily rising, and by 2030, EVs could account for over 50% of new vehicle sales worldwide (Patel, Vyas, and Markana 2022).

Despite the environmental benefits stemming from the reduced emissions of electric vehicles, their production, particularly the sourcing of raw materials, remains one of the greatest challenges to the sustainability of the vehicle's entire life cycle. The batteries that power electric vehicles require materials such as lithium, cobalt, and nickel, the extraction of which has significant critical environmental and social impacts. For example, lithium extraction in South American salt flats involves significant water and energy consumption in regions already affected by drought, thus disrupting local ecosystems and the communities that rely on those resources (Chen et al. 2019). Similarly, nickel extraction, which primarily occurs in Russia and Indonesia, is associated with substantial CO_2 emissions (Masoumi, Kazemi, and Abdul-Rashid 2019).

The supply chain for battery materials is highly complex and global in scale. Raw materials are extracted in resource-rich countries often characterized by weak environmental and social regulations before being processed and assembled in facilities around the world. This process significantly increases the carbon footprint associated with material transport and processing, while also raising the risk of supply chain disruptions due to geopolitical instability (Gebhardt, Beck, and Spieske 2022). Automakers do not directly extract these raw materials but rely on a global network of suppliers, reducing their ability to directly control the conditions of extraction and production. This makes it difficult for companies to manage sustainability across the entire supply chain. Moreover, the lack of transparency and uniform global standards for monitoring emissions and working conditions further complicates ensuring that raw materials are sourced sustainably and ethically (Masoumi, Kazemi, and Abdul-Rashid 2019). To address these challenges, sustainable supply chain management for critical battery materials has become a priority for automotive companies seeking to align with global CO_2 emission reduction goals. Transparency and accountability throughout the entire supply chain are essential to achieving these goals. Automotive companies can no longer focus solely on production efficiency or vehicle performance. They must also ensure that the entire product life cycle, from raw material extraction to battery disposal and recycling, adheres to high environmental and social standards. This shift necessitates a rethinking of project management practices and relationships with suppliers, particularly regarding the sourcing of raw materials (Dhar, Pathak, and Shukla 2017). In this context, this research seeks to define strategies that automotive companies can implement by adopting more proactive and transparent approaches to ensure sustainability throughout the entire supply chain for critical battery materials. Specifically, this study aims to identify which project management practices can be used to improve collaboration with suppliers and promote the adoption of sustainable standards, while minimizing the environmental and social impact of resource extraction. Automotive companies will play an increasingly active role in improving the sustainability of their supply chains, with a particular focus on managing the necessary information that suppliers must provide.

The ultimate goal of the framework is to provide practical recommendations for companies seeking to adopt sustainable supply chain management practices, contributing not only to reducing their environmental impact but also to enhancing their global competitiveness and reputation (Gebhardt, Beck, and Spieske 2022).

2. Literature Review: Critical Analysis of Processes, Impacts, and Regulations in Battery Production for Automotive Companies

Before developing the direct research, it is essential to thoroughly understand the process of battery creation and the impact of each phase on the ecosystem. This complex process can be divided into four phases: extraction, refining and processing of the extracted materials, cell assembly, and battery pack production.

2.1 The Battery Production Process and Environmental Impact:

The production of lithium-ion batteries for electric vehicles (EVs) requires a complex and resource-intensive process, which has a significant environmental impact. This process begins with the extraction of raw materials, such as lithium, nickel, cobalt, and graphite critical materials sourced from different parts of the world. Specifically, lithium extraction primarily occurs in the salt flats of Chile, Bolivia, and Argentina, collectively known as the "lithium triangle." One of the most critical environmental impacts in this phase is the massive amount of water and energy required for extraction. It is estimated that producing one ton of lithium requires approximately 500,000 liters of water, a scarce resource in desert regions like Chile. This process has led to the drying up of water basins, with negative consequences for local farming communities and natural ecosystems (Schomberg, Bringezu, and Flörke 2021).

Nickel and cobalt, two key battery components, are extracted in countries such as Indonesia and the Democratic Republic of Congo. The extraction of these materials brings about various environmental impacts, including deforestation and water contamination. Moreover, the cobalt industry in Congo has been heavily criticized for dangerous working conditions and child labor (Rajaeifar, Ghadimi, and Raugei 2022).

The next phase of battery production, which involves the refining and processing of extracted materials, is highly energy-intensive and contributes significantly to global CO_2 emissions. This processing mainly involves the production of anodes and cathodes, central components of batteries, and accounts for approximately 72% of the total emissions associated with battery production. Much of the energy used in these stages comes from non-renewable sources, further exacerbating the overall environmental impact of the process. It is estimated that producing a battery for a mid-sized electric car generates about 5 tons of CO_2, a higher figure compared to the production of an internal combustion engine, which generates about 2 tons (Harper, Sommerville, and Kendrick 2019).

Battery cell production and battery pack production occurs in large-scale facilities known as gigafactories, which are among the world's largest consumers of energy. Tesla, for example, has built one of the largest gigafactories in Nevada, where it produces batteries not only for its vehicles but also for other energy storage systems such as the Powerwall. However, despite efforts to use renewable energy in some gigafactories, most of these plants continue to rely on fossil fuels. This is particularly true in countries like China, where many gigafactories still rely on coal as their primary energy source (Harper et al. 2019).

2.2 Comparison of Environmental Impact Between EV Batteries and Internal Combustion Engines:

When comparing electric vehicles (EVs) and internal combustion engine vehicles (ICEs), it is crucial to adopt a life-cycle analysis approach, considering both the emissions produced during production and those generated during the vehicle's entire operational life. It is now widely acknowledged that producing an electric vehicle particularly its batteries results in a higher carbon footprint than an internal combustion engine vehicle (ICE). Recent data from the International Council on Clean Transportation (ICCT) indicates that producing an average electric vehicle generates about 9 tons of CO_2, with 5 tons coming from the battery production alone (ICCT 2022). However, despite the initially higher emissions, life-cycle analysis demonstrates that EVs are significantly more sustainable than ICE vehicles in the long term. During their operational life, EVs compensate for the initial negative environmental impact due to their lack of direct emissions. Specifically, EVs register 60%-69% lower lifecycle emissions than ICE vehicles in regions like Europe and the United States, where the use of renewable energy for electricity generation is rapidly increasing (ICCT 2022). The variation in emission estimates depends on several factors, including battery capacity and the source of electricity used for recharging. For example, in terms of battery capacity, vehicles with larger batteries, such as those with 100 kWh, can produce up to 6 tons of CO_2 just for the battery. Regarding the energy mix for recharging, countries like Norway and Germany, which have cleaner energy mixes, help reduce the overall impact of electric vehicles (Schomberg, Bringezu, and Flörke 2021).

In addition to emissions, energy consumption during production is also a key factor to consider. Producing an electric vehicle requires about twice as much energy as producing an internal combustion engine vehicle. This is primarily due to the need to extract and refine rare materials like lithium and cobalt, which require energy-intensive processes. However, with the development of new technologies, such as solid-state batteries, it is expected that the energy efficiency of electric vehicles will further improve, thus reducing the overall impact (Harper et al. 2019).

In conclusion, although the production of electric vehicles, particularly their batteries, initially generates a higher carbon footprint compared to internal combustion engine vehicles, EVs are more sustainable in the long term due to lower operational emissions, especially when powered by renewable energy sources. This makes them a more advantageous solution in terms of reducing overall emissions and contributing to the fight against climate change (ICCT 2022; Schomberg et al. 2021).

2.3 The Major Players in Battery Production and Automotive Clients:

The electric vehicle battery market is experiencing exponential growth, driven by the rising demand for low-emission vehicles and the expansion of production infrastructure. The global battery market value is currently estimated to reach $347 billion by 2030, with an anticipated production capacity of approximately 4,500 GWh per year (McKinsey 2022, 1-5). This rapid expansion is being supported by significant investments in new gigafactories across Europe, Asia, and North America, necessary to meet the growing electric vehicle market.

The EV battery market is dominated by a few major players. These include CATL (China), LG Energy Solution (South Korea), Panasonic (Japan), and BYD (China). CATL, with a global market share of around 34%, is the leading supplier of batteries to many automotive manufacturers, including Tesla, Volkswagen, and BMW. LG Energy Solution is another dominant player, supplying batteries to automotive companies such as General Motors, Ford, and Renault. Panasonic, a long-time partner of Tesla, is one of the primary suppliers for Tesla's electric vehicles in the U.S. market (Sun et al. 2019). A noteworthy case of vertical integration is Tesla, which, in addition to purchasing batteries from specialized suppliers, produces some of its batteries at its Gigafactory in Nevada. This facility manufactures batteries not only for electric vehicles but also for other energy storage solutions. This strategy allows Tesla to have greater control over its supply chain, reducing reliance on external suppliers, potentially lowering production costs, and improving overall efficiency (Rajaeifar et al. 2022).

2.4 International Regulations and Standards for Battery Production:

The growing focus on sustainability and emission reductions has led to the implementation of several international regulations governing the production of batteries for electric vehicles. One of the most important regulations is the EU Battery Regulation 2023, which imposes stringent requirements for transparency and traceability along the entire battery supply chain. The regulation mandates that companies disclose detailed information about the origin of raw materials and the CO_2 emissions generated during battery manufacturing. Additionally, it promotes the use of recycled materials, setting ambitious targets for recycling lithium, nickel, and cobalt by 2030 (Sun et al. 2019). In China, the world's leading battery producer, regulations have also been introduced to reduce emissions from battery production and improve the energy efficiency of factories. One of the Chinese government's goals is to reduce emissions generated per kilowatt-hour (kWh) of battery capacity, from 17 kg of CO_2 per kWh in 2022 to less than 10 kg of CO_2 per kWh by 2030 (Rajaeifar et al. 2022). These efforts align with international regulations aimed at minimizing the environmental impact of the battery industry. In Europe, the EU Battery Regulation 2023 also aims to improve the traceability of raw materials used in batteries and promote corporate responsibility by ensuring that minerals such as cobalt are extracted and processed ethically. The adoption of a circular economy is one of the regulation's main objectives, which mandates the use of recycled materials for new battery production. This regulation is seen as a crucial step in making the entire battery life cycle more sustainable (Schomberg et al. 2021).

2.5 Relationships Between Battery Suppliers and Automakers:

The relationships between battery manufacturers and automakers are crucial to ensuring a stable and sustainable supply of batteries. Automakers such as Tesla, Volkswagen, and General Motors have signed long-term contracts with battery suppliers such as CATL, LG Energy Solution, and Panasonic to secure the availability of the batteries needed for their electric vehicles. However, one of the main concerns is the lack of transparency along the supply chain (Harper et al. 2019). Several non-governmental organizations have raised concerns about child labor in cobalt mines, particularly in the Democratic Republic of the Congo. As a result, many automakers have been criticized for not taking adequate measures to monitor their supply chains (Sun et al. 2019).

In response to these issues, many companies are investing in technologies such as blockchain to improve the traceability of materials along the supply chain. This system allows each stage of the process to be monitored, from extraction to battery production, ensuring greater transparency and reducing the risk of unethical practices (Schomberg et al. 2021).

Another aspect of the relationship between battery suppliers and automakers concerns recycling awareness at the end of a vehicle's life cycle. Recent data indicates that the global electric vehicle battery recycling market reached a value of $6.90 billion in 2024, with projected growth to $27.53 billion by 2029, with a compound annual growth rate (CAGR) of 31.87% (MarketsandMarkets 2024; Market Data Forecast 2024). In terms of recycling rates, progress has been made, particularly in Europe and China, where investments in large-scale recycling plants are expanding. However, the recycling rate remains low, with estimates suggesting that only 5-10% of end-of-life batteries are currently recycled globally (Market Data Forecast 2024). This gap underscores the urgent need for more efficient recycling technologies and better infrastructure to manage the growing number of electric vehicle batteries reaching the end of their useful life. Moreover, regulatory pressure, particularly in Europe, is pushing for stricter controls and greater transparency in the battery life cycle to improve recycling rates and reduce environmental impact (Market Data Forecast 2024).

In conclusion the production of batteries for electric vehicles presents a complex environmental and social challenge. While EVs offer significant advantages in terms of emission reductions during use, the production phases of batteries, particularly raw material extraction and refining, continue to pose significant negative impacts. International regulations, such as the EU Battery Regulation 2023, are trying to improve the sustainability of this sector. However, greater collaboration between battery manufacturers and automakers is needed to ensure that the entire battery life cycle is both sustainable and transparent (Rajaeifar et al. 2022).

3. Scope of Application: Definition of the Scope of Study and Objectives for the Transparent and Sustainable Management of the Battery Supply Chain

In a context where the electric vehicle (EV) industry faces external complexity related to the procurement of critical battery materials, companies' responses in terms of sustainability have become increasingly crucial and relevant. The organizational structure of the electric vehicle sector must engage in a global community that is constantly striving for innovative solutions to reduce the environmental and social impacts associated with the sourcing of raw materials. There is a growing recognition of the active role companies must play in adopting new strategies to contribute positively to a world where environmental education and ecological transition are becoming ever more relevant. Given the increasing importance of electric vehicles in achieving global sustainability goals, the effective management of their supply chain represents both a challenge and an opportunity.

The research focuses on identifying and implementing sustainable project management practices within the electric vehicle supply chain. The goal is to explore strategies that can be integrated into supply chain management processes to reduce overall environmental impact while simultaneously improving efficiency and transparency. Key areas of interest include resource management, CO_2 emissions reduction, supplier engagement, and the adoption of real-time monitoring technologies. This research aims to assess the existing collaboration between automotive companies and their suppliers to ensure the adoption of sustainability measures at all stages, from raw material extraction to battery production and assembly, with the goal of developing a framework that supports a more proactive approach to supplier interaction.

3.1 Specific Objectives:

1. Develop a sustainable project management framework that can be applied in real-world contexts within the electric vehicle supply chain.

2. Test and evaluate the effectiveness of the framework through the collection of primary data.

3.2 Research Questions:

1. What are the main challenges and barriers that supply chain managers face in implementing sustainable project management practices?
2. What are the most effective project management strategies for improving sustainability in the electric vehicle supply chain?
3. To what extent can active collaboration with suppliers and the use of real-time emission monitoring technologies influence the reduction of CO_2 emissions?

3.3 Hypotheses:

1. The lack of adequate monitoring tools and limited awareness of the benefits of sustainable practices are the main barriers to adopting sustainable project management strategies.
2. Proactive supplier engagement, especially in regard to sustainability goals, will lead to a significant reduction in CO_2 emissions along the supply chain.
3. The integration of real-time emission monitoring technologies and transparency in decision-making processes will facilitate the co-creation of more sustainable solutions with suppliers, improving the overall environmental impact.

This structured approach will enable a comprehensive assessment of the challenges and potential solutions for improving sustainability in the electric vehicle supply chain. The research will be based on information provided by survey respondents, which will be critical to testing the hypotheses and formulating practical recommendations for future practices in the sector.

4. Methodology and Approach: Research Methodologies To Measure And Evaluate The Transparency And Sustainability Of Battery Manufacturers In Their Relations With Automotive Companies

In a context already defined in the introductory phase where the automotive sector of electric cars is facing external complexities represented by the procurement of critical materials for batteries, the response of automotive companies in terms of sustainability becomes an extremely current and important issue. The corporate organization of the electric car sector must interact within a global community in constant tension towards the search for innovative solutions to reduce the environmental and social impact related to the procurement of raw materials; there is indeed official recognition of the active role that the company has in adopting innovative strategies to contribute positively in a global world where environmental education and ecological transition become increasingly relevant topics. In order to analyze the ways in which automotive companies of electric cars are managing this growing complexity, a questionnaire was specifically constructed, articulated in the following phases.

1. Clarification of the purpose and theme: analysis of current practices and the development of new project manager strategies in order to identify the most suitable solutions to reduce the environmental and social impact related to the procurement of raw materials.
2. Definition of background variables, to which the first section is dedicated, including both the characteristics of the company (number of employees, number of raw material suppliers, and their location), and the description of the subjects to whom the questionnaire is addressed (role within the company, length of employment in the sector).
3. Formulation of questions based on identified indicators and operational definitions. In this phase, the following indicators were used: sustainability, collaboration, monitoring

and innovation in the supply chain, transparency, traceability and social responsibility of suppliers, awareness of pollution caused by raw material extraction, reduction of environmental impacts, opinions on the future of sustainability and compliance with regulations. For each indicator, multiple questions were defined with the option of choosing within predefined response alternatives; closed multiple-choice questions with the possibility of checking only one answer. The closed question allows for more structured information and exploration with the available data analysis techniques. Only in the final question was an open question used, of a more exploratory nature, to allow a richer and more useful response regarding the identification and elaboration of possible practices and innovations to improve the sustainability of the supply chain.

4. Definition of the order of questions and structuring of the questionnaire into sections. Each question was then numbered, for a total of twenty nine questions.
5. Preparation of the questionnaire presentation mode through Qualtrics survey and preparation of a presentation letter.
6. Evaluation of the length of the questionnaire, so as to require at most half an hour of work.
7. First administration on a small sample of subjects to whom the questionnaire is addressed, for a first verification of the validity of the questionnaire in relation to the research theme. The questionnaire was administered to a small sample of eight subjects representative of the target group, who expressed positive feedback on the validity of the proposed themes.
8. Implementation of some verification questions to validate the reliability of the responses and the consequent reliability of the framework being developed. Here are examples of potential response control questions within your questionnaire: Question 2 ("How long have you worked in the automotive sector?") and Question 14 ("How aware is your

company of the environmental impacts associated with raw material extraction?") can serve as indirect response controls. Someone with 20+ years of experience in the automotive industry should, theoretically, be "very aware" or "moderately aware" of the impacts of raw material extraction. Inconsistencies between these questions might flag potential issues with the response. Question 8 ("What percentage of the raw materials used by your suppliers come from certified sustainable sources?") and Question 14 ("What criteria are prioritized when selecting raw material suppliers?") could be checked against each other. A respondent who selects "Sustainability certifications" in Question 14 should, in principle, provide a higher percentage range in Question 8 (e.g., 76–100%). Question 13 ("Does your company require suppliers to provide regular reports on their CO_2 emissions or other environmental impacts?") can be checked against Question 15 ("How does your company actively collaborate with suppliers to improve sustainability practices?"). If a company does not request environmental impact reports, it would seem inconsistent for them to claim they "jointly set emission reduction targets" with suppliers. Question 15 ("How does your company actively collaborate with suppliers to improve sustainability practices?") and Question 24 ("Has your company developed measurable targets for reducing emissions throughout the raw materials supply chain?") could also act as response control questions. A company that actively collaborates with suppliers would likely indicate more active supplier involvement in sustainability goal-setting. The control questions allowed verifying the validity of the responses received.

5. Data Analysis: Towards a Sustainable Future: Summary of Findings and Strategic Recommendations for the Automotive Sector

The questionnaire thus structured was then sent to prominent figures within these organizations, including executives, purchasing managers, and sustainability managers, with the aim of involving professionals in strategic and decision-making positions. Of the numerous requests sent, 54 individuals responded, representing a more than significant participation rate for an investigation of this type. This high adherence indicates widespread interest and growing awareness regarding sustainability and transparency themes in the supply chain.

A preliminary analysis of the responses allowed verifying the absence of significant bias signals. Of the 54 responses received, two were found to be distorted due to inconsistent or irrelevant answers, while three were considered incomplete and therefore excluded from the in-depth analysis. The final sample, composed of 49 valid responses, provided a solid basis for subsequent analyses. The comparison between responses to reformulated questions showed a consistency higher than 95%, confirming the reliability of the collected data and the accuracy of the adopted methodological approach. After verifying the consistency of the responses received, the data analysis was entirely conducted in Excel.

Regarding the position within the company of the respondents, the majority hold high-level roles within their respective organizations. In particular, "executives" represent 33% of the sample, followed by "purchasing managers" (21%), "sustainability managers" (19%), “supply chain managers” (17%) and “other” (10%). This distribution suggests that the questionnaire mainly reached strategic and managerial figures, directly involved in decisions related to the supply chain, sustainability, and procurement. Executives tend to provide more diversified responses or focus on global strategies, reflecting an overall view of corporate policies. Purchasing managers and supply chain managers offer a more operational perspective, linked to tactical decisions and direct management of suppliers.

Regarding the geographical distribution of suppliers, it is highly diversified, highlighting the complexity and internationalization of supply chains in the automotive sector. Many companies rely on global suppliers, with combinations that include South America, Asia, Africa, and Europe. This geographical diversification mainly reflects corporate strategies oriented towards cost optimization, access to critical raw materials, and presence in emerging markets. Some respondents focus on specific regions, probably due to regional corporate strategies, consolidated partnerships, or particular needs related to the required materials. In general, automotive companies turn to multiple suppliers located in different continents and countries; strategic plants for battery supply are indeed distributed globally. It is noted, however, that in addition to consolidated suppliers in continents like Asia and South America, other electric battery producers are emerging, investing in facilities to support the demand of car manufacturers. While the data relating to the role of respondents and that relating to the geographical distribution of suppliers do not seem to be particularly significant in terms of correlation with other trends emerged from other questions, the data analysis revealed a possible significant correlation between the number of employees of a company and the level of transparency and sustainability in relationships with suppliers. To verify this hypothesis, a correlation study was conducted between the question relating to the number of employees and other questions focused on sustainability practices and transparency in the supply chain. The results showed:

- A significant positive correlation (+0.68) between the number of employees (Q3) and the level of raw materials suppliers' involvement in setting environmental objectives suggests (Q24) that larger firms are more inclined to share their sustainability goals with their suppliers, indicating a higher degree of transparency along the supply chain.

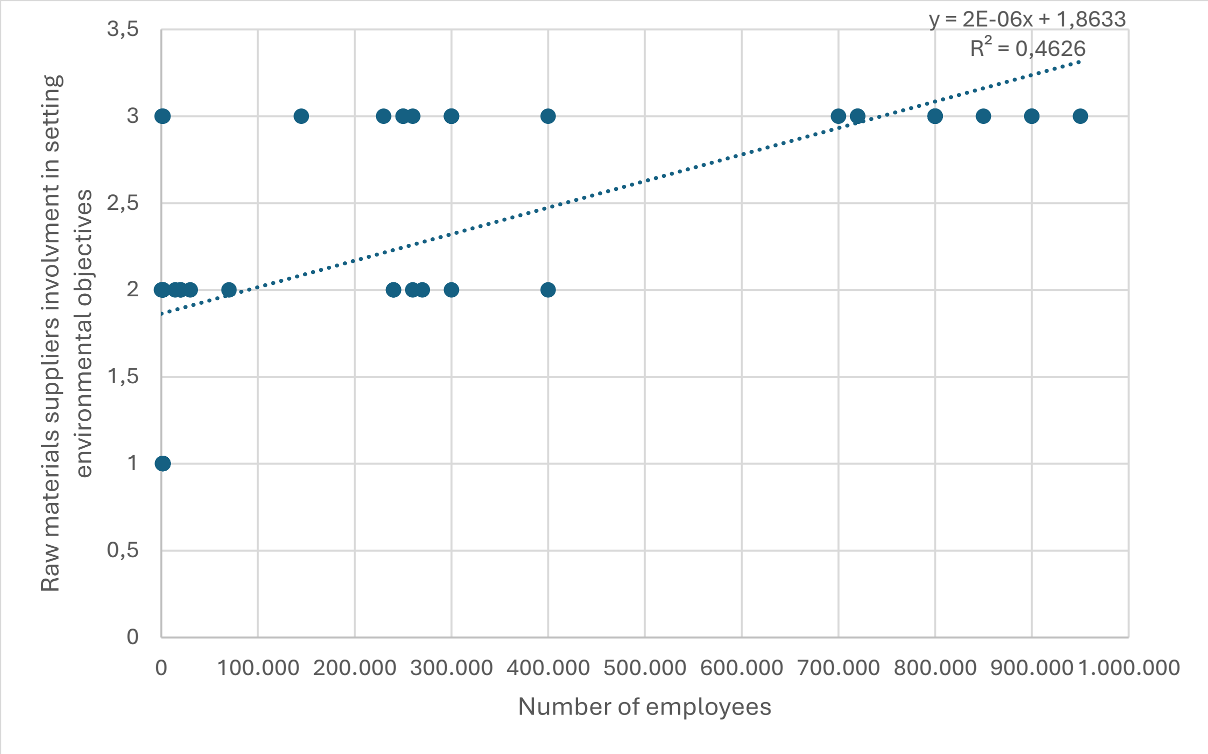

Figure 1: Relationship between the number of employees and the level of raw materials suppliers involvement in setting environmental objectives

- A moderate positive correlation (+0.52) between the number of employees (Q3) and the level of raw material traceability was observed (Q11). This indicates that larger companies generally possess more resources and structured mechanisms, enabling them to ensure greater transparency throughout their supply chain.

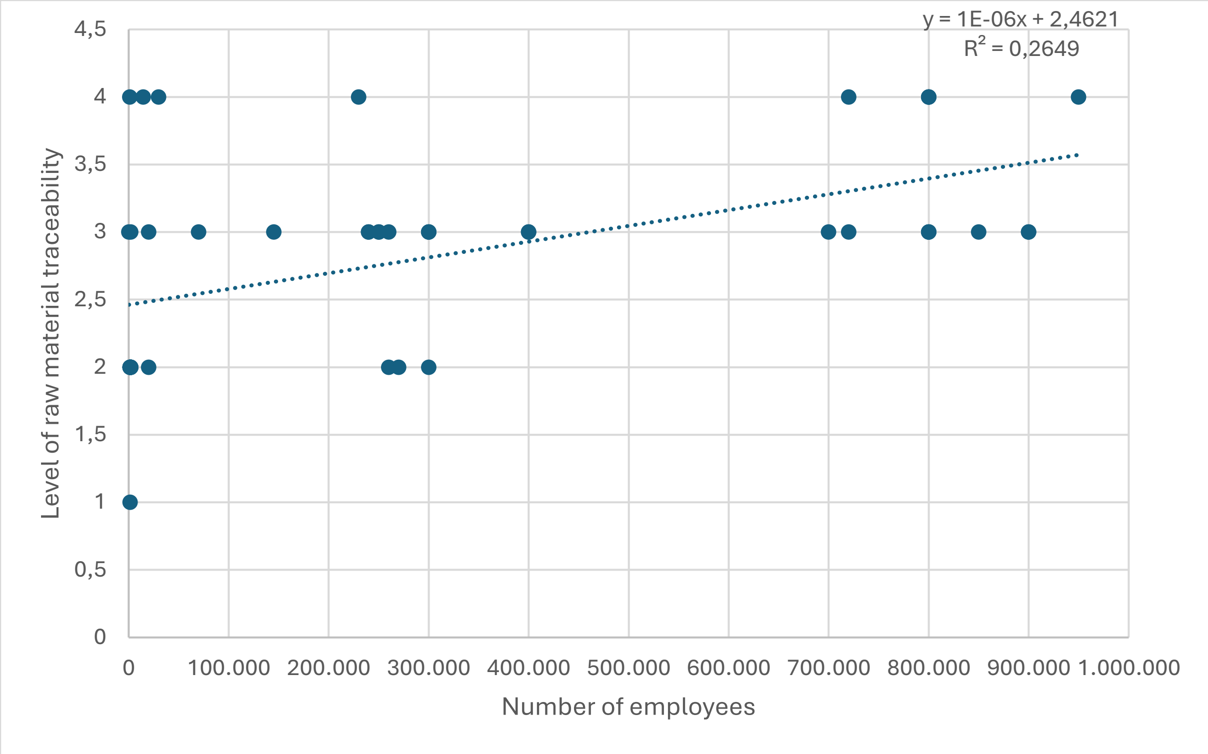

Figure 2: Relationship between the number of employees and the level of raw material traceability.

- A moderate correlation (+0.68) between the number of employees (Q3) and the number of suppliers managed (Q4). Larger companies tend to manage wider and more complex supply networks, reflecting operations on a global scale. Conversely, smaller companies work with local and fewer suppliers, with less investment in traceability.

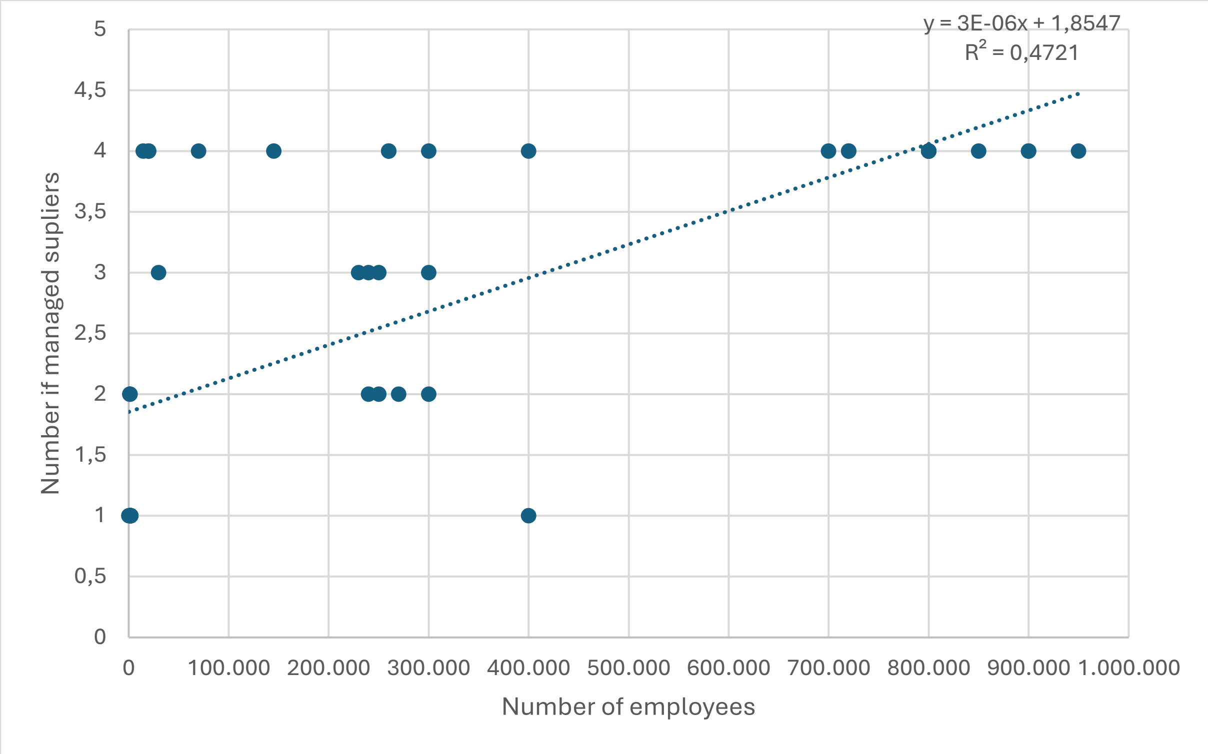

Figure 3: Relationship between the number of employees and the number of managed suppliers.

In all three correlations, the linear regression confirmed the statistical significance of the variables analyzed, highlighting relevant relationships and supporting the validity of the results obtained.

Delving into this link, three cases have been identified that clearly define three different corporate realities:

1. **Cluster 1**: Companies with a number of employees between 150 and 30.000.
2. **Cluster 2**: Companies with a number of employees between 70,000 and 400.000.
3. **Cluster 3**: Companies with a number of employees grater than 400.000.

Cluster 1 includes companies like DR Automobiles Groupe, which have limited production. DR, for example, currently has eight models in its range, of which only one variant is available as fully electric vehicles. The reduced production of electric vehicles and the lack of stringent statutory obligations make transparency and sustainability towards suppliers still a marginal theme. DR encounters limits in the large-scale implementation of advanced measures, especially considering limited resources and the focus on a niche market.

The data indicate that only 30% of companies in this cluster have implemented formal sustainability practices. The main challenges emerged include:

- High implementation cost: 48% of companies report that high costs represent a significant barrier.
- Limited traceability: 65% of the companies report minimal transparency in raw material traceability, admitting difficulties in monitoring most stages of the production process.
- Lack of investment in monitoring technologies: limited resources prevent the adoption of advanced tools for traceability and environmental monitoring.
- Limited ability to influence supplier practices: smaller companies have less interest in imposing sustainability standards and transparency practices on their suppliers.

Cluster 2 represents companies in a transition phase, such as the Stellantis N.V. group, which is facing the challenge of adapting to European regulations that, starting from 2035, ban the sale of new vehicles with internal combustion engines. Stellantis aims for carbon neutrality by 2038, adopting a systematic approach to sustainability that includes responsible management of raw materials and the imposition of specific emission limits on suppliers. The company actively monitors supply chains through corporate social responsibility programs (Stellantis 2023, p. 25).

50% of the companies in this cluster adopt traceability systems and conduct regular audits. However, barriers persist related to:

- Lack of uniform standards along the supply chain: 40% of companies highlight difficulties in coordinating sustainable practices with suppliers operating in different regions and regulatory contexts.
- Competitive pressures on material costs: 50% report that price-based competition limits the implementation of sustainable practices, as additional costs can affect competitiveness.

- Partial traceability: 75% of the companies in this cluster report only partial transparency regarding the traceability of raw materials, stating that traceability is only present at certain stages of the supply chain.

Cluster 3 includes the largest companies, such as the Volkswagen group, which show significant commitment towards sustainability. Volkswagen has implemented strategies to ensure sustainability in critical raw materials, establishing clear requirements for suppliers through the Code of Conduct for business partners. The company participates in global initiatives like "Drive Sustainability," aimed at improving social and environmental standards along the supply chain (Volkswagen 2024, pp. 12–14).

In this cluster:

- 100% of companies use advanced technologies for emission monitoring and traceability.
- 93% adopt tools like blockchain to monitor the origin of raw materials and conduct regular environmental audits.
- The primary barriers include the operational complexity, reported by 54%, of managing sustainability initiatives on a global scale.
- 62% of the companies in this cluster report partial transparency in the traceability of raw materials, while the remaining 38% report complete transparency in this regard.

The verification of the hypotheses and objectives of the thesis confirmed that company size significantly affects transparency towards suppliers and the ability to adopt sustainable practices along the supply chain. In particular:

- **In Cluster 1**, the main barriers are high implementation costs, resistance to change from suppliers, and lack of adequate technology. Engagement with suppliers is not systematic, and transparency is limited.
- **In Cluster 2**, companies face similar barriers but show greater involvement in setting measurable objectives. Price-based competition limits the adoption of sustainable

practices, as additional costs can impact competitiveness. The sector is highly competitive, and customers are generally price-sensitive. Mitigation strategies include improvements in energy efficiency and reforestation initiatives. However, direct engagement with suppliers remains moderate.

- **In Cluster 3**, despite facing challenges related to operational complexity and lack of stringent regulations in some markets, companies show greater commitment in setting measurable objectives and adopting advanced technologies for transparency. Strategies like purchasing carbon credits and implementing innovative technological solutions are prevalent, although transparency regarding results is not always guaranteed.

Regulatory and market pressures represent an important driver for the adoption of sustainable practices, especially for medium-large companies. Large companies (Cluster 3) are often subject to stringent regulations, such as the 2023 EU Battery Regulation, which requires complete traceability of raw materials and emission reduction. Conversely, smaller companies (Cluster 1) tend not to be subject to such regulations and face difficulties in managing a sustainable supply chain due to lack of resources and technological capabilities.

To develop a sustainable project management framework applicable to real contexts, it is fundamental for the future to develop personalized strategies for each cluster, encouraging the adoption of technological and regulatory solutions that can improve sustainability along the entire supply chain. In particular:

- **Cluster 1**: These companies need regulatory and collaborative support to overcome economic and technological barriers. Promoting incentives for the adoption of monitoring technologies, developing training and certification programs for suppliers, and facilitating access to dedicated financing could facilitate the transition towards more sustainable practices.

- **Cluster 2**: With targeted investments, these companies have the potential to become leaders in sustainable practices in the medium term. Promoting collaboration between companies of different sizes to share best practices and resources, as well as encouraging joint research and development projects, can accelerate this process.
- **Cluster 3**: The largest companies must harmonize sustainability with operational complexity, continuing to invest in innovative technologies and developing effective governance models. It is essential that these companies take a leading role in the industry, promoting global standards and collaborating with international stakeholders to address environmental challenges.

6. Conclusions: Summary of Results and Future Perspectives for Sustainability in the Automotive Sector

In recent years, sustainability has become an absolute priority for the automotive sector, especially in the context of electric vehicles. This study has demonstrated that the ability of companies to adopt sustainable and transparent practices depends significantly on their size and available resources. However, it is not only size that determines the success of these initiatives. Strategic vision, collaboration, and the adoption of innovative technologies are necessary to tackle the complex challenges related to sustainability.

In a sector where regulatory pressures and stakeholder expectations are constantly growing, the responsibility of companies is no longer limited to the production of ecological vehicles. Today, sustainability must be integrated into every phase of the supply chain, from the management of critical raw materials to the recycling of batteries. This path is not only a response to regulatory obligations but represents an opportunity to redefine competitive advantage in a global market increasingly oriented towards sustainability.

One of the main findings of this research concerns the relationship between company size and the effectiveness of sustainable practices. Larger companies, with greater financial and operational resources, generally manage to implement advanced technologies to improve the traceability of raw materials and conduct regular environmental audits. However, operational complexity and the need to harmonize global standards represent a significant challenge even for these organizations. On the other hand, smaller companies face greater difficulties due to limited resources and a lesser ability to influence suppliers. This is where targeted interventions, such as tax incentives, facilitated access to emerging technologies, and specific training programs, can make a difference, supporting these enterprises in the transition towards more sustainable practices.

The potential of advanced technologies, such as blockchain, artificial intelligence, and the Internet of Things (IoT), deserves particular attention. These tools allow real-time monitoring of sustainability along the entire supply chain, increasing transparency, operational efficiency, and reducing the risks of unethical practices. However, it is fundamental that these technologies are also made accessible to smaller enterprises through incentive programs, public-private partnerships, and collaborative initiatives between companies and academic institutions.

Despite the results obtained, this study is not without limitations. The sample size and the self-reported nature of the collected data could influence the interpretation of the conclusions. Participants responses could be influenced by social desirability bias or subjective interpretations of the questions. To address these limitations, future studies could adopt a longitudinal approach, monitoring the evolution of sustainable practices over time, or include integrative quantitative data, such as environmental and social performance indicators. Additionally, a comparison with other industries, such as electronics or textiles, could offer useful insights to identify transferable practices and innovations applicable to the automotive sector.

Looking to the future, it is evident that the success of the ecological transition will depend on the ability of companies to adapt to an increasingly complex and competitive context. Smaller enterprises need support to overcome technological and economic barriers, while medium-sized ones can become leaders in sustainable practices through targeted investments, collaborative strategies, and greater integration of digital technologies. Larger companies, on the other hand, must continue to invest in advanced technologies, develop effective governance models, and take a proactive role in defining international standards.

In a sector like electric vehicles, characterized by strong competition, rapid technological advancements, and complex operational challenges, sustainability is no longer a choice but an urgent necessity. It is fundamental that companies harmonize economic needs with sustainable practices to remain competitive in the long term. Building transparent and sustainable supply chains represents not only a response to regulatory pressures but also a strategy to responsibly address the challenges of climate change, contributing to the achievement of the Paris Agreement objectives and the United Nations Sustainable Development Goals.

In conclusion, the ecological transition of the automotive sector requires an integrated and multisectoral approach involving all actors, from private companies to public institutions, from suppliers to end consumers. Through targeted strategies, investments in research and development, incentive policies, and closer collaboration among all stakeholders, it is possible to promote a sustainable transformation of the sector. Only through collective commitment and a long-term vision will it be possible to address the environmental, social, and economic challenges of our time, building a future where innovation, social responsibility, and environmental protection are the foundations of a prosperous, resilient, and responsible automotive industry.

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Appendix

Survey:

Q1 What is your role in the company (select the one closest to your position)

1. Executive
2. Sustainability Manager
3. Purchasing Manager
4. Supply Chain Manager
5. Other

Q2 How long have you worked in the automotive sector?

1. Less than 1 year
2. 1-5 years
3. 5-10 years
4. 10-20 years
5. More than 20 years

Q3 How many employees does your company have?

- Open question

Q4 How many raw materials suppliers does your company work with?

1. 1-10
2. 11-50
3. 51-100
4. More than 100

Q5 In which geographic regions are most of your raw materials (for electric vehicles) suppliers located?

1. Europe
2. North America

3. South America
4. Asia
5. Africa

Q6 Does your company conduct regular audits on raw materials suppliers to monitor their sustainability practices? (Audits could include social, environmental or governance aspects)

1. Yes, annually
2. Yes, but less frequently
3. No, we do not conduct audits

Q7 Correlated to the question before, if yes how often?

1. Annually
2. Every two years
3. Every three years
4. Ad-hoc

Q8 What percentage of the raw materials used by your suppliers come from certified sustainable sources (e.g., ISO 14001, Fairtrade)?

1. 0-25%
2. 26%-50%
3. 51%-75%
4. 76%-100%

Q9 What actions are being taken to reduce CO_2 emissions along the supply chain? (Select all that apply)

1. Use of low-emission transportation
2. Collaboration with suppliers to reduce energy consumption
3. Optimization of production processes
4. No specific actions

5. Other

Q10 Has your company implemented or planned the use of real-time monitoring technologies to track environmental impacts along the supply chain?

1. Yes, already implemented
2. Yes, planned within the next year
3. No, not planned

Q11 How transparent is your supply chain in terms of raw material traceability?

1. Not transparent
2. Minimally transparent (difficulties in tracing some stages)
3. Partially transparent (traceability in some stages of the chain)
4. Completely transparent (full traceability to the origin)

Q12 What data do suppliers share to ensure the traceability of raw materials? (Select all that apply)

1. Geographical origin of raw materials
2. Sustainability certifications
3. CO_2 emissions reports
4. Report on emissions from energy used (renewable and non-renewable).
5. No specific data is shared
6. Other

Q13 Does your company require raw material suppliers to provide regular reports on their CO_2 emissions or other environmental impacts?

1. Yes, regularly
2. Yes, but irregularly
3. No, we do not request such reports

Q14 What criteria are prioritized when selecting raw material suppliers? (Select all that apply)

1. Price
2. Sustainability certifications
3. Respect for human rights and working conditions
4. Production capacity
5. Other

Q15 How does your company actively collaborate with suppliers to improve sustainability practices? (Select all that apply)

1. Training suppliers on best sustainability practices
2. Jointly setting emission reduction targets
3. Sharing technology and innovations to improve efficiency
4. No active collaboration
5. Other

Q16 Has your company established incentives for suppliers that meet specific sustainability goals?

1. Yes, financial incentives
2. Yes, non-financial recognition (e.g., certificates)
3. No, there are no specific incentives

Q17 Does your company use artificial intelligence (AI) tools or advanced technologies to monitor the efficiency and sustainability of the raw materials supply chain?

1. Yes, already implemented
2. No, but planned within the next 2 years
3. No, not planned
4. Other

Q18 What technological innovations (e.g., blockchain, IoT) have been adopted to improve the traceability of raw materials and transparency in your supply chain? (Select all that apply)

1. Blockchain
2. Internet of Things (IoT)
3. Automated tracking systems
4. No technological innovations adopted
5. Other

Q19 How aware is your company of the environmental impacts associated with raw material extraction (e.g., lithium, cobalt, nickel)?

1. Moderately aware, but with limited monitoring
2. Unaware
3. Very aware, we actively monitor such impacts
4. Minimally aware, we do not monitor the impacts

Q20 What type of environmental impact concerns you the most in the context of raw material extraction? (Select all that apply)

1. CO_2 emissions
2. Excessive water resource consumption
3. Deforestation
4. Social impacts (e.g., local working conditions)
5. No specific concern
6. Other

Q21 What do you consider to be the main operational challenges in making the electric vehicle supply chain more sustainable? (Select all that apply)

1. High costs of sustainable practices
2. Difficulty in monitoring the entire supply chain
3. Lack of transparency from suppliers
4. Lack of uniform regulations

5. Other

Q22 To what extent do you believe that adopting sustainable practices in the supply chain can improve your company's competitiveness?

1. Greatly, it increases reputation and competitive advantage
2. Moderately, but not a decisive factor
3. Slightly, the costs outweigh the benefits
4. Not relevant to our company

Q23 What carbon offsetting strategies has your company adopted to reduce the environmental impact of the supply chain? (Select all that apply)

1. Purchasing carbon credits
2. Reforestation
3. Improving energy efficiency
4. No offsetting strategy
5. Other

Q24 Has your company developed measurable targets for reducing emissions throughout the raw materials supply chain?

1. They are not involved
2. They are informed, but not directly involved
3. They are actively involved in goal setting

Q25 Does your company have training programs or initiatives to help raw materials suppliers improve their sustainability practices?

1. Yes, we offer regular training programs
2. Yes, but in a limited capacity
3. No, we do not offer training programs
4. Other

Q26 What barriers do you encounter in collaborating with raw materials suppliers to improve the sustainability of the supply chain? (Select all that apply)

1. High implementation costs
2. Lack of adequate technology
3. Resistance to change from suppliers
4. Lack of stringent regulations
5. No significant barriers

Q27 Does your company comply with international environmental regulations throughout the entire supply chain?

1. Yes, we comply with all international regulations
2. Yes, but only in regions where applicable
3. No, there are no strict controls in some areas

Q28 Does your company comply with international environmental regulations throughout the entire supply chain?

1. ISO 14001
2. EMAS (Eco-Management and Audit Scheme)
3. Fairtrade
4. No certification
5. Other

Q29 What other practices or innovations do you believe could improve the sustainability of your supply chain?

- Open question