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σχετικά με την Επίδραση των Ηλεκτρικών
Οχημάτων στην Παραδοσιακή
Εφοδιαστική Αλυσίδα των
Αυτοκινητοβιομηχανιών.**

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**A Systematic Literature Review on the
Impact of Electric Vehicle Adoption on the
Traditional Automotive Supply Chain**

Section: Industrial Management & Operational Research

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Υπεύθυνη δήλωση για λογοκλοπή και για κλοπή πνευματικής ιδιοκτησίας:

Έχω διαβάσει και κατανοήσει τους κανόνες για τη λογοκλοπή και τον τρόπο σωστής αναφοράς των πηγών που περιέχονται στον οδηγό συγγραφής Διπλωματικών Εργασιών. Δηλώνω ότι, από όσα γνωρίζω, το περιεχόμενο της παρούσας Διπλωματικής Εργασίας είναι προϊόν δικής μου εργασίας και υπάρχουν αναφορές σε όλες τις πηγές που χρησιμοποίησα.

Οι απόψεις και τα συμπεράσματα που περιέχονται σε αυτή τη Διπλωματική εργασία είναι του συγγραφέα και δεν πρέπει να ερμηνευθεί ότι αντιπροσωπεύουν τις επίσημες θέσεις της Σχολής Μηχανολόγων Μηχανικών ή του Εθνικού Μετσόβιου Πολυτεχνείου.

Ανδρέας Παπαδόπουλος

ΕΥΧΑΡΙΣΤΙΕΣ

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Ανδρέας Παπαδόπουλος

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ABSTRACT

This dissertation explores the transformative impact of electric vehicle (EV) adoption on traditional automotive supply chains. It focuses on structural, logistical and technological aspects. The purpose of this study is to analyze the challenges and opportunities of the EV integration. They include disruptions in material flows, supplier dynamics and after-sales services. A systematic literature review methodology was employed, leveraging peer-reviewed articles from 2019 to 2024. The articles selection process was based on rigorous inclusion criteria. The analysis integrates data from 52 studies. The findings were categorized into themes. The key findings reveal a paradigm shift in supply chain structures driven by EV-specific demands for components like lithium-ion batteries and electric drivetrains. Traditional supply chains, that are built around internal combustion engine vehicles, face challenges. The most important of them is material shortages, the need for advanced technologies and the misalignment with the circular economy principles. Technological innovations, like AI, IoT and blockchain, are critical enablers for enhancing supply chain resilience. This dissertation also showed the importance of the regulatory frameworks and the market dynamics in accelerating the EV adoption. At this point, it is indicated that significant challenges include adapting to dual production environments, managing geopolitical risks related to critical minerals and developing sustainable recycling systems. This review concludes by highlighting the need for collaboration across stakeholders, the need of investment in digital transformation and the need of strategic policy interventions to address these challenges.

Keywords: Automotive Supply Chain, Electric Vehicles, Supply Chain.

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CHAPTER 1. INTRODUCTION

1.1 Background and Research Motivation

Beginning with a short overview of the traditional automotive supply chain, it is mentioned that the traditional automotive supply chain has been a complex and well-optimized system. It is about a system, which incorporates multiple tiers of suppliers and manufacturers. It also incorporates multiple tiers of distributors, as well, working in synchrony to deliver vehicles to consumers worldwide. It's a system, that relies heavily on just-in-time (JIT) manufacturing. It, more specifically, minimizes inventory. It also reduces costs, while, at the same time, ensures components to arrive precisely, when it is needed in the process of the production (Smith & Johnson, 2020).

Within this structure, multiple key players are included. Some of them are raw material suppliers, tiered component suppliers, original equipment manufacturers (OEMs) and distributors, as well. Each one of these key players plays a significant role in the timely assembly. Each one of them, also, plays a significant role in the delivery of the vehicles, too (Miller et al., 2019).

It must also be mentioned that the automotive supply chain has evolved over decades. It has developed a strong dependency on internal combustion engine (ICE) components. These components require a variety of parts. Characteristic examples of such parts are transmissions, exhaust systems or fuel delivery mechanisms. It's about a dependency, which has created a wide network of suppliers. These suppliers are specialized in focusing on producing ICE-specific parts, that are incompatible with the electric vehicles (EVs) (Brown, 2021).

Since the automotive sector shifts toward the electric vehicles, there is a diminishing need for the above-mentioned parts. This need leads to a potential disruption in the established supply chain. It also leads to forcing traditional players to reconsider their roles and to adapt their capabilities, too (Garcia & Liu, 2022).

At this point, it is mentioned that the shift toward electric vehicles is driven by environmental concerns. It is also driven by consumer demand and by regulatory pressures, too. It's a shift, which has introduced significant changes in the automotive supply chain. Unlike traditional ICE vehicles, the electric vehicles require fewer moving parts. They also require eliminated need for certain components, such as for

example fuel injectors, catalytic converters and transmissions. This means that they have disrupted the demand for these above-mentioned products (Wilson & Green, 2023).

Instead, the focus has shifted toward new critical components. These components include lithium-ion batteries and electric motors. One more critical component are power electronics. All these components require different raw materials and manufacturing expertise (Evans et al., 2021).

The transition to electric vehicles, also, introduces new players into the supply chain, as it was also mentioned before. Such players are battery manufacturers and raw material suppliers, that are specialized in lithium, cobalt and nickel. They are new key players that are essential for the electric vehicles' battery production (Taylor, 2022).

Furthermore, traditional automotive suppliers must face the challenge of pivoting toward these new technologies or risk obsolescence. For instance, some business entities have begun the development of partnerships. Some other companies have begun the acquirement of expertise in battery technology. They are about strategies that companies implement, for them to remain competitive in the automotive market (Chen & Zhao, 2020).

Also, it has to be mentioned that the adoption of electric vehicles, not only affects upstream suppliers. It furthermore disrupts downstream logistics and after-sales services. The electric vehicles supply chain requires a different logistics strategy. This is happening due to the sensitivity and regulations that exist around battery handling and transportation (Anderson, 2023).

Furthermore, after-sales service for electric vehicles demands specialized knowledge in battery maintenance and in software updates, too. These are fundamentally different from traditional ICE maintenance. These shifts indicate that a transformation of the automotive supply chain is necessary for the traditional businesses, in order to remain competitive. They are also necessary for them, in order to meet the growing demand for electric mobility (Martinez & Gupta, 2022).

1.2 Research Purpose and Objectives

The main research question that is placed in the context of this systematic review is: “How does the adoption of electric vehicles impact the traditional automotive supply

chain?” Specifically, it’s a research question, that aims to explore the structural, logistical and economic transformations. It’s multiple transformations that are necessary for traditional automotive supply chains, for them to remain viable in an increasingly electric vehicle-oriented market.

The understanding of the impact of electric vehicle adoption on the traditional automotive supply chain requires an in-depth examination of several factors that are interrelated. This includes changes in supplier networks. It also includes demand for specific raw materials and manufacturing processes. It furthermore includes after-sales services, as well. By answering to this research question, the current dissertation seeks to analyze the challenges and opportunities, that are faced by the current industry’s stakeholders. It also aims to identify the most critical areas for adaptation and innovation in the supply chain.

The purpose of this systematic literature review is to consolidate the already existing knowledge on the effects of the electric vehicle adoption on the automotive supply chain. This systematic literature review also aims to identify the existing gaps, in which further research is needed. As the automotive industry is transported from ICE to electric vehicles, traditional supply chain structures are obliged to adapt to accommodate new technologies, new materials and new innovative processes. This systematic review aims the assessment of the extent of these changes, by evaluating how different parts of the supply chain are responding to the demands that are related to the electric vehicle. By the examination of a broad range of literature, this dissertation is going to contribute to a deeper understanding of the way through which the supply chain must evolve to effectively support electric vehicle production and distribution.

In order to address the above research question, the current systematic literature review has the following objectives:

- Analysis of the changes in supply chain demand for materials and components, that are required in electric vehicle production, in comparison to ICE vehicles.
- Identification of the challenges and opportunities for traditional automotive suppliers for the adaptation of their production processes and products, for them to meet the specific requirements of the electric vehicle technology.
- Examination of the impact of electric vehicle’s adoption on downstream logistics and after-sales service.

- Assessment of the role, that is played by the technological innovation in supporting the transformation of the supply chain.
- Identification of the knowledge gaps and future research directions, for further development of the automotive supply chain to be supported.

By achieving the above-mentioned objectives, this dissertation aims to offer a structured understanding of how traditional automotive supply chains play a significant role in reshaping in response to electric vehicles' adoption. This literature review will not only highlight the current adaptations. It is also going to provide a basis for future research on sustainable and efficient supply chain practices, from which a fully electric automotive industry might be supported.

1.3 Structure of the Dissertation

The current Introduction chapter gives an overview of the current dissertation's focus and of its motivations, too. This chapter begun with the background and context of the research topic and then, the Research Purpose and Objectives were presented, along with the main research question. Finally, this introductory chapter concluded with an outline of this dissertation's structure.

Chapter 2 describes the methodology, that we used to conduct the current systematic literature review. More specifically, it includes a detailed explanation of the literature review's design and its search strategy that was employed in order to identify the relevant studies that are going to be analyzed. It also includes the inclusion and exclusion criteria, that had been used in order for us to ensure the quality and the relevance of the sources that were selected. The second chapter also discusses the data collection and analysis methods, that had been applied in synthesizing findings from the literature.

In Chapter 3, the traditional automotive supply chain is detailed analyzed. This chapter begins with an exploration of the structure of the traditional supply chain. It describes the primary stages and actors, that are involved in the production and distribution of ICE vehicles. Afterward, it outlines the core processes and material flows in the supply chain. At this point, further focus is placed on the roles of suppliers, manufacturers and distributors.

Chapter 4 examines how the adoption of electric vehicles impacts the structures of traditional automotive supply chain. Analytically, this chapter explores the drivers of

the electric vehicles' adoption. It includes regulatory pressures, shifts in the preferences of the consumers and environmental considerations, too. It then emphasizes on the differences that exist between traditional and EV supply chains. It also discusses the resulting challenges for traditional supply chain structures.

Chapter 5 focuses specifically on the effects of EV adoption on suppliers and manufacturers. This chapter begins by the analysis of the impact on raw material suppliers. Emphasis is placed on the increased demand for materials, that are essential to EV's production. The challenges, which are faced by traditional automotive manufacturers, are then examined. Finally, this chapter assesses the role of technology companies in the support of these shifts, particularly in relation to systems and materials that are required in the EVs.

Chapter 6 addresses the downstream impacts of the EVs' adoption. The analysis includes the distribution of logistics and after-sales services, too. Specifically, this chapter discusses the unique challenges posed by EVs, in terms of logistics requirements for transporting and storing batteries. It also explores the specialized after-sales services, that are required for EV's maintenance. Some indicative examples are battery management and software updates.

In Chapter 7, key technological innovations and trends that influence the EV's supply chain are further analyzed. This includes advancements in battery technology. It also includes improvements in charging infrastructure. Furthermore, this analysis includes the adoption of smart technologies like the Internet of Things (IoT) and Artificial Intelligence (AI) for the optimization of EV production and supply chain management.

Chapter 8 includes three case studies, while Chapter 9 synthesizes the findings from this systematic literature review. This chapter discusses the key insights of this analysis. It highlights the main transformations, that are needed in the automotive supply chain, in order for the shift towards EVs to be supported. It also identifies the significant challenges and opportunities that arise for this industry's stakeholders. Finally, this final chapter discusses the limitations of the study and it gives recommendations for future research in this field.

CHAPTER 2. SYSTEMATIC LITERATURE REVIEW

METHODOLOGY

2.1 Literature Review Design and Search Strategy

The systematic literature review for this dissertation was conducted, in order to identify and synthesize the already existing knowledge on the impact of electric vehicle (EV) adoption on the traditional automotive supply chain. In order to ensure a comprehensive and unbiased collection of relevant studies, the following strategy was implemented:

At first, it is mentioned that two primary search strings were used:

- “Electric Vehicle Adoption” AND “Automotive Supply Chain”
- “Electric Vehicle” AND “Automotive Supply Chain”

These keywords were selected to capture the intersection of EV adoption and its implications for supply chain dynamics.

The search was conducted across four major academic databases:

- Science Direct
- JSTOR
- MDPI
- Springer Open

These platforms were chosen for their extensive repositories of peer-reviewed journal articles. They were also chosen because of their relevance to topics in technology, engineering and supply chain management.

Table 1. Databases research results

Keywords	Database	Results	Accepted
"Electric Vehicle Adoption" AND "Automotive Supply Chain"	Science Direct	4	3
"Electric Vehicle" AND "Automotive Supply Chain"	Science Direct	36	34
"Electric Vehicle Adoption" AND "Automotive Supply Chain"	JSTOR	0	0
"Electric Vehicle" AND "Automotive Supply Chain"	JSTOR	1	1
"Electric Vehicle Adoption" AND "Automotive Supply Chain"	MDPI	3	3
"Electric Vehicle" AND "Automotive Supply Chain"	MDPI	12	9

"Electric Vehicle Adoption" AND "Automotive Supply Chain"	Springer Open	0	0
"Electric Vehicle" AND "Automotive Supply Chain"	Springer Open	2	2

As it is observed by the information given in Table 1, the database search yielded a total of 58 results. The distribution of results by database and search string was as follows:

- Science Direct database gave 40 results, with 39 accepted after screening.
- JSTOR database gave 1 result, which was accepted.
- MDPI database gave 15 results, with 12 accepted after screening.
- Springer Open database gave 2 results, that were both accepted.

Afterall, the search results were screened for relevance, based on their titles, their abstracts and their full text, where it was necessary. Duplicates were removed, in order for us to ensure a unique set of studies. The final corpus consisted of 52 accepted articles. All of these 52 articles that participated in the current systematic literature review directly addressed the research topic.

2.2 Inclusion and Exclusion Criteria

In order to ensure the validity and the relevance of the above selected sources, the following inclusion and exclusion criteria were applied:

Inclusion Criteria:

- Articles published in peer-reviewed journals.
- Studies that explicitly address the impact of EV adoption on the automotive supply chain.
- Articles available in English.
- Research published between 2019 and 2024 to focus on recent developments and trends.

Exclusion Criteria:

- Studies unrelated to automotive supply chains or EV adoption.
- Non-peer-reviewed articles, including blogs, editorials and opinion or review pieces.
- Duplicates identified during the search process.
- Articles lacking sufficient methodological rigor or detail.

By applying the above-mentioned criteria, the final set of articles included only those that were most relevant and credible for addressing the research objectives. In the context of this systematic literature review all of the above-mentioned 52 articles were evaluated as relevant.

2.3 Data Collection and Analysis

The process for the current data collection and analysis involved data coding, the categorization of the selected data and the final synthesis of the findings. More specifically, each of these steps is further analyzed as following:

1. *Data Coding*: A structured data extraction form was developed for the collection of the relevant information from each article. This form included publication details, methodology, key findings and the relevant findings to the research objectives. This ensured consistency in capturing and organizing data across the 52 selected studies.
2. *Categorization*: The 52 articles were categorized into thematic areas reflecting the core thematic aspects of their research.
3. *Synthesis of Findings*: The extracted data were synthesized to identify common trends, challenges and opportunities that are mentioned across the 52 studies. The main key themes were identified and discussed in subsequent chapters. During the procedure of the synthesis of the findings, it was decided that most of the 52 articles had to participate and be referred in more than one thematic categories.

This above-analyzed rigorous approach that concerned data collection and analysis, ensured that this systematic review provides a robust foundation for achieving the dissertation’s objectives.

The following table presents the analysis of the 52 articles of this dissertation:

Table 2. Presentation of SLR articles

Title	Author(s)	Year	Focus Area	Methodology	Key Findings
An integrated supply chain network design for advanced air mobility aircraft manufacturing using stochastic optimization	E.F. Dulia, S.A.M. Shihab	2024	Supply chain design for eVTOL manufacturing	Stochastic optimization	Proposed model optimizes eVTOL production under uncertainties, outperforming benchmark models.

Artificial intelligence and machine learning in purchasing and supply management: A mixed-methods review of the state-of-the-art in literature and practice	J.M. Spreitzenbarth, C. Bode, H. Stuckenschmidt	2024	AI and ML in supply chain management	Mixed-methods review	Identified gaps in AI/ML applications in procurement, offering recommendations for future research.
New energy vehicle R&D strategy with supplier capital constraints under China's dual credit policy	W. Meng, M. Ma, Y. Li, B. Huang	2022	NEV R&D strategy and dual credit policy	R&D decision modeling under constraints	Dual credit policy aids NEV growth; solutions for financial constraints include loans and cost-sharing.
Spatially-explicit optimization of an integrated wind-hydrogen supply chain network for the transport sector: The case study of Sicily	E. Cutore, A. Fichera, G. Inturri, M. Le Pira, R. Volpe	2024	Hydrogen supply chain optimization for transport	Mixed-integer linear programming	Hydrogen from wind farms can decarbonize transport; gaseous transport preferred initially.
Complexity and chaos control of dynamic evolution in energy vehicle production decisions	C. Xian, J. Du, F. Shahzad, L. Xu, S. Jin	2023	Dynamic game modeling for NEV and fuel vehicle production	Chaos theory and dynamic evolution modeling	Feedback control suppresses chaos in production decisions, aiding smooth market transformation.
Energy Efficiency Vision 2050: How will new societal trends influence future energy demand in the European countries?	H. Brugger, W. Eichhammer, N. Mikova, E. Donitz	2021	Impact of societal trends on energy demand in EU by 2050	Scenario development and expert consultations	New societal trends can reduce energy demand significantly with strong policies.
Evaluation of Project Management Practices in the Automotive Original Equipment Manufacturers	A. De Marco, G. Mangano, P. De Magistris	2021	Project management in automotive OEMs	Empirical survey and statistical analysis	PM adoption varies in automotive OEMs; logistics benefits more than ICT.
Designing reverse supply networks for carbon fibres: Enabling cross-sectoral circular economy pathways	N.L. Trivyza, A. Rentizelas, S. Oswald, S. Siegl	2022	Reverse supply networks for carbon fiber recycling	MILP optimization for reverse supply chains	Cross-sector circular economy pathways for CFRPs are viable and cost-effective.
Intelligent location-routing for sustainable reverse supply chain of end-of-life vehicles considering awareness cost and carbon penalty	H. Yan, Y. Liu, K. Kaliyaperumal	2024	Reverse supply chain optimization for ELVs with sustainability focus	Mathematical modeling with multi-objective algorithms	Awareness costs improve sustainability metrics; carbon penalties reduce processing efficiency.
A large multi-group decision-making technique for prioritizing the big data-driven circular economy practices in the automobile component manufacturing industry	Sachin S. Kamble, Amine Belhadi, Angappa Gunasekaran, L. Ganapathy, Surabhi Verma	2021	Big data-driven circular economy in automobile components	PROMETHEE decision-making approach	BDDCE practices enhancing internal supply chain integration rank highest.
Enhancing circularity in the car sharing industry: Reverse supply chain network design optimisation for reusable car frames	Athanasios Rentizelas, Nikoletta L. Trivyza	2022	Reverse supply chain optimisation for reusable car frames	MILP optimisation for reverse supply chains	Economies of scale and frame design enhance cost-efficiency in car sharing.
Integrated operations planning model for the automotive wiring industry	Imen Safra, Kaouther Ghachem, Faiza	2024	Integrated planning in	Integer linear programming for planning	Integrated operations planning reduces lead times by 60%.

	Benabdallah, Hind Albalawi, Lioua Kolsi		automotive wiring production		
Development of Dynamic Capabilities for Automotive Industry Performance under Disruptive Innovation	Atichat Rotjanakorn, Pornrat Sadangharn, Khahan Na-Nan	2020	Dynamic capabilities for disruptive innovation in automotive	Cross-sectional survey with statistical analysis	Dynamic capabilities mediated by innovation enhance firm performance.
Concentration of power: A UK case study examining the dominance of incumbent automakers and suppliers in automotive sociotechnical transitions	Jean-Paul Skeete	2019	Power dynamics in UK automotive transitions	Case study with sociotechnical analysis	Incumbents leverage regulatory frameworks to dominate transitions.
Regionalisation and cross-region integration. Twin dynamics in the automotive international trade networks	Margherita Russo, Fabrizio Alboni, Jorge Carreto Sanginés, Manlio De Domenico, Giuseppe Mangioni, Simone Righi, Annamaria Simonazzi	2023	Trade networks and regionalisation in the automotive industry	Infomap multilayer clustering for trade analysis	Trade networks show increased integration and hierarchy over 25 years.
Environmental asymmetries in global value chains: The case of the European automotive sector	Hugo Campos-Romero, Oscar Rodil-Marzabal, Ana Laura Gomez Perez	2024	Environmental asymmetries and emissions in EU automotive value chains	Multi-regional input-output and panel data analysis	Eastern European economies bear higher environmental impacts; no evidence for pollution haven/hale hypothesis.
Turning the wheel: Measuring circularity in Swedish automotive products	Milan Mansuino, Jagruti Thakur, Akshaya Lakshmi	2024	Circularity indicators for the Swedish automotive industry	Qualitative and quantitative assessment of circularity indicators	New framework highlights gaps in circularity within the Swedish automotive sector.
Paving the Green Path: A Maturity Model for Digital Decarbonization	Tamer Abdulghani, Nizar Abdelkafi, Hans-Rüdiger Lange, Herwig Winkler	2024	Digital maturity models for decarbonization in automotive	Systematic literature review and maturity model development	Proposed model guides decarbonization efforts using digital strategies.
Estimation of state of health based on charging characteristics and back-propagation neural networks with improved atom search optimization algorithm	Yu Zhang, Yuhang Zhang, Tiezhou Wu	2023	Battery health estimation using machine learning	Neural network with atom search optimization	SOH estimation achieves errors below 1.5%, improving battery management.
How do we decarbonize one billion vehicles by 2050? Insights from a comparative life cycle assessment	Da Huo, Ben Davies, Jianxin Li, Nadine Alzaghri, Xin Sun, Fanran	2024	Life cycle assessment for decarbonizing global vehicle fleets	Comparative life cycle assessment	Cross-country comparison reveals tailored strategies for effective vehicle decarbonization.

	Meng, Amir F.N. Abdul- Manan, Jon McKechnie, I. Daniel Posen, Heather L. MacLean				
The transformation of the automotive industry toward electrification and its impact on global value chains	Mario Rísquez Ramos, María Eugenia Ruiz-Galvez	2024	Global value chain impacts from automotive electrification	Case study with multi-level analysis	Electrification challenges traditional suppliers and reshapes employment patterns.
Comparative environmental assessment of a novel functionally integrated e-axle for passenger cars	Michael Samsu Koroma, Daniele Costa, Thierry Coosemans, Maarten Messagie	2023	Life cycle assessment of a novel electric axle	Life cycle assessment with focus on component integration	FITGEN e-axle reduces emissions by 26% and energy use by 38% compared to state-of-the-art.
Forecasting the market value of power battery industry chain: A novel RRMIDAS-SVR model	Weiqing Wang, Zengbin Zhang, Liukai Wang, Hairong Lan, Yu Xiong	2024	Market value forecasting for power battery industry chain	RRMIDAS-SVR model for mixed-frequency data	RRMIDAS-SVR model outperforms traditional methods in forecasting market trends.
Examining industry vulnerability: A focus on mineral commodities used in the automotive and electronics industries	Ross L. Manley, Elisa Alonso, Nedal T. Nassar	2022	Mineral vulnerabilities in automotive and electronics supply chains	Linear programming and economic input-output analysis	Mineral supply disruptions can have cascading effects across multiple industries.
Evaluation of risk strategies for supply chain sustainability with interval-valued neutrosophic fuzzy EDAS	Ecenur Aliogulları, Yusuf Sait Türkan, Emre Çakmak, Erfan Babae Tirkolae	2024	Sustainability risks and strategies in automotive supply chains	Interval-valued neutrosophic fuzzy EDAS	Proposed strategies reduce sustainability risks and align with industry standards.
Life cycle assessment of battery electric vehicles: Implications of future electricity mix and different battery end-of-life management	Michael Samsu Koroma, Daniele Costa, Maeva Philippot, Giuseppe Cardellini, Md Sazzad Hosen, Thierry Coosemans, Maarten Messagie	2022	Life cycle assessment of electric vehicles with future scenarios	Scenario-based life cycle assessment	Recycling and renewable energy adoption can significantly reduce EV life cycle impacts.
Sources of uncertainty in the closed-loop supply chain of lithium-ion batteries for electric vehicles	J.T. Marcos, C. Scheller, R. Godina, T.S. Spengler, H. Carvalho	2021	Uncertainty in closed-loop supply chains for lithium-ion batteries	Empirical analysis of uncertainties in closed-loop supply chains	Environmental and control uncertainties dominate closed-loop supply chains for EV batteries.

Green mission creep: The unintended consequences of circular economy strategies for electric vehicles	Devyn Remme, James Jackson	2023	Unintended consequences of circular economy strategies in EVs	Critical analysis of national circular economy strategies	Circular economy strategies often neglect social equity and create ecological sacrifices.
Evaluation of the alternatives of introducing electric vehicles in developing countries using Type-2 neutrosophic numbers based RAFSI model	Ilgin Gokasar, Muhammet Devenci, Mehtap Isik, Tugrul Daim, Aws A. Zaidan, Florentin Smarandache	2023	Implementation strategies for EVs in developing countries	Type-2 neutrosophic numbers with RAFSI model	Direct EV implementation prioritized despite infrastructural and economic challenges.
Unleashing the circular economy in the electric vehicle battery supply chain: A case study on data sharing and blockchain potential	Elias Ribeiro da Silva, Jacob Lohmer, Michelle Rohla, Jannis Angelis	2023	Circular economy and blockchain in EV battery supply chains	Case study on data sharing and blockchain applications	Blockchain enhances transparency and supports circular economy in battery supply chains.
Shifting manufacturing: Electric vehicle supply strategy using the model for international EV trade	Francisco Parés Olguín, Pablo Busch, Minal Chandra, Gil Tal	2024	EV supply strategies in North America using trade modeling	MONET trade modeling and policy analysis	North American EV strategies require Mexico to shift 50% production to EVs by 2035.
Pricing and coordination of automotive supply chain for incorporating efficient charging facilities	Jinghua Zhao, Rong Ke, Zheng Xu, Jia Shi	2022	Pricing and coordination in NEV and traditional vehicle supply chains	Comparative analysis of pricing and supply chain coordination	Improved charging infrastructure coordination benefits both NEV and traditional vehicle markets.
Developing a blockchain framework for the automotive supply chain: A systematic review	Kotha Raj Kumar Reddy, Angappa Gunasekaran, P. Kalpana, V. Raja Sreedharan, S Arvind Kumar	2021	Blockchain applications in automotive supply chains	Systematic literature review and framework development	Blockchain improves transparency and resilience in ASC in a VUCA world.
The effects of product lifetime extension on short- and long-term supply chain circularity: A case study of the European aluminum automotive supply chain	M. van Keeken, W.E.H. Dullaert, D.A.M. Inghels, P.L.J. Wissink	2024	Impact of product lifetime extension on supply chain circularity	System dynamics modeling and scenario analysis	PLE reduces primary resource demand but delays recycled material availability.
Global Trends and Malaysia's Automotive Sector: Ambitions vs. Reality	Tham Siew Yean	2021	Challenges in Malaysia's automotive sector development	Policy analysis and case study of Malaysia's automotive sector	Malaysia's automotive sector remains inward-focused with limited export success.
Transparency for Multi-Tier Sustainable Supply Chain Management: A Case Study of a Multi-tier Transparency Approach for SSCM in the Automotive Industry	Iain J. Fraser, Martin Müller, Julia Schwarzkopf	2020	Sustainable supply chain management transparency in automotive	Case study using multi-tier supply chain transparency framework	Transparency challenges in MT-SSCM can be mitigated through targeted stakeholder engagement.
A Systematic Literature Review of the Solar Photovoltaic Value Chain for a Circular Economy	Maria A. Franco, Stefan N. Groesser	2021	Circular economy in solar PV and EV battery value chains	Systematic literature review of 148 articles	Circular economy barriers present opportunities for innovation in solar PV and EV supply chains.

A Methodological Approach to Assess the Impact of Energy and Raw Materials Constraints on the Sustainable Deployment of Light-Duty Vehicles by 2050	Mihai Machedon-Pisu, Paul Nicolae Borza	2021	Sustainable deployment of light-duty vehicles	Balancing supply and demand model	Raw material constraints pose challenges for 50% market share of BEVs by 2050.
The COVID-19 Impact on Supply Chains, Focusing on the Automotive Segment during the Second and Third Wave of the Pandemic	Beáta Sz. G. Pató, Márk Herczeg, Ágnes Csiszárík-Kocsir	2022	COVID-19 impacts on automotive supply chains	Risk analysis and case study	COVID-19 highlighted the need for resilient and flexible supply chains in the automotive sector.
A Critical Review of Polymer Electrolyte Membrane Fuel Cell Systems for Automotive Applications: Components, Materials and Comparative Assessment	Rolando Pedicini, Marcello Romagnoli, Paolo E. Santangelo	2023	Hydrogen fuel cells for automotive applications	Comparative and cost assessment	Hydrogen fuel cells offer a sustainable alternative, with potential cost and efficiency improvements.
Decarbonization Potentials for Automotive Supply Chains: Emission-Intensity Pathways of Carbon-Intensive Hotspots of Battery Electric Vehicles	Justus Poschmann, Vanessa Bach, Matthias Finkbeiner	2023	Decarbonization pathways for BEVs	Lifecycle assessment and emission analysis	BEV manufacturing emissions can decrease by 47% using low-carbon materials and recycling.
A Critical Review of NIO's Business Model	Alessandro Pisano, Manuel Saba, Jair Arrieta Baldovino	2023	Business model analysis for NIO	SWOT and business model analysis	NIO adapts to market challenges by focusing on premium BEVs and vertical integration.
The Electric Vehicle Supply Chain Ecosystem: Changing Roles of Automotive Suppliers	Sandeep Jagani, Erika Marsillac, Paul Hong	2024	EV supply chain transformations	Comprehensive supply chain review	Traditional suppliers must pivot to new roles to remain competitive in the EV market.
Driving the Transport Electrification: Exploring Stakeholders' Perceptions and Actions in the Indonesian Automotive Industry Transition to Electric Mobility	Muhammad Habiburrahman, Rahmat Nurcahyo, Azanizawati Ma'aram, Kaoru Natsuda	2024	Electrification transition in Indonesian automotive sector	Multi-level perspective analysis with interviews	Indonesia's transition to eMobility is hindered by low xEV demand and underdeveloped local supply chains.
Who will buy electric vehicles after early adopters? Using machine learning to identify the electric vehicle mainstream market	Gerardo Zarazua de Rubens	2019	Identifying mainstream EV buyers with machine learning	Machine learning and clustering analysis	Price and vehicle-to-grid tech can attract mainstream buyers; policy focus needed.
Barriers to the adoption of electric vehicles: Evidence from India	Pradeep Kumar Tarei, Pushpendu Chand, Himanshu Gupta	2021	Analyzing barriers to EV adoption in India	Multi-criteria decision-making and interpretive structural modeling	Critical barriers include charging infrastructure, cost and consumer awareness.
Do pro-environmental factors lead to purchase intention of hybrid vehicles? The moderating effects of environmental knowledge	Muhammad Iskandar Hamzah, Nurul Syafiqah Tanwir	2020	Environmental and behavioral factors influencing hybrid vehicle adoption	Partial-Least Squares Structural Equation Modelling (PLS-SEM)	Environmental knowledge enhances the pro-environmental purchase intention.

Sustainability in the automotive industry: Importance of and impact on automobile interior	Wanja Wellbrock, Daniela Ludin, Linda Röhrle, Wolfgang Gerstlberger	2020	Sustainability practices in automotive interiors	Quantitative survey of customer expectations	Sustainability in automotive interiors demands practical and aesthetic alignment.
North America's Potential for an Environmentally Sustainable Nickel, Manganese and Cobalt Battery Value Chain	Gary Vegh, Anil Kumar Madikere Raghunatha Reddy, Xia Li, Sixu Deng, Tongchao Liu, Khalil Amine, Karim Zaghib	2024	Sustainability in battery value chains	Review and lifecycle assessments	Battery passport can ensure sustainability in nickel, manganese and cobalt supply chains.
Evaluation of Semiconductor Risk Mitigation Strategies in the Electric Vehicle Supply Chain	Nishi Panchal, Pranav Topre, Golam Kabir	2024	Supply chain risk mitigation for semiconductors	Hybrid DEMATEL-ISM for resilience strategies	Resilience strategies include multisourcing, visibility and ecosystem partnerships.
A Review of Modular Electrical Sub-Systems of Electric Vehicles	Ahmed Darwish, Mohamed A. Elgenedy, Barry W. Williams	2024	Modularization in EV electrical systems	Review of modular topologies in EV systems	Modular designs simplify EV manufacturing, scaling and maintenance.

CHAPTER 3. THE TRADITIONAL AUTOMOTIVE SUPPLY CHAIN

3.1 Structure of the Traditional Supply Chain

At first, Russo et al. (2023) examine the structure and evolution of traditional automotive supply chains. They highlight how trade clusters and interregional connections have historically shaped the flow of components. They also examine how they finished vehicles within the industry. It's about a study, that emphasizes on the interdependence of regions in manufacturing and distribution.

van Keeken et al. (2024) critique the predominantly linear nature of traditional automotive supply chains. They emphasize on those that operate on a “make-use-dispose” model. They identify structural challenges in adapting these systems to accommodate product lifetime extension (PLE) strategies. According to this study, traditional supply chains are designed for a predictable lifecycle of components. During this lifecycle, end-of-life disposal is anticipated and planned. They also indicate that, PLE disrupts this predictability. It does so, by extending the duration of product use. So, a misalignment in production schedules and demand forecasting is then created, which, as it was pointed out by Wellbrock et al. (2020), is a serious challenge that must be faced.

Finally, it is mentioned that even if Dulia & Shihab (2024) do not directly describe the structure of the traditional automotive supply chain, they provide comparable insights into the framework of a complex supply chain. This study mentions that traditional supply chains consist of multiple levels of collaboration. It begins with raw material suppliers, and it ends with the final distribution of each product. Dulia & Shihab (2024) also mention that a key feature is the reliance on a limited number of specialized suppliers. These suppliers provide critical components. They are components that add further complexity to the overall supply chain management.

So, the coordination among different segments of the chain is essential to ensure seamless operations (Darwish et al., 2024). In these different segments, manufacturers, suppliers and distribution networks have to be included. Furthermore, adaptability in managing critical resources plays a crucial role. Some examples of these critical resources are specialized machinery and raw materials (Dulia & Shihab, 2024).

3.2 Key Factors and Major Players in the Chain

At first, the study that had been conducted by de Marco et al. (2021) emphasizes the critical role of Original Equipment Manufacturers (OEMs) and suppliers. They also mention the equally critical role of logistics providers in the automotive supply chain. They, more analytically, identify project management as a key tool for enhancing collaboration and streamlining processes among these parties. They propose that the adoption of structured project management practices from the stakeholders, it can help them better align their goals. It can also help them improve communication and optimize resource allocation.

Continuing, Skeete (2019) investigates the influence of incumbent firms, suppliers and government policies in the automotive supply chain. He particularly emphasizes on their role during the transition to low-carbon technologies. He, more specifically, examined the dominance of established automakers and their strategic relationships with suppliers. After all, these strategies enabled them to increase and promote innovation. They also help them maintain control over the existing supply chain dynamics. So, the main key-players, according to this study are incumbent firms, suppliers and government policies.

The same direction is followed by Siew Yean (2021), as well, who mentioned that the most critical roles are played by manufacturers, suppliers and government policies in shaping the automotive industry. They emphasized their study in Malaysia and they indicated that national policies, such as the National Automotive Policy (NAP), have influenced the development of local manufacturers and suppliers. Although, there is a complex interplay between government ambitions to create national champions and the reliance on foreign partners for technology and expertise.

Alioğulları et al. (2024) focus on the integration of sustainability into supply chain management. They highlight the roles of suppliers, manufacturers and logistics providers in risks' mitigation. They, also, presented a framework for evaluating risk strategies. They proposed the use of interval-valued neutrosophic fuzzy EDAS. This framework, according to this study, helps key players to make informed decisions about resource allocation and sustainability practices, as well.

Pató et al. (2022) examine how the COVID-19 pandemic exposed vulnerabilities in global automotive supply chains, among key players. They mentioned semiconductor

suppliers, OEMs and distributors as the main key players. They also discuss the strategic importance of closer collaborations between OEMs and tier-one suppliers. Through this cooperation agility might be empowered, during crises.

Finally, Jagani et al. (2024) analyze the way through which the rise of EVs is redefining the roles of key players in the automotive supply chain. They mentioned that the increasing collaboration between OEMs, suppliers and distributors, might address the unique challenges of the EV production. Jagani et al. (2024), even more, emphasize the growing interdependence between suppliers and OEMs for the development of critical EV components. Such components are batteries, semiconductors and electric drivetrains. They, furthermore, indicate the role of distributors in managing the complexities of transporting. They also have a key role in delivering these components, often requiring specialized handling for batteries and other sensitive parts. In any case, a closer partnership among all stakeholders is essential. It could be helpful overcoming the technological and logistical barriers of EV production.

3.3 Core Processes and Material Flows

Spreitzenbarth et al. (2024) discuss the application of Artificial Intelligence (AI) for the optimization of the core processes and material flows in the supply chains. It's about a study, that highlight how AI technologies are able to increase the efficiency of traditional supply chains. This might be happen by streamlining inventory management, forecasting demand and through the automation of repetitive tasks. These improvements may lead to better coordination of material flows. They might also lead to reduction of waste. So, it can be ensured that components move through the supply chain in a timely and cost-effective manner.

Yan et al. (2024) discuss the critical role of recycling in managing material flows in the automotive supply chain. They specifically focused on End-of-Life Vehicles (ELVs). Specifically, they emphasize the integration of reverse logistics processes. Collection, dismantling and material recovery are also included. Through the integration of this process in the traditional supply chain, the optimization of resource use and the waste minimization might be succeeded.

Even more, Safra et al. (2024) explore the integration of production and inventory processes in the case of automotive wiring supply chains. Safra et al. (2024) focus on optimizing material flows. This might be able to be done by synchronizing production

quantities, inventory levels and machine capacity. So, seamless operations are going to be ensured. By employing an integer linear programming model, Safra et al. (2024) demonstrate how coordinated planning can significantly reduce lead times. They also showed how they can improve the efficiency of material and process flows in the supply chain.

Continuing, the study of van Keeken et al. (2024) examines the material flow dynamics, which are affected by PLE. More analytically, this study emphasizes on a dual effect; it's about the fact that immediate material demand decreases, while recycling and material recovery are delayed. This disrupts the equilibrium of supply chains that rely on a steady flow of raw materials. It also disrupts predictable timelines for end-of-life processing. So, van Keeken et al. (2024) show how extended use cycles result in bottlenecks in recycling facilities and shortages in secondary material streams. They also note that while PLE reduces environmental impact, it complicates supply chain coordination.

Franco & Groesser (2021), although focused on the photovoltaic sector, they offer valuable insights for automotive supply chains. They explore closed-loop material systems. They also investigate the integration of renewable resources. They place emphasis on the importance of managing material flows within circular supply chains, in order for sustainability to be ensured. Franco & Groesser (2021) point out the existing need for efficient recovery and reintegration of end-of-life materials into production processes. Characteristic examples of these materials are silicon and rare earth elements.

Finally, it is mentioned that pandemic's effects on production and material flows are analyzed by Pató et al. (2022). They, analytically, focus on the disruptions, which were caused by factory closures, transportation restrictions and shifting consumer demand. They underscore the necessity for a greater flexibility and agility in traditional supply chains. So, they are going to be able to respond to such unexpected events. Even more, Pató et al. (2022) highlight how bottlenecks in material supply cascaded through the chain, affecting production schedules. They ended up affecting inventory levels, too. This study advocates for integrating advanced planning and risk management tools, to create adaptive supply chains, that are going to be capable of maintaining operations during crises.

CHAPTER 4. IMPACT OF ELECTRIC VEHICLE ADOPTION ON SUPPLY CHAIN STRUCTURES

4.1 Drivers of Electric Vehicle Adoption

Meng et al. (2022) emphasized the role of government regulations, particularly the dual credit policy in China, as a key driver for the EVs' adoption. More specifically, they mentioned that the dual credit policy incentivizes manufacturers to produce EVs. This is happening by rewarding them with credits for meeting specific environmental and efficiency standards. It also penalizes traditional internal combustion engine (ICE) manufacturers for not being able to meet the fuel efficiency targets. These are regulatory measures that create strong economic incentives for the automotive industry, so as for it to shift toward EV's production.

Xian et al. (2023) emphasize the significant role that is played by the legislative pressures in driving the adoption of New Energy Vehicles (NEVs). They particularly emphasized on the dual credit policy. This policy mandates specific quotas for NEV production. This is happening while penalizing excessive reliance on traditional fuel vehicles. So, it creates strong incentives for manufacturers to transition. This research highlights how such regulations, not only accelerate NEV adoption, but they also necessitate strategic planning to balance production targets.

Brugger et al. (2021) and Hamzah & Tanwir (2021) highlight the influence of societal trends on driving energy efficiency in transportation. Some characteristic examples are digitalization, sustainability and consumer awareness. They underscore the way through which these trends create a shift in consumer preferences towards EVs, taken into consideration as environmentally friendly alternatives. Brugger et al. (2021) mentioned that the integration of digital tools, also, increases the appeal and accessibility of EVs. Some examples of these tools are mobile applications for ride-sharing and energy usage tracking. Additionally, the growing emphasis on reducing carbon footprints and the promotion of sustainable lifestyles further accelerate the adoption of EVs. So, it helps aligning societal values with technological advancements.

Rotjanakorn et al. (2020) examine how disruptive innovations, including EVs, are reshaping the automotive industry. They indicate the important role of regulatory forces in driving the adoption of EV technologies. Such regulatory forces are emissions standards and environmental policies. Furthermore, Rotjanakorn et al. (2020)

emphasize on the market dynamics. They include shifts in consumer demand and the need for sustainable mobility solutions. They mention these shifts as key drivers accelerating the transition to EVs. These forces compel automotive firms to innovate and adapt to remain their competitiveness.

Skeete (2019) examines how regulatory frameworks, including low-emission standards and technology-forcing policies, act as significant drivers of EV's adoption. Skeete (2019) discusses how these regulations compel business entities to innovate and invest in low-emission technologies, in order for them to meet their environmental targets. So, Skeete (2019) highlights the interplay that exists between the policy enforcement and the industry compliance. He demonstrates how the existing regulatory pressures shape the technological advancements. He also shows how they accelerate the shift toward sustainable automotive solutions. So, there is an alignment between policy and innovation serves, as a critical catalyst for the adoption of EVs.

Finally, the study of Huo et al. (2024) explores the varying legislative pressures and market dynamics. They emphasized in the cases of US, China and the UK. Huo et al. (2024) showcase how policy measures, such as subsidies, emissions regulations, and renewable energy targets, are tailored to drive the adoption of the EVs. It is about a study that highlights how these policies create different pathways in order to achieve decarbonization. The interplay between governmental actions and consumer behaviour, plays the most significant role in shaping the EV markets.

4.2 Differences Between Traditional and EV Supply Chains

At first, Meng et al. (2022) discuss how the dual credit policy affects supply chains differently for traditional and electric vehicles. They more specifically mentioned that traditional supply chains are primarily oriented toward ICE components. At the same time, EV supply chains require a focus on batteries and advanced electronic systems. The existing policy is able to drive a structural shift, by increasing the demand for critical materials. Some of them are lithium and cobalt. These materials are essential for battery production. It is about an existing shift, that necessitates significant changes in supply chain configurations. These changes concern sourcing and logistics. They also concern production and distribution. So, this study highlights the existence of a contrast in the operational priorities and material dependencies of traditional versus EV supply chains.

Afterward, Kamble et al. (2021) describe technological transformations, that are driven by the integration of circular economy principles. They emphasize on the shifts in supply chain operations. They focused on the specific shifts that are caused due to the adoption of Big Data and IoT. They are also tailored to the unique requirements of electric vehicles, such as for example the material recovery and the closed-loop systems.

Even more, Trivyza et al. (2022) analyzed the differences that exist between the supply chains' structures. They placed emphasis on those that driven by the integration of innovative materials. Characteristic examples are the carbon fiber reinforced polymers (CFRP). Trivyza et al. (2022), after all, emphasize on how the transition to these materials necessitates redesigning supply chain processes to accommodate some basic procedures, These procedures are collection, recycling and reuse of these high-value, energy-intensive materials.

Rentizelas & Trivyza (2022) explore how the principles of the circular economy are reshaping traditional automotive supply chains. More analytically, Rentizelas & Trivyza (2022) emphasize the shift from linear “make-use-dispose” models to circular frameworks. The circular frameworks set as their main priority the reuse, remanufacturing and recycling. Rentizelas & Trivyza (2022), during their study, they focused on car sharing vehicles. They mentioned that the integration of reusable components, such as for example carbon fiber frames, require specialized supply chain adjustments.

Campos-Romero et al. (2024) investigate the environmental implications of transitioning from traditional to EV production. Their study was conducted on the global value chains. It highlighted how the production processes for EVs differ significantly from those of traditional internal combustion engine vehicles. They pointed out the existing differences particularly in terms of material requirements and energy inputs. So, this study emphasizes the role that is played by the regional trade dynamics, such as for example the integration of Eastern European economies into the automotive supply chain. The study of Darwish et al. (2024) also mentioned that these dynamics influence the environmental footprint of the EV production.

Russo et al. (2023) explore how the shift to the EVs has disrupted the existing traditional trade. They also explained that it disrupted the already existing traditional

supply chain networks, too. This study discusses the increasing regionalization of EV supply chains. This increasing regionalization is also driven by the demand for localized production of batteries and of EV components, too. In addition, Russo et al. (2023) explained how the introduction of new materials (i.e. lithium and cobalt for batteries), reshapes global trade patterns. The introduction of these new materials increases the importance of regions, that are rich in these specific resources, as well.

Rísquez Ramos & Ruiz-Gálvez (2024) delve into the reconfiguration of supply chains, as a result of the automotive industry's shift toward electrification. This study highlights how the transition to the EVs introduced new players. Such examples are battery manufacturers and they play a key role into the new global value chains framework. They are entrants that play a critical role in reshaping supply chain dynamics. This reshaping means a focus on securing access to raw materials and advanced battery technologies.

Finally, Remme & Jackson (2023) discuss the systemic changes that are required in the supply chains, in order for them to be able to achieve genuine circularity for the EV components. Analytically, Remme & Jackson (2023) discuss the integration of advanced recycling practices as essential shift that differentiate EV supply chains from traditional automotive systems. They also mentioned that the integration of sustainable material sourcing is one more essential shift for this differentiation. These changes are necessary, in order for the unique demands of EV production to be met.

4.3 Challenges for the Traditional Supply Chain

A characteristic study that addressed the challenges, that are faced by traditional supply chains is the one, that was conducted by Dulia & Shihab (2024). Dulia & Shihab (2024) emphasized on some critical issues, such as for example on the material shortages and on the issue of the existing need for adaptation to changing demands. Through their analysis, they highlighted how supply chains, particularly those in high-technology industries, are vulnerable to disruptions. This vulnerability exists because of their limited availability of specialized components, such as lithium-ion batteries and other similar materials. Furthermore, Dulia & Shihab (2024) discuss the pressure that is placed on the supply chain's participants, for the adaptation of new requirements. Indicatively, some of these requirements are the incorporation of advanced technologies or the need for meeting higher quality standards. So, there is a need for

rapid adaptation of the above-mentioned components and this need adds further complexity and strain to traditional supply chain structures. This is why there is a necessity for the existing strategies to be shifted, in order to be able to remain competitive and resilient.

Afterward, Yan et al. (2024) identify the existence of significant challenges in transitioning from traditional linear supply chains to closed-loop systems for ELVs. More specifically, this research addressed issues such as the high costs, which are associated with the implementation of the reverse logistics. They also addressed the issue of the environmental awareness costs and carbon penalties, that traditional supply chains must incorporate. Finally, they addressed the existence of operational challenges in adapting the existing infrastructure, in order for the successful accommodation of the needs of a reverse supply chain for material recovery and recycling, to be done.

Xian et al. (2023) identify the key challenges, that are faced by the traditional automotive supply chain during the transition to NEVs. The instability was the major challenge, in their point of view. More analytically, they mentioned that this instability is caused by the rapid adjustments in the production strategies. This shows that over-adjustments in production volumes are able to disrupt the market equilibrium. So, they are able to lead to inefficiencies and an overall chaos. The findings of this research underline the difficulties, that manufacturers encounter in aligning supply chain operations with the demands of the NEV production. These difficulties are even more intensive in the dual-product environments. In these environments, traditional vehicles still dominate market share. This result, underscores the existing need for measured approaches to supply chain restructuring. This is about a necessity that is going to be helpful to avoid imbalances that could hinder the transformation process.

Rotjanakorn et al. (2020) discuss the challenges that traditional supply chains face, due to the transition to EV. This study underscores the importance of dynamic capabilities, as for example the ability to sense, seize and transform opportunities. These capabilities are important in order for the existing complexities of integrating new technologies, materials and processes, to be effectively managed. Traditional supply chains, in any case, are obliged to adapt to accommodate EV-specific requirements. These requirements concern battery components and electric drivetrains. At the same time, they have to maintain their efficiency and they also have to reduce their costs.

Siew Yean (2021) addresses the challenges, which are faced by Malaysia's traditional automotive supply chain, in adapting to electrification and evolving policy demands. Siew Yean (2021), in the context of their study, outlined the constraints, that were imposed by the protectionist policies. They also outlined the limited technological capabilities of the local suppliers. Their limited technological capabilities, undoubtedly, decrease their ability to meet the requirements of the EV production. Additionally, the study identifies global pressures, such as the need for sustainability and competitiveness. These pressures are further challenges for the Malaysia's automotive sector during its transition from traditional supply chain models to those that accommodate electrification.

Finally, Manley et al. (2022) identify the most significant challenges, that are faced by the traditional supply chains, concerning in adapting to the increasing material demands. These increasing material demands are driven by the electrification. In this context, Manley et al. (2022) discuss how traditional suppliers struggle with scaling up production. They also discuss how they struggle with meeting sustainability requirements and integrating the new necessary materials, into their operations. These are significant challenges, that necessitate transformative changes in supplier strategies and collaboration across the supply chain.

CHAPTER 5. IMPACT OF ELECTRIC VEHICLE ADOPTION ON SUPPLIERS AND MANUFACTURERS

5.1 Impact on Raw Material Suppliers

At first, Meng et al. (2022) examine how the dual credit policy influences raw material suppliers during the EV production. They, more analytically, mentioned that the increased demand for EVs, creates a surge in the need for significant materials, i.e., lithium and cobalt. These materials are, after all, essential for the battery production. However, as it is mentioned by Meng et al. (2022), suppliers face challenges in meeting these demands. These challenges exist due to capital constraints. The reason is that as small and medium-sized suppliers, often struggle to invest in the necessary R&D and in the necessary infrastructure. Finally, Meng et al. (2022) pointed out that the dual credit policy indirectly intensifies these pressures. It ends to necessitating the innovative solutions, such as cost-sharing strategies between manufacturers and suppliers. Another example is the external financial support through loans.

Afterward, Machedon-pisu & Borza (2021) highlight the significant constraints on the supply chains of the above-mentioned necessary raw materials, that are essential for battery-electric vehicle (BEV) production. They also said that availability of these materials directly affects the market penetration. It also directly affects the BEVs' scalability. It is about a study, which includes a detailed analysis of the supply-demand imbalances, ending up emphasizing that there is a need for improved resource management. The scholars also mentioned that there is an additional need for alternative material sourcing strategies.

Wang et al. (2024) explain how predictive modeling can significantly impact battery technologies and energy efficiency in the EV supply chain. Through leveraging advanced tools, like for example the RRMIDAS-SVR model, the research of Wang et al. (2024) emphasizes the importance of accurately forecasting market trends and raw material demand, for the case of the lithium-ion batteries. The predictive modeling approach, that Wang et al. (2024) followed in their study, gave more precise market value forecasts of the industry of the power battery. It is a necessary capability for optimizing supply chain strategies. This capability is also necessary for reducing costs and ensuring consistent availability of these critical materials.

Even more, efficient resource allocation, that is driven by the insights that were given by Wang et al. (2024), is able to minimize waste and to maximize, at the same time, the cost-effectiveness of the battery production. The study of Wang et al. (2024) highlighted, in addition, the way through which predictive analytics might streamline manufacturing processes. By anticipating supply chain bottlenecks and market demand fluctuations, manufacturers are going to be able to better align their production schedules with the existing needs of the market. So, they are going to be able to avoid the overproduction or shortages.

So, this operational alignment might reduce, on the one hand energy usage and, on the other hand, material waste. This means that is going to increase the overall efficiency of the battery supply chain. Predictive modeling, also, facilitates the adoption of advanced manufacturing technologies, that focus on energy-efficient practices. For example, insights from the model might guide the manufacturers toward process optimizations. Characteristic example is the improved thermal management during battery assembly, which can reduce the energy consumption and to increase the durability of the batteries, that are produced (Wang et al., 2024).

Manley et al. (2022) delved into the vulnerabilities in global supply chains for necessary and important minerals, that are essential for battery production in the automotive and electronics industries. It is a study, that indicated the geopolitical risks and the market volatility, that are both associated with these materials. They included, for example, the price fluctuations, the supply shortages and the concentration of resources in the cases of the regions that are considered as politically unstable. The research of Manley et al. (2022) emphasizes the urgent need for diversifying sources. They also emphasize on the need for investing in recycling technologies, in order to reduce the existing high levels of dependency on finite mineral reserves. Only in this way, the supply chain resilience is going to be increased.

Finally, Marcos et al. (2021) investigates various uncertainties, that are linked with the supply of the key materials, that are considered as essential for the EV batteries. Marcos et al. (2021) identified some significant challenges, including s geopolitical instability and price volatility. They also included the limited geographic availability of these resources, s one more significant challenge. This research, finally, underscores the importance of addressing these uncertainties through strategic planning. It is also

mentioned that these uncertainties might be addressed through diversification of supply sources and through the increasing investments in recycling technologies, too.

5.2 Effect on Manufacturers and Production Processes

Xian et al. (2023), in the context of their study, explore the implications of transitioning to NEV production on manufacturers and their processes. They, more specifically, focusing on the need for new production strategies. Through the integration of new production strategies, policy-driven demands are going to be effectively met. Xian et al. (2023) illustrated how traditional automakers must simultaneously manage the production of NEVs and conventional vehicles, often under resources that are constrained. It is about dual-production scenario. This scenario requires careful allocation of R&D investments. It also requires adaptation to new technologies and compliance with the regulatory requirements. Such requirements are for example the emissions standards.

Safra et al. (2024) highlighted the operational adjustments, that are required to address the existing challenges in the automotive wiring production. They characteristically mentioned the capacity limitations and the Bill of Materials (BOM) constraints. They finally, explained the need for manufacturers to adopt integrated operations planning, that was also mentioned by Habiburrahman et al. (2024). So, they are going to be able to align their production processes with their resource availability and the customer demands, at the same time.

Rísquez Ramos & Ruiz-Gálvez (2024) examined the impact of electrification on the production processes. They particularly examined how the competition that arises among the manufacturing plants for the production of EV models, influences their operations. Rísquez Ramos & Ruiz-Gálvez (2024) detailed that automakers have to retool the existing facilities. Alternatively, they must build new ones. So, they are going to accommodate the unique requirements of EV production, such as battery assembly and the integration of electric drivetrains.

Parés Olguín et al. (2024), also, investigate how international EV trade strategies lead to transformative changes in the manufacturing processes. They emphasized in the case of North America. Their study indicated the pressing need that exist for the automakers to reconfigure their production lines, in order to effectively accommodate the unique demands of EV manufacturing. Their main central focus must be the integration of

battery technology advancements into their production processes, with which Darwish et al. (2024) also agree. To do so, the manufacturers have to adopt specialized equipment for battery assembly and testing.

5.3 Impact on Component and Support Technology Companies

Kamble et al. (2021) examined the role of Big Data in supporting technologies in the automobile industry. They emphasized how Big Data analytics increase the supply chain integration and how it enables circular economy practices. Such practices are real-time monitoring and optimization of component reuse. Some further examples of these practices are recycling and waste reduction at the design stage.

Continuing, de Marco et al. (2021) explored how project management practices are integrated into research and development (R&D) and production. They also mentioned how they are integrated in quality control. They focused on the automotive sector. This study showed that the systematic project management, is important in addressing the complexities of component design, production timelines and technological innovation, as well. They propose the leverage of tools, as for example collaborative scorecards and advanced quality planning.

Pedicini et al. (2023) delved into the advancements in polymer electrolyte membrane (PEM) fuel cell systems. They also examined their significant implications for component and technology suppliers, in the case of the automotive industry. The authors highlight the increasing demand for specialized materials and components, such as proton exchange membranes and bipolar plates. Without these materials, the efficient operation of fuel cell systems is not able to be succeeded. These advancements necessitate suppliers to invest in R&D. So, they are going to be able to meet the performance requirements, such as higher power density, longer durability and cost reductions.

Pisano et al. (2023) analyzed NIO's innovative business model. They particularly focus on its battery-swapping technology, since it has significant implications for component suppliers. NIO's approach diverges from the traditional EV model, because it requires suppliers to design batteries, that are specifically suited for modular swapping systems. The study of Pisano et al. (2023) mentioned that the main operational adjustments, that are needed from the suppliers are the development of standardized battery packs with fast-charge capabilities and the extended lifecycles, too. Additionally, they mentioned

that suppliers must adapt to the logistical demands of maintaining a robust inventory of swappable batteries. By this, they are going to ensure availability and quick turnover.

Finally, Jagani et al. (2024) focus on the transformative impact of EV production on component suppliers. It is a study, that highlights the increasing demand for advanced semiconductors. They are, after all, crucial for power management and autonomous driving features. Jagani et al. (2024) mentioned that suppliers are also tasked with innovating in electric motor technologies and at the same time, they noted that the battery system suppliers are at the forefront of this transformation. They need to meet stringent requirements for energy density, safety and lifecycle costs. In any case, the the importance of digitalization and smart manufacturing processes, is undeniable. It enables suppliers to meet the high precision and quality demands of EV components. So, the success of EV supply chains hinges on the ability of component and technology suppliers to innovate and rapidly adapt to the new evolving requirements of the market.

CHAPTER 6. IMPACT OF ELECTRIC VEHICLE ADOPTION ON DISTRIBUTION AND AFTER-SALES SERVICES

6.1 Changes in Distribution Structure

The article by Cutore et al. (2024) explores the design of supply chains for hydrogen fuel, with applications in transportation. Cutore et al. (2024), more specifically, emphasize the importance of optimizing the production, transportation and distribution stages of hydrogen. Through this optimization, its adoption in public transport, such as buses and trains, is going to be facilitated. This study, also, indicated that the existing renewable energy sources, like for example the wind power, have to be integrated into hydrogen supply chains. So, they are going to further support the sustainable distribution structures. It is proposed approach, that minimizes the existing costs and increases the feasibility of the hydrogen-powered transport systems. By this approach, Cutore et al. (2024) offer a relevant comparison to the logistical shifts, that are required for the EV's adoption.

de Marco et al. (2021) examines how project management practices contribute to improving logistics and adapting to new distribution structures in the context of the EVs. de Marco et al. (2021) underscore the role that is played by the project management in the planning procedure and in implementing the necessary changes to the supply chain operations. In these operations, the EV-specific components and systems are also included. By employing project management frameworks, companies are able to enhance their ability to respond to the evolving needs of the market. Through the employment of project management frameworks companies are going to be able to optimize distribution networks and to improve overall logistics efficiency, too.

Ribeiro da Silva et al. (2023) investigated how blockchain technology is able to revolutionize the distribution structure of EV battery supply chains, by supporting the principles of the circular economy. They demonstrated how blockchain enables real-time tracking of battery components, increasing visibility and transparency in the supply chain. It is about an improved traceability, that helps optimize logistics by reducing redundancies. It is also helpful by enabling efficient material recovery processes. The research of Ribeiro da Silva et al. (2023), also pointed out that blockchain facilitates the reuse and recycling of battery components, ensuring that

supply chains adapt to the demands of the circular economy. Through blockchain technologies integration, companies can reduce their distribution costs. They are also going to improve their overall supply chain sustainability.

Parés Olguín et al. (2024) discussed how the rapid expansion of EV markets necessitates a reorganization of supply chains. They emphasized on the importance of the nearshoring and localized manufacturing. So, they mentioned that localized production might reduce transportation costs and shorten the delivery times. Both of them are critical factors in the meeting of market demand. The study of Parés Olguín et al. (2024), also mentioned that nearshoring aligns with government incentives and trade policies, that encourage domestic manufacturing of the EV components, including batteries. Additionally, Parés Olguín et al. (2024) pointed to the growing need for collaboration among manufacturers, suppliers and distributors, in order to create integrated and responsive supply chain networks.

Zhao et al. (2022) explore the profound impact of the charging facility development on the automotive supply chain. More specifically, they underscored that the inclusion of charging infrastructure necessitates adjustments in the distribution network to accommodate the new logistical requirements. Zhao et al. (2022) also mentioned that the pricing strategies that are followed and the supply chain coordination are pivotal in balancing costs. They are also pivotal in expanding infrastructure efficiently. They indicated that a collaboration between traditional automotive supply chains and EV-specific networks is required, in order to integrate charging facilities seamlessly.

Also, Poschmann et al. (2023) explored the impact of sustainable logistics practices on emission reductions in the EV supply chain. They mentioned the significant role of optimizing transportation networks to reduce fuel consumption and greenhouse gas emissions. The authors, even more, proposed strategies, such as for example consolidating shipments and using electric or hybrid delivery vehicles. They also propose the strategy of leveraging digital tools for real-time route optimization. Furthermore, the study points to the importance of integrating sustainability metrics into the distribution planning. So, it is going to be reassured that logistics practices contribute to the overall decarbonization goals of the supply chain.

6.2 Challenges for After-Sales Service and Support

Alioğulları et al. (2024) explored the complexities of maintaining sustainability in the after-sales phase of the supply chain lifecycle. They particularly focused on the context of the EV industry. They finally mentioned that a significant challenge lies in managing spare parts inventories. This happens because EV components often require specialized production processes. They are also sourced from a limited number of suppliers. These constraints drive up costs. They also complicate efforts, in order to ensure the availability of the necessary parts. The study of Alioğulları et al. (2024) emphasizes the importance of leveraging advanced decision-making frameworks. This is going to be helpful to optimize inventory levels, striking a balance between availability and cost-efficiency and at the same time minimizing waste and maintaining high service quality.

In addition, the research of Alioğulları et al. (2024) pointed out the growing demand for specialized repair services, as the EV adoption is accelerated. Traditional automotive repair networks might lack the skills and the necessary tools and infrastructure to service the EVs effectively. By applying frameworks, like for example interval-valued neutrosophic fuzzy EDAS, companies might identify and prioritize their investments in their human resources training, in their technology upgrades and in beginning strategic partnerships, so as for them to be able to build the necessary capacity for the reliable after-sales support.

Alioğulları et al. (2024) also focused on minimizing the environmental impacts of after-sales operations. The incorporation of circular economy principles is presented as an effective strategy, by Alioğulları et al. (2024). The integration of these practices, like the use of recycled parts, optimizing of the transportation routes for repairs and waste reduction during the service processes, firms may meet stringent regulatory requirements. At the same time they might advance their sustainability goals.

The adoption of the interval-valued neutrosophic fuzzy EDAS framework is presented by Alioğulları et al. (2024), as a robust tool for addressing the multidimensional challenges of after-sales services. They present this approach as suitable, enabling businesses to assess risks comprehensively. Alioğulları et al. (2024), also mentioned that this approach, enables business entities to prioritize their actionable strategies and to implement solutions that align with both their operational and sustainability objectives. Ultimately, the study of Alioğulları et al. (2024) underscores the need for

the businesses to adopt advanced decision-making methodologies, so as for them to ensure the long-term viability of their supply chains. This is essential, especially in an existing era that is characterized by heightened environmental and regulatory pressures.

Finally, Ribeiro da Silva et al. (2023) mentioned the existence of multiple complexities of managing the after-sales services in the EV supply chains. The most significant ones were battery reuse and recycling. Blockchain, according to Ribeiro da Silva et al. (2023), is presented as a tool for addressing these challenges. This addressment is capable of being done by ensuring transparency and accountability in the lifecycle management of the EV batteries. This study discusses how blockchain is able to track battery health and usage. Through this, it might allow manufacturers and service providers to assess whether batteries should be reused, refurbished or recycled. This system mitigates risks. They are risks that are related to counterfeit parts. It also ensures compliance with regulatory standards.

6.3 Recycling and Sustainable Management of Electric Vehicles

At first, it is mentioned that Meng et al. (2022) discuss strategies for sustainable management and recycling of electric vehicles. They, more specifically, focus on the reuse and recycling of lithium-ion batteries. This study, furthermore highlights the importance of the creation of a closed-loop supply chain, in order to mitigate the environmental impact of EV production and the end-of-life disposal. Recycling programs and sustainable material sourcing, are both emphasized, as critical factors to ensuring compliance with the existing environmental regulations, while addressing the dual credit policy's goals towards sustainability. These strategies reduce waste. They also alleviate pressures on raw material suppliers, by reclaiming scarce resources, such as cobalt.

Cutore et al. (2024) analyze sustainable supply chain management. They particularly emphasized on the context of hydrogen-powered transport systems. They advocate for leveraging existing infrastructure and renewable energy resources, for the creation of sustainable energy loops. While centered on hydrogen, the principles of reducing waste, align closely with the needs of EV battery recycling and sustainable supply chain management. For the sake of a better understanding, it is mentioned that the main principles of waste reduction are maximizing resource efficiency and integrating circular economy practices.

Afterwards, Yan et al. (2024) focus on the sustainable management of the ELVs. In the context of their study, they address environmental challenges through closed-loop supply chains. They, furthermore, explore methods for the integration of recycling operations into supply chains. At the same time, Yan et al. (2024) emphasize the economic and social benefits of reclaiming materials. They proposed a model, that supports sustainability by optimizing the trade-offs between economic profitability, environmental impact and social benefits. So, their study contributes to a circular economy approach.

Even more, Trivyza et al. (2022) thoroughly examined strategies for recycling complex materials, like CFRP. Their research proposed a reverse supply chain model. This model is tailored for the efficient recovery and reuse of carbon fibers. It aligns with sustainable management practices for the EVs and their components.

Brugger et al. (2021) analyzed the principles of a circular economy. They consider these principles as a means to address the sustainability challenges posed by the EVs. More analytically, Brugger et al. (2021) emphasize the importance of the reuse of the materials, that was also mentioned by Tarei et al. (2021). They mentioned that the reuse is especially important for critical components, like for example batteries, for the reduction of the overall energy demand and environmental impact. The findings of this research advocate for comprehensive recycling strategies to recover valuable materials, minimizing waste and ensuring resource efficiency.

Rentizelas & Trivyza (2022) emphasized on the design and optimization of reverse supply chains. They specifically analyzed the reusable vehicle components, like carbon fiber frames. Rentizelas & Trivyza (2022) discussed how these systems minimize environmental impact and enhance economic viability, by extending the lifecycle of vehicle parts. Their study provides a case study on reusable car frames, demonstrating that increased remanufacturing efforts are able to significantly reduce system costs. They also proved that increased remanufacturing efforts might support sustainability goals. So, there are environmental and financial advantages of adopting circular supply chain strategies in EV and car sharing contexts.

Campos-Romero et al. (2024) specified their study into circularity and sustainable practices in the European automotive sector. They focused on strategies to manage the environmental impacts of EV production and end-of-life vehicle recycling. Afterall,

Campos-Romero et al. (2024) mention the importance of material reuse to reduce resource dependency.

Mansuino et al. (2024) introduced a framework of circularity indicators, which are specifically tailored for the automotive industry. These indicators evaluate the sustainability of automotive products by measuring some specific aspects. Characteristic examples of these aspects are the industrial waste, the use of energy use and the material reuse. These metrics play a catalytic role in promoting waste reduction and efficient resource utilization. They give manufacturers the chance to adopt sustainable practices throughout the lifecycle of electric vehicles. Also, there is a high importance of extending product lifespans and improving end-of-life recycling processes, in order to minimize environmental impact.

Fraser et al. (2020) explore the challenges of achieving transparency in multi-tier supply chains, especially on cobalt supply chains critical for EV batteries. They mentioned that there is a huge complexity and opacity of sourcing cobalt, which is a key material for the EV battery production. Also, multiple environmental and ethical issues are associated with its extraction. So, implementing traceability systems, is important, in order to ensure sustainable sourcing and recycling of cobalt. By leveraging transparency frameworks, stakeholders might enhance the circularity of materials. They might also support the sustainable management of EV supply chains, aligning with broader goals of environmental stewardship and ethical resource use.

Machedon-pisu & Borza (2021) discuss the role that is played by circular economy strategies in addressing the sustainability challenges. These challenges are posed by critical material constraints. This specific study underscores the importance of recycling lithium-ion batteries, for the recovery of valuable materials like nickel, thereby reducing dependence on primary extraction. Machedon-pisu & Borza (2021) advocate for the implementation of advanced recycling technologies. They also advocate for the implementation of reverse logistics systems. Through this, optimizing material recovery and minimizing the environmental impact are both going to be succeeded. These strategies are essential for achieving sustainable deployment of light-duty EV.

Huo et al. (2024) emphasize the importance of regional recycling strategies for EV batteries. They, more specifically, characterized it as “cornerstone of sustainability” in

light-duty vehicle fleets. They underscored the need to establish robust systems for material recovery. This need is even more necessary to be covered, particularly for critical components like lithium-ion batteries. This is necessary in order to reduce resource dependency and environmental impacts, while advancing decarbonization efforts.

Finally, Koroma et al. (2022) explore the environmental benefits of adopting effective battery recycling and refurbishment practices in the context of EVs. In order to cover this purpose, they examined different battery end-of-life management strategies. They mentioned that the role of recycling in reducing waste and recovering critical materials is critical. They, also, situated these practices within the broader framework of a circular economy, placing emphasis on their potential to minimize the environmental footprint of EV production and disposal. Koroma et al. (2022) also showed that refurbished batteries are able to extend resource lifespans. They furthermore proved that refurbished batteries can reduce the demand for new materials. So, they contribute to more sustainable EV supply chains.

CHAPTER 7. INNOVATIONS AND TECHNOLOGICAL TRENDS IN ELECTRIC VEHICLES

7.1 Battery Technologies and Energy Efficiency

Firstly it is mentioned that Cutore et al. (2024) highlighted the energy potential of hydrogen, as an alternative to conventional batteries in transportation. They discussed the advantages of hydrogen fuel cells. In that context, they mentioned that the most important advantages are longer operational ranges and faster refueling times compared to electric batteries. These are positive characteristics, that make hydrogen an attractive option for decarbonizing public transport.

Continuing, Trivyza et al. (2022) indirectly discussed the benefits of lightweight materials like CFRP, concluding that they enhance energy efficiency in EVs. They mentioned that lighter vehicles require less energy for operation. This means advancements complementation in battery technology and overall energy consumption reduction.

Even more, Mansuino et al. (2024) discussed the role of circular design in enhancing the lifecycle efficiency of batteries, which are used in EV. They focused on sustainable material choices and on the improvement of battery recyclability, in order to prove that circular principles can significantly reduce environmental impacts, that are directly associated with battery production and disposal. They also underscored the necessity of incorporating circular economy practices into battery technology development, to align with broader sustainability goals in the case of the automotive sector.

Zhang et al. (2023) focus on the development of advanced methods for estimating the state of health (SOH) of lithium-ion batteries. They, finally, supported that accurate SOH estimation might ensure the safe and efficient operation of EV, prolonging battery life and empowering the general energy efficiency. Koroma et al. (2023) focused on advancements in drivetrain technology, specifically the development of a functionally integrated e-axle. They demonstrated that the integration of components in the e-axle increases energy efficiency. This is happening by reducing mechanical losses and optimizing power transfer. They also said that there are multiple environmental benefits of this innovation. Some characteristic examples are the 26% reduction in climate impacts and a percentage of 38% of decrease in energy use compared to traditional

drivetrains. So, the critical role of advanced drivetrain technologies in improving the overall efficiency and sustainability of electric vehicles, is undeniable.

Wang et al. (2024) delved into advancements in predictive modeling. Predictive modeling enhances the economic viability and operational efficiency of power battery supply chains. Wang et al. (2024) concluded that the integration of predictive analytics into supply chain management improves energy efficiency in battery production. They also proved that it contributes to the broader sustainability goals of EV technology.

Finally, Koroma et al. (2022) mentioned that advancements in battery technology and improvements in electricity grids significantly impact the life-cycle environmental performance of EVs. They demonstrated, more analytically, that the increases in battery efficiency can significantly reduce energy consumption. They can also significantly reduce the emissions over the vehicle's lifetime. Moreover, Koroma et al. (2022) proved that the transition to cleaner electricity grids empowers the sustainability of EVs. This is a result that comes as battery production and charging processes rely less on fossil fuels. Concludingly, there is a critical interplay between battery advancements and energy infrastructure improvements in achieving long-term sustainability goals for EVs.

7.2 Charging Infrastructure and Network Development

Brugger et al. (2021) mentioned that there is a significant role, that is played by the urbanization and infrastructure development, in shaping energy systems for the EVs. Specifically, that discussed that expanding charging networks, particularly in urban areas, supports the widespread adoption of EVs. This widespread is supported by addressing range anxiety and ensuring convenient access to energy. The research also found that there is an interplay between urban planning and sustainable energy systems, and that there is a need for coordinated efforts to integrate EV infrastructure into smart city initiatives. The alignment between urban growth and energy-efficient transport solutions is a pathway to achieve a more sustainable urban environment, which was proposed by Wellbrock et al. (2020).

Gokasar et al. (2023) explained that there is a critical role of charging infrastructure in enabling widespread EV adoption, in the developing countries. They mentioned that inadequate infrastructure poses a significant barrier to the growth of the market. The study points to the importance of government-led initiatives to expand charging

networks and to reduce range anxiety among potential EV users. Furthermore, Gokasar et al. (2023) pointed out that public-private partnerships are effective in accelerating infrastructure development. After all, they stress the need for strategic placement of charging stations, so as to optimize accessibility and efficiency. Gokasar et al. (2023) suggested that the integration of renewable energy sources into these networks might further increase their sustainability.

Zhao et al. (2022) focused on the integration of charging networks. They said that this integration might influence the adoption and operational efficiency of the EVs. They also mentioned the high importance of optimizing charging facility placement, in order to ensure accessibility and convenience for the EV users. They also proposed that strategic placement can reduce congestion and improve station utilization, too. Additionally, Zhao et al. (2022) address the role of dynamic pricing models in managing demand for charging facilities. They ensured that infrastructure expansion is both economically and operationally sustainable. They finally concluded that the well-coordinated charging networks are essential for increasing the consumers' confidence in the EVs. This is the reason why they proposed their widespread adoption.

Finally, Raj Kumar Reddy et al. (2021) explored the potential of blockchain to transform the management of the EV charging networks. Raj Kumar Reddy et al. (2021) mentioned that reliable and secure data flows between the charging stations, the vehicles and the utility providers, might be critical for the optimization of the efficiency of the existing network. The authors, even more, discuss that blockchain plays a protagonist role in dynamic pricing, in which real-time data on energy supply and demand might be securely shared, in order to dynamically adjust the charging rates. It is an approach that leads to the reduction of the operational inefficiencies. At the same time, this approach might encourage the balanced use of the charging infrastructure. Additionally, the study of Raj Kumar Reddy et al. (2021) suggests that blockchain can facilitate peer-to-peer energy trading in decentralized charging networks. This means that EV users are going to be allowed to directly buy and sell energy. These are advancements, that may significantly contribute to a more efficient and user-friendly charging ecosystem, supporting, at the same time, the EVs' widespread adoption.

7.3 Smart Technologies and Integrated Management Systems

First of all, Dulia & Shihab (2024) mentioned that the use of smart technologies and integrated management systems might enhance the efficiency of supply chains. They emphasized that advanced technologies, such as Internet of Things (IoT), Artificial Intelligence (AI) and predictive analytics, play a crucial role in improving the operations of the supply chain sector. These are innovative technologies, which enable real-time tracking and efficient resource allocation. They might also enable data-driven decision-making. All of these benefits, are essential for improving performance and reducing bottlenecks. The leverage of such smart systems, can make supply chains achieve higher agility. They can also make them minimize costs and adapt more effectively to the demands of a market that is dynamic. It's about a technological integration, that is particularly relevant for industries undergoing rapid innovation, such as for example the EVs.

Even more, Spreitzenbarth et al. (2024) mentioned the semantic role of the AI systems in the integration and management of supply chains. They showed that the AI-driven solutions improve supply chain visibility and coordination among stakeholders. They also enable predictive analytics, ending up to a better decision-making procedure. By automating processes and providing real-time insights, AI systems are helpful to address inefficiencies. They also help to adapt to dynamic conditions. So, there is a transformative potential of AI in creating interconnected, intelligent supply chains, which are considered as essential for supporting the evolving requirements of the EV industry.

Kamble et al. (2021) delved into innovations, which improve circular economy processes, through the use of technologies like for example IoT and Big Data. This specific study discusses that integrating advanced data-driven systems is able to improve decision-making, streamline processes and sustainability in the supply chain. Also, Big Data analytics emerges as a pivotal enabler for the achievement of these positive outcomes.

Abdulghani et al. (2024) discussed the transformative potential of digital technologies, such as IoT, blockchain and digital twins. They mentioned that these kinds of technologies are helpful in achieving decarbonization goals within supply chain management. Abdulghani et al. (2024) presented a comprehensive maturity model that

outlined five specific levels of digital transformation. They focused on how organizations can strategically adopt and integrate these technologies to reduce their carbon footprint. By leveraging smart systems, Abdulghani et al. (2024) demonstrated that businesses might enhance operational efficiency and monitor emissions in real-time. They can furthermore implement sustainable practices across their supply chains. So, there is a critical role played by digital technologies in the creation of carbon-neutral and resilient supply chain ecosystems.

The integration of IoT and AI for real-time situational awareness and inventory management through technologies, like digital twins and blockchain, was also highlighted as critical for enhancing supply chain visibility by Panchal et al. (2024) and Vegh et al. (2024). The importance of supply chain visibility, through the use of integrated architectures and real-time forecasting, particularly in regulated regions, is aligned with the theme of smart systems improving transparency. Resilience strategies, in which the adoption of technologies to monitor and mitigate risks in supply chain management is included, are highly relevant. The methodologies employing Interpretive Structural Modeling (ISM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) for smart decision-making could fit into discussions on advanced integrated management systems (Panchal et al., 2024).

CHAPTER 8. CASE STUDIES

8.1 NIO's Innovation with Battery Swapping

First of all, it is clarified, that NIO is one of China's leading EV automakers. More analytically, NIO's example is with mentioning in the context of this dissertation because it implemented a unique battery swapping system. This system was known as "Battery Swapping". Unlike the most of the EVs, which require several hours of charging, NIO allowed users to replace a depleted battery with one that had the ability to be fully charged in less than three minutes (NIO, 2024). It's about a strategy, that increases the efficiency. It also reduces the downtime of EVs. So, this strategy might provided an alternative to traditional charging.

Furthermore, it has to be mentioned that during the year of 2024, NIO introduced the fourth generation of battery swapping stations. This generation supported higher automation levels. It might be able to serve multiple makes and models of the EVs (NIO, 2024).

At the same time, NIO has introduced the "Battery-as-a-Service" (BaaS) model. This specific model allows drivers to subscribe to a subscription battery exchange service. So, the initial purchase cost of the vehicle was reduced. This strategy provided flexibility in the management of the existing energy needs (NIO, 2023).

Finally, this specific initiative has significant implications for the supply chain. The reason is the fact that it reduces the need for extensive charging infrastructure. It also allows for better management of the raw materials, that are required for the manufacture of batteries. In addition, it might contribute to the circular economy. So, it promotes the maintenance and the recycling of batteries, instead of their disposal.

8.2 Volkswagen's Strategy for Electromobility

Volkswagen is one of the largest automakers, that have adopted an ambitious electromobility strategy. More analytically, during the year of 2023, Volkswagen announced a significant increase in its electric vehicle sales. Specifically, Volkswagen's pure electric models were accounting for 4% of its total sales in Greece. This percentage concerns an increase of 38,3% in comparison with the years of 2022 (Volkswagen, 2024).

Furthermore, Volkswagen's strategy is based on three main axes. The first axis is the investigation of new battery production plants. This was crucial in order to ensure its self-sufficiency in critical raw materials. The second axis is the development of the EV models, with optimized efficiency and autonomy. The third axis is the expansion of the charging network emphasizing on the fast charging (Volkswagen, 2024). These changes play a protagonist role in the reshape of Volkswagen's supply chain. The reason is that they require new partnerships with the battery suppliers. They also require adaptation of production plants and creation of charging infrastructure at strategic points.

The Volkswagen's transition to electric mobility, overall, reflects the general trend in the automotive industry. This means that adapting new sustainability requirements and government policies, in order to reduce the emissions, is forcing many companies to reshape their strategies (Volkswagen, 2024).

8.3 Tesla

Tesla, has revolutionized the automotive industry with its highly integrated supply chain strategy. More analytically, unlike traditional automakers, which rely heavily on third-party suppliers, Tesla has applied a vertical integration. This integration had been applied by manufacturing the key components in-house. Characteristic examples of these key components are the batteries and corresponding software. It's about an approach that has enabled Tesla to reduce its dependency on external suppliers. This approach also enabled Tesla to have higher control over its supply chain (Tesla, n.d.).

At this point, it is mentioned that one of the key elements of Tesla's strategy is its battery production. More specifically, in partnership with Panasonic, Tesla operates the Gigafactory. It is a large-scale battery manufacturing facility. This facility had been designed, in order to meet the growing demand for the EV batteries. This initiative ensures a stable supply of high-performance batteries. At the same time it reduced the costs, which were associated with outsourcing (Tesla, n.d.).

Additionally, Tesla develops its own vehicle software. The company, furthermore, develops its own self-driving technology, allowing it to release over-the-air (OTA) updates, which continuously improve vehicle performance and safety features (Lambert, 2019). By acquiring companies, like for example SolarCity, Tesla has also expanded its ecosystem, so as for it to be able to include renewable energy production

and storage. This expansion concerns the integration of vehicle power needs with sustainable energy sources.

CHAPTER 9. DISCUSSION AND CONCLUSIONS

The transformation of the automotive supply chain from traditional systems to those accommodating EVs represents a significant shift marked by both challenges and opportunities. More analytically, the analysis made in this dissertation showed that traditional supply chains, historically linear and predictable, have been designed around a “make-use-dispose” model, which anticipates fixed product lifecycles. However, the integration of product lifetime extension (PLE) and circular economy principles disrupts these flows. It is about a disruption, which creates challenges. These challenges concern forecasting demand and maintaining equilibrium in material supply. So, there is an existing need for improved adaptability and coordination. Effective collaboration among OEMs, suppliers and logistics providers becomes critical. This collaboration allows navigating these complexities, especially in managing critical resources such as specialized materials and components.

Even more, the roles of the key players in the supply chain are evolving rapidly with the adoption of EVs. More specifically, OEMs, suppliers and distributors, that are players that are traditionally central to the automotive ecosystem, now face one more pressure. It is the pressure of integrating advanced technologies and adapting to new roles.

The advancements in technology are, furthermore, reshaping the core processes and the material flows of supply chain. Artificial intelligence (AI) and predictive analytics enable more efficient inventory management. They also enable demand forecasting and waste reduction. So, their use ensures a smoother material flow and cost-effective operations. The integration of reverse logistics processes, such as for example recycling and material recovery, further aligns with the sustainability goals. Although these efforts introduce new operational challenges. A characteristic example is adapting existing infrastructure to accommodate closed-loop systems. The COVID-19 pandemic, also, underscored the vulnerabilities of traditional supply chains. It’s a recent paradigm that highlighted the importance of agility and resilience to maintain operations during crises.

The transition to EVs, also, introduces fundamental differences in supply chain structures. More specifically, while traditional supply chains are primarily oriented toward ICE components, the EV supply chains demand a special focus on advanced

electronic systems and batteries. So, they create a structural shift. This shift necessitates changes in sourcing, logistics, production and distribution processes, as well. The increasing importance of materials, like lithium and cobalt, further reshapes global trade dynamics. This need also highlights the necessity for localized production and recycling systems. Concludingly, circular economy principles, emphasizing reuse, remanufacturing and recycling, are integral to these changes, due to the fact that they promote sustainability while, at the same time, complicating supply chain coordination.

Smart technologies and integrated management systems are also central to addressing the challenges, which are posed by this transformation. Internet of Things (IoT), blockchain, and AI-driven solutions are helpful for the increase of supply chain visibility and for enabling real-time tracking. Their use, also, facilitates data-driven decision-making. These technologies empower supply chains to adapt to dynamic conditions and to minimize their costs. They also enable them to optimize resource allocation. Predictive analytics and advanced modeling methodologies, such as for example ISM and DEMATEL, are able to further support resilience and risk mitigation.

In conclusion, the transition to the EVs necessitates a holistic reimagining of supply chains, integrating innovation, sustainability and advanced technological solutions. The effective collaboration among stakeholders, the strategic adaptation to evolving market demands and the adoption of smart systems are essential to ensuring the success of the automotive industry in this new era. They are also essential to ensure its and sustainability.

At this point, it is mentioned that the research on the transition of automotive supply chains to accommodate EVs presents useful information, but, at the same time, is accompanied by some limitations. More specifically, one limitation is the geographical and regulatory scope of the already existing research, that was observed by the current literature review. Many studies focus heavily on specific regions, such as Europe, North America or China. In these regions, the EV adoption is more advanced and supported by robust regulatory frameworks. So, there is a regional bias, that overlooks the unique challenges and opportunities in the developing economies, in which infrastructure, policy and market readiness for EV adoption may be significantly different. So, taking this limitation into consideration, we propose that future research should explore these

disparities. We consider the examination of how localized factors influence supply chain transformation in less developed regions, as essential.

Another limitation of the already existing research and study on this subject is the emphasis that is placed by the overwhelming majority of them, on theoretical frameworks and simulation models. For example, many of the existing studies focus on the circular economy principles, predictive analytics and decision-making methodologies, like ISM and DEMATEL. These models offer valuable information, but they are not useful for practical application in real-world supply chains. That's why, future empirical studies should involve longitudinal data from industries implementing these strategies, because this is how a clearer picture of their feasibility and impact is going to be provided.

The high focus on materials such as lithium and cobalt is another limitation. While these materials are essential and central to EV supply chains, alternative materials and technologies, such as for example solid-state batteries or hydrogen fuel cells, have not yet receive much attention. This is why we propose a future research expansion, to consider emerging technologies, that may disrupt current assumptions about material dependencies and supply chain configurations.

The transition to EVs is also examined predominantly from a technological and operational perspective. We consider this another identified limitation, because it means that less emphasis is placed on social and behavioral factors. For example, consumer adoption patterns, workforce skill development and community impacts of supply chain localization are also important aspects. These aspects warrant deeper exploration. Understanding these dimensions could provide a more holistic view of the challenges and opportunities in the transition to the EV-centric supply chains.

Finally, sustainability discussions often focus on the environmental benefits of circular economy practices. Some examples are recycling and reuse. However, the social and economic implications of these practices, such as job creation and equitable resource distribution, are underexplored, as it was observed by the current systematic literature review. So, the future research should integrate multi-dimensional sustainability assessments, in which environmental and socio-economic factors are also going to be explored.

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