

Review

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Review

After-Sales and Maintenance Services: The Hidden Pillar Behind a Successful Electric Vehicle Deployment – A Systematic Literature Review

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Abstract

This paper examines the state of academic literature on the development of after-sales and maintenance services for electric vehicles (EVs), highlighting their critical yet underexplored role in the transition to electrified mobility. Against the backdrop of rising EV sales, the study investigates how service ecosystems influence long-term adoption. A systematic review was conducted to identify recurring themes, barriers, and proposed solutions related to EV maintenance and after-sales systems. The findings indicate that, despite lower mechanical complexity compared to internal combustion vehicles, EVs generate new service demands due to their reliance on electronics, software, and high-voltage systems. Key barriers to EV adoption include high purchase costs, limited charging infrastructure, and shortages of skilled technicians, which collectively affect consumer confidence beyond the point of acquisition. The analysis shows that after-sales services constitute both a technical and economic bottleneck in large-scale EV diffusion. Existing literature predominantly emphasizes theoretical solutions, such as digitalized maintenance and data-driven business models, with limited focus on practical implementation strategies. The paper concludes that sustainable EV adoption depends not only on technological and infrastructural progress but also on workforce adaptation, proposing a transitional management framework to support independent workshops in shifting toward fully electric service operations.

Keywords: electric vehicles; after-sales services; dual maintenance providers; workforce adaptation; electrification transition

1. Introduction

Climate change and its potentially irreversible consequences have become central concerns across social, economic, political, and financial agendas worldwide[1]. Over the past decade, climate mitigation and the pursuit of climate neutrality have emerged as critical global priorities. A significant milestone in this effort was the entry into force of the Paris Agreement in 2016, a legally binding international treaty designed to align national policies with the objective of achieving climate neutrality by 2050. In accordance with the Agreement and the seventeen Sustainable Development Goals (SDGs), the European Union introduced major policy initiatives, including the European Green Deal and the Fit for 55 package, which aim to limit global warming to 1.5 °C above pre-industrial levels while promoting circular economy principles and sustainable industrial transformation [2]. Achieving these objectives requires significant structural transformation in high emission sectors, particularly power generation and transportation, which accounted for 38.24% and 21.11% of global CO₂ emissions respectively in 2023 [3], within the transport sector, road vehicles constituted by far the largest source of emissions, accounting for approximately three quarters of total transportation related emissions 74,33%, in 2024 [4]. Moreover, passenger vehicles emissions increased by approximately 20% between 2010 and 2023, reaching 3.2 GtCO₂ and establishing them as the largest

contributors to global road transport emissions [5]. Consequently, the transition toward electric mobility has been widely promoted as a key strategy for decarbonizing transport systems, given the potential of electric vehicles (EVs) to substantially reduce greenhouse gas emissions.

The electrification of transport also contributes to the advancement of several United Nations Sustainable Development Goals. Electric mobility supports SDG 7 (Affordable and Clean Energy) by facilitating the integration of renewable energy into transport systems; SDG 9 (Industry, Innovation, and Infrastructure) through the development of advanced technologies and charging infrastructure; SDG 11 (Sustainable Cities and Communities) by reducing urban air pollution and improving livability; SDG 12 (Responsible Consumption and Production) through battery recycling and circular economy practices; and SDG 13 (Climate Action) by contributing to green-house gas mitigation and climate neutrality objectives. In addition, the transition toward electric mobility intersects with SDG 8 (Decent Work and Economic Growth), as it generates demand for new technical and digital competencies while simultaneously requiring large scale workforce reskilling to ensure a just and inclusive transition [6,7].

Despite their environmental benefits and increasing market penetration, electric vehicles continue to face technical, social, and infrastructural barriers that influence consumer acceptance and large-scale adoption. In pursuit of a rapid decarbonization, European economic and regulatory frameworks have introduced ambitious timelines requiring original equipment manufacturers (OEMs) to transition from internal combustion engine (ICE) technologies to fully battery-electric vehicles. However, such accelerated timelines have raised concerns regarding their broader implications for the automotive market, supply chains, and overall economic performance [8].

Recent data highlight both the rapid growth and the structural challenges of this transition. According to the International Energy Agency's 2024 report on electric vehicle progress, the global electric car fleet approached 58 million units by the end of 2024. Regional disparities remain substantial: in China, approximately one in ten vehicles is electric, whereas in Europe the proportion is closer to one in twenty vehicles. These trends raise increasing concerns regarding the preparedness of after-sales service infrastructures to support a rapidly expanding EV fleet. Additional challenges are likely to emerge as warranties start to expire and the demand on secondary markets for electric vehicles will increase [5].

An important yet relatively underexplored dimension of the electrification transition concerns its implications for the automotive aftermarket workforce. The shift toward software intensive vehicle architectures and high-voltage electric systems requires specialized competencies that differ substantially from those associated with conventional internal combustion engine vehicles. At the same time, Europe faces significant labor shortages across multiple sectors due to demographic changes, an aging workforce, and limited training capacities—factors further exacerbated by social and geopolitical instability. Evidence indicates growing shortages of skilled technical labor, while several major automotive manufacturers have simultaneously announced workforce reductions in response to cost pressures, market uncertainty, and slower than expected EV adoption. These developments reveal an emerging structural imbalance characterized by a potential surplus of labor specialized in traditional automotive technologies alongside a shortage of technicians qualified to service electric vehicles [9].

Although the issue of reconversion and reskilling of existing personnel and the need to supply new, EV-specialized professionals on the workforce market has been addressed before by [10], the purpose of this research is to establish, if the academic literature has answered the following questions: **RQ1:** How has the literature addressed occupational requirements, safety, and skills for EV maintenance personnel? **RQ2:** To what extent has the literature provided structured operational or business models for hybrid ICEV–EV service ecosystems? Addressing the emerging skills gap requires coordinated action across education systems, training institutions, industry actors, and policymakers to establish targeted vocational, technical, and academic programs and developing a concrete, applicable, dual business model for both ICEVs and EVs maintenance operations is vital for both the economy and the future diffusion of EVs. Only through timely institutional adaptation can

the European automotive sector maintain competitiveness and ensure reliable after-sales support within an increasingly electrified mobility landscape.

2. Methodology

In order to achieve the main objective of this paper - to establish the current state of knowledge and research regarding after-sales services for electric vehicles (hybrids, plug-in hybrids, and battery electric vehicles) a systematic and bibliometric literature review was conducted, between 2024 and the end of February 2026. The research process was designed to ensure transparency, reproducibility, and comprehensiveness, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Three internationally recognized academic databases— Elsevier/Scopus, Elsevier/ScienceDirect, and Web of Science (ISI) were selected for their broad coverage of peer-reviewed publications and high citation relevance. While these databases represent the most comprehensive sources in the field of engineering and management sciences, a limitation of this selection is the exclusion of grey literature, such as conference papers, theses, and industry reports, which may also contain relevant but non-peer-reviewed insights.

Table 1, below, contains the methodology applied to identify relevant studies about the after-sales/maintenance/repairs of the electric cars and all the issues encountered in this matter.

Table 1. Refinement list applied to the literature review.

Resources used for the literature review	International Data Base (BDI): Elsevier/Scopus, Elsevier/Science Direct and Web of Science (ISI)
Key words	<ul style="list-style-type: none"> ▪ “Electric Car Maintenance” ▪ “After Sales Services” AND “Electric Cars” ▪ “Electric Cars Aftermarket” ▪ “Electric Cars Repairs” ▪ “Electric Car” AND “Repairs” ▪ “Electric Car” AND “Aftermarket” ▪ “Electric Car” AND “After Sales Services”
Search strategy	The keywords were introduced in the field called “Subject”.
Inclusion criteria	<ul style="list-style-type: none"> ▪ Only peer-reviewed review and research studies dating between the years, 2001- 2025, written in English, published in journal articles. ▪ Published between 2001 and 2025, corresponding to the period following the mass production onset of electric vehicles (around 1999); ▪ Studies explicitly addressing after-sales, maintenance, repair, or service-related topics concerning electric vehicles.
Exclusion criteria	<ul style="list-style-type: none"> ▪ Theses, dissertations, conference proceedings were excluded. ▪ Book chapters, commentaries, and editorials were, also, excluded.

1) Stage one: Researching within the databases – quantitative search

The relevant keywords, as mentioned in Table 1, were introduced separately, in each database, according to the inclusion criteria, resulting in 183 papers, in Science Direct; 176 papers, in Scopus;

34 papers, in Web of Science. Based on the above-mentioned criteria of inclusion and exclusion, one author screened the list of titles and abstracts retrieved through electronic and manual searches.

2) Stage two: Organizing and deduplication of the papers

To ensure a systematic, logical, and reproducible refinement of the collected documents, this analysis employed Zotero as the primary reference management tool. A folder containing papers from the aforementioned databases, was created, in order to accurately find and eliminate the duplicate papers.

3) Stage three: Qualitative screening

After the initial assessments in stage 1 and 2, a substantial volume of existing researches took shape, however, closer examination of each paper's title and then abstract revealed that the majority of the studies addressed electric mobility in alternative transport modes, such as trucks, trains, and buses, or focused on battery technologies and electric vehicle management systems. Comparatively little attention was given to the maintenance and repair of electric vehicles as a complex, system-level domain undergoing a profound transitional process. Accordingly, the screening process at this stage resulted in the exclusion of approximately two-thirds (from Scopus and Science Direct) of the initially identified studies, thereby substantially narrowing the body of literature relevant to the research scope.

The final list of papers consists in 91 documents to be further scrutinized. This systematic review combines systematic screening (for methodological rigor) with bibliometric evaluation (for identifying publication trends, thematic clusters, and research gaps). This dual approach ensures both conceptual depth and quantitative validation of patterns in the field of EV after-sales services. An initial assessment of each paper's title, then abstract, only those meeting the relevance criteria were included in the qualitative analysis stage. The final list of papers consists in 91 documents to be further scrutinized. This hybrid review combines systematic screening [for methodological rigor] with bibliometric evaluation (for identifying publication trends, thematic clusters, and research gaps). This dual approach ensures both conceptual depth and quantitative validation of patterns in the field of EV after-sales services.

Figure 1 illustrates the systematic procedure employed to identify and select relevant academic publications from three major bibliographic databases—ScienceDirect, Scopus, and Web of Science. This structured, multi-stage filtration process was designed to ensure both the rigor and the relevance of the final dataset used for analysis. Consequently, the resulting group of papers consists exclusively of peer-reviewed, relevant, and non-duplicative articles, establishing a robust foundation for subsequent qualitative or bibliometric analyses.

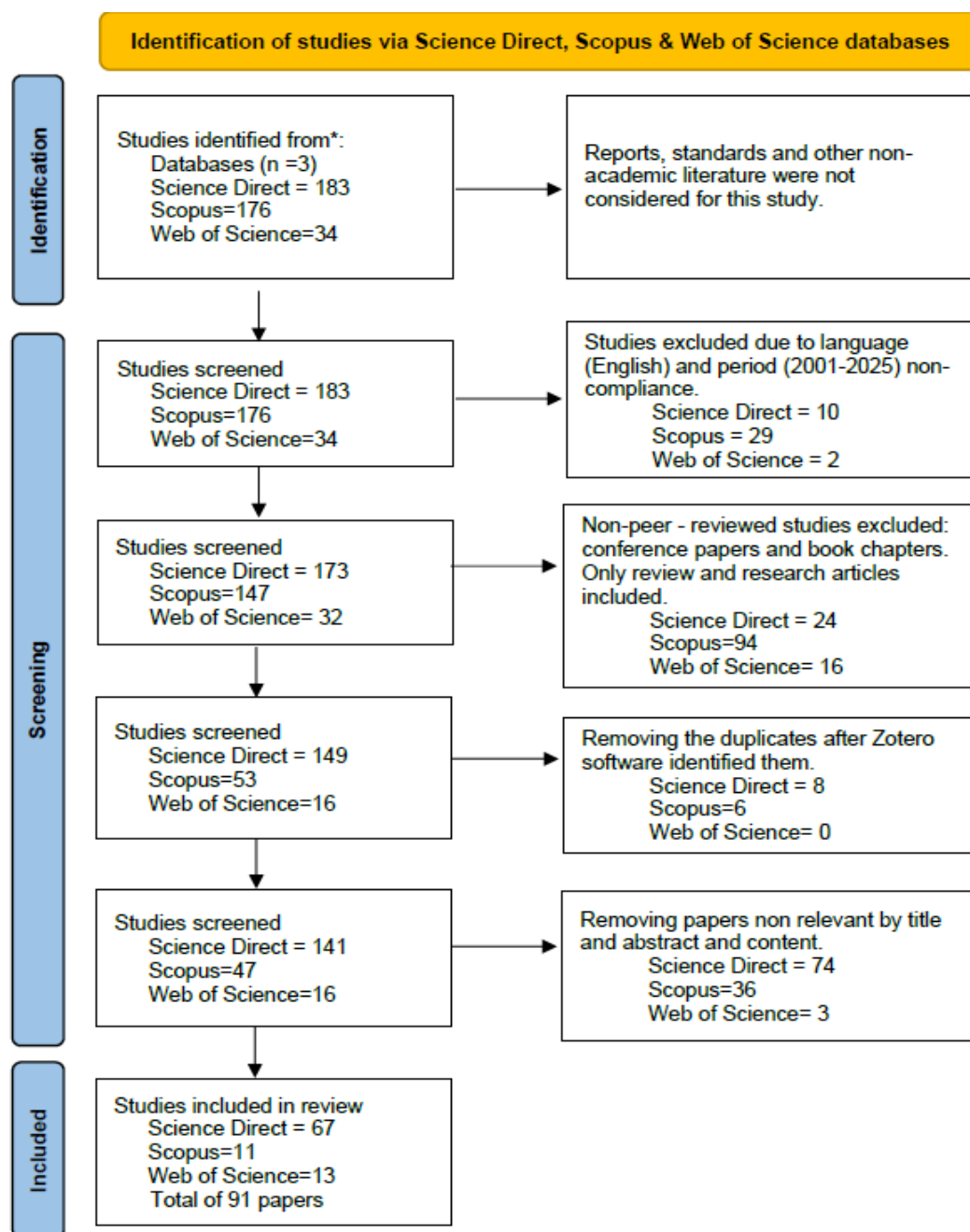


Figure 1. The flow diagram of the selection, exclusion and inclusion process.

This structured, multi-stage filtration process was designed to ensure both the rigor and the relevance of the final dataset used for analysis. Consequently, the resulting group of papers consists exclusively of peer-reviewed, relevant, and non-duplicative articles, establishing a robust foundation for subsequent qualitative or bibliometric analyses. The methodology adheres to the principles of transparency and rigor outlined in established systematic literature review protocols of PRISMA.

3. Bibliometric Information

In this section, a bibliometric assessment is conducted on the final set of 91 publications. The evaluation encompasses several dimensions, including the temporal evolution of research output, publication sources, co-authorship networks, citation performance, and the geographical distribution of contributing authors. Below, in Table 2, general data regarding the 91 selected papers are presented.

Table 2. Descriptive analysis of the main bibliometric indicators.

General Information	Meaning	No.
Papers	Total number of selected papers	91
Sources	The origin of the papers (Elsevier, Clarivate)	2
Period	Years of publication	2001– 2025
Authors	Total number of authors	339
Journals	Total number of journals covering the topic	49
Authors of single-authored papers	The number of single authors per articles	6
Authors of multi-authored papers	The number of authors of multi-authored articles	333
Authors per paper	Average number of authors in each paper	3.72
Co-Authors per papers	Average number of co-authors in each paper	3
Average citations per article	Average number of citations in each article	56.76
Collaboration Index		3.91

Source: Elaborated by the authors.

The bibliometric analysis revealed a moderately collaborative and mature research field characterized by diverse authorship and a relatively high citation impact. A total of 339 authors contributed to the dataset, yielding an average of 3.72 authors per paper. This indicates that most publications were co-authored, reflecting an established pattern of collaborative research rather than individual scholarship, only 6 papers were written by single authors. The average number of co-authors per paper (3) and a collaboration index of 3.91 further emphasize the cooperative nature of the domain, suggesting the presence of research networks and interdisciplinary engagement.

Publications originated from two major academic databases (Elsevier and Clarivate), encompassing 57 distinct journals, which illustrates the multidisciplinary dissemination of the topic, this vast distribution suggesting that the subject area — likely relating to electric vehicle adoption, maintenance, and after-sales service — is of interest to multiple academic audiences, including engineering, sustainability, business, and policy researchers.

The dataset average citation rate of 56.76 citations per article signifies strong scholarly impact, exceeding typical benchmarks for emerging fields. Such a citation profile indicates that the topic has attracted sustained academic attention and influence, particularly in recent years (as research output peaked between 2021–2023).

In summary, the bibliometric indicators collectively suggest a collaborative, high-impact, and interdisciplinary research field that has evolved significantly over the past two decades.

3.1. The Evolution of Publications

Research on electric vehicle (EV) adoption, maintenance, and after-sales services received limited academic attention prior to 2013. A noticeable surge in publications emerged after 2018, coinciding with global initiatives promoting sustainability, electric mobility, and low-carbon policies. The research activity peaked between 2021 and 2023, reflecting strong momentum and increasing relevance in both academic and policy contexts. As illustrated in Figure 2, a slight decline in publication frequency is evident from 2024 onward, suggesting a temporary stabilization in research output.

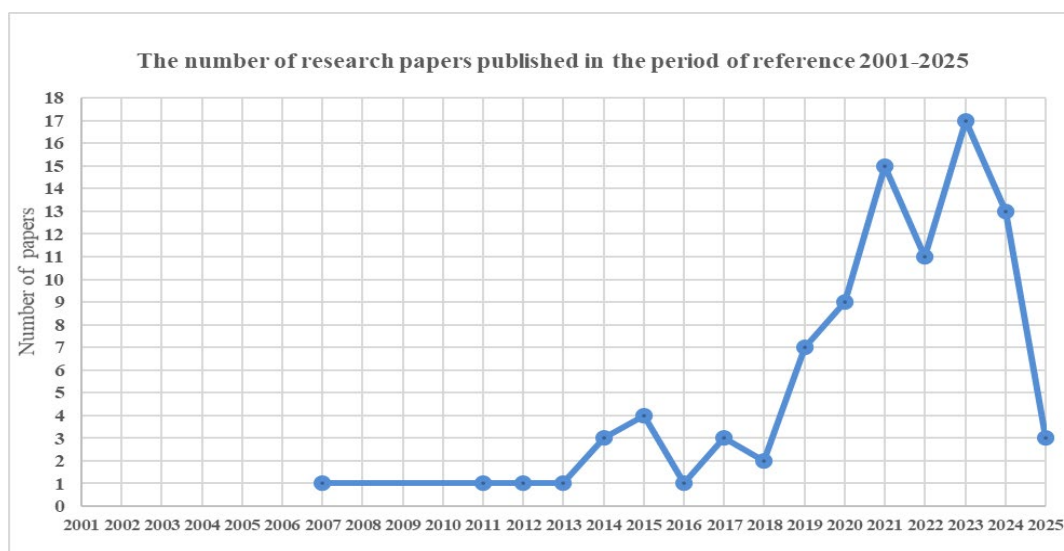


Figure 2. The evolution of EV related scientific papers between 2001-2025.

3.2. Publications Distribution

The Table 3 shows the distribution of published papers across different journals and conferences. The publication landscape reveals that EV-related research, especially in maintenance, after-sales, and adoption studies, is interdisciplinary but concentrated in sustainability and energy journals. Journal of Cleaner Production dominates the field, while transportation and energy journals provide secondary strongholds. However, the dispersion across numerous smaller outlets highlights ongoing fragmentation and the potential for greater consolidation in dedicated EV-focused publication channels.

Table 3. Distribution of Published Articles by Journal and Coverage Period [2007–2025].

Name of the publication	Number of articles published	Period covered
Journal of Cleaner Production	9	2019-2025
Technological Forecasting and Social Change	5	2020-2022
Transportation Research Part D: Transport and Environment	4	2018-2024
Research in Transportation Business & Management	4	2022-2024
Transportation Research Part A: Policy and Practice	3	2012-2022
Transportation Research Interdisciplinary Perspectives	3	2021-2024
Applied Energy	3	2016-2021
Energy Policy	3	2011-2023
Renewable and Sustainable Energy Reviews	3	2017-2023
Case Studies on Transport Policy	2	2021-2022
Computers in Industry	2	2007-2022
Energies	2	2021-2023
Energy for Sustainable Development	2	2022-2024

Sustainability [Switzerland]	2	2019
Transport Policy	2	2023-2024
World Electric Vehicle Journal	2	2024
Total	51	2007-2025

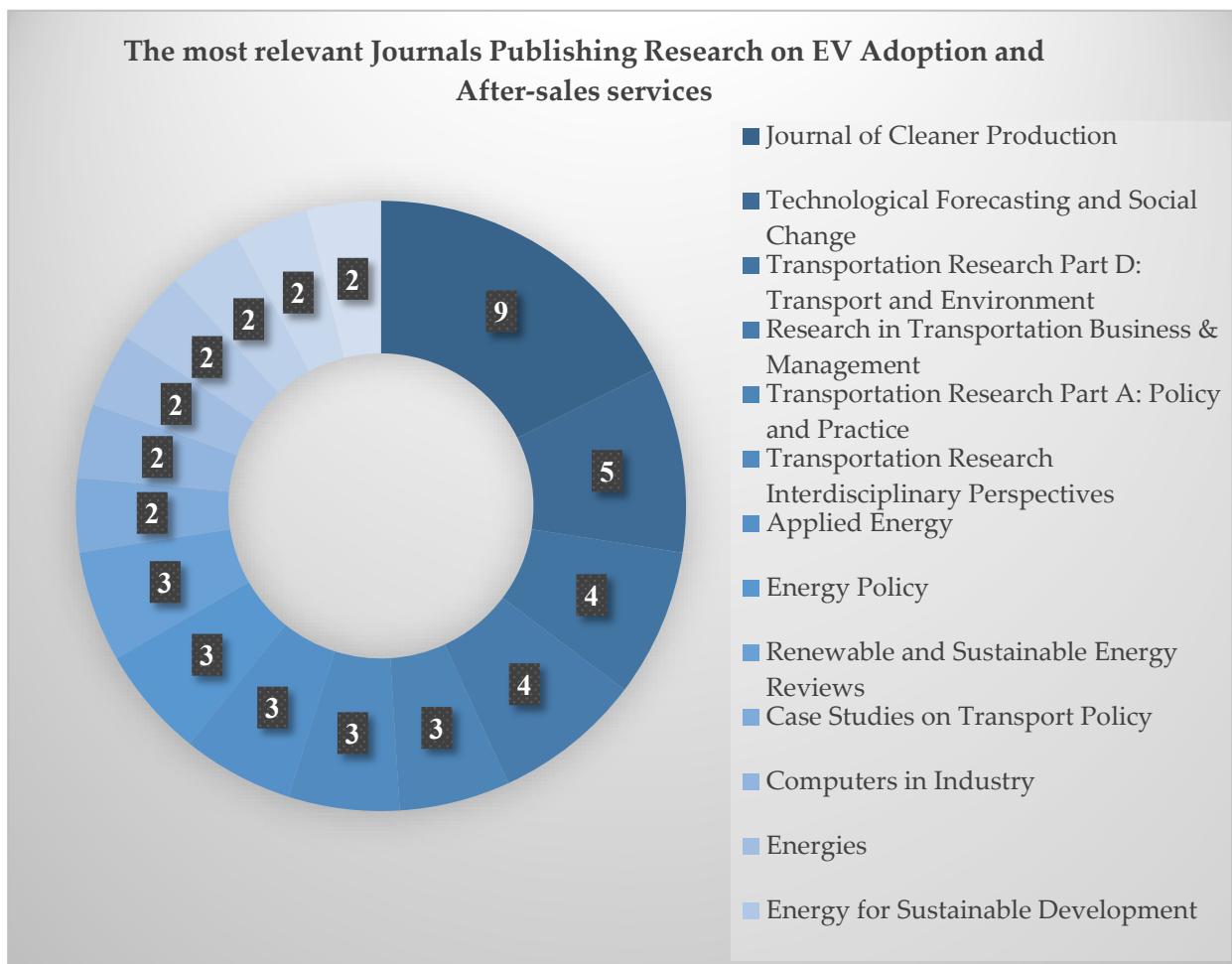


Figure 3. The most important publications covering EV topic in this literature review.

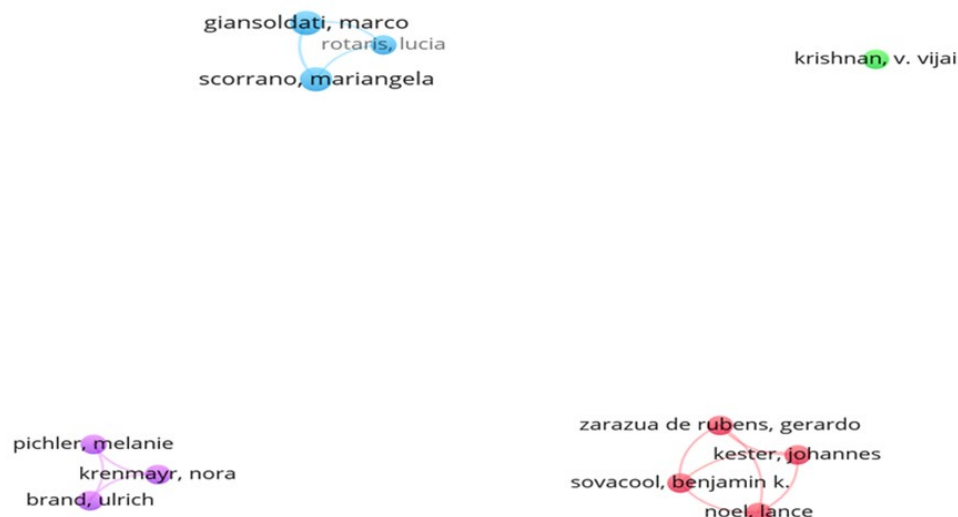
Figure 3 presents the distribution of 51 selected papers across the most active academic journals contributing to research on electric vehicle (EV) adoption, maintenance, and after-sales systems. The visualization demonstrates a moderate concentration of research output among a small group of high-impact journals, with the remaining studies dispersed across a diverse range of outlets.

The Journal of Cleaner Production emerges as the most prolific source, publishing nine articles on the topic. Its dominance reflects the strong environmental and sustainability orientation of EV research, aligning with the journal's focus on sustainable production systems and green technologies. The Technological Forecasting and Social Change journal ranks second with five publications, highlighting the growing emphasis on forecasting, innovation diffusion, and socio-technical transitions toward electrified mobility. Other prominent outlets include Transportation Research Part D: Transport and Environment (four papers) and Research in Transportation Business & Management (four papers), both of which underscore the field's applied and policy-oriented dimensions. A cluster of journals—including Transportation Research Part A, Transportation Research Interdisciplinary Perspectives, Applied Energy, Energy Policy, Renewable and Sustainable Energy Reviews, and Case Studies on Transport Policy—each contributed between two and three papers, indicating a diversified research landscape that spans energy systems, policy analysis, and

transport management. The remaining 40 papers were published either in conference proceedings or in journals that featured only a single article on the topic.

Overall, the data suggest that scholarship on EV adoption and after-sales services is interdisciplinary, with strong representation in sustainability, transport, and energy journals. This cross-sectoral distribution reflects the multifaceted nature of EV research, bridging technological innovation, policy development, and business transformation.

3.3. Co-Authorship Analysis



Using a VOSviewer network visualization, the co-authorship relationships among researchers working on electric vehicle [EV]-related topics were mapped and analysed. In the visualization, each node [circle] represents an individual author, while the connecting lines indicate co-authorship links. The visualization reveals several collaboration clusters: from Italy authors Marco Giansoldati, Lucia Rotaris and Mariangela Scorrano, who form a tightly knit research group with frequent co-authorship ties. Authors Gerardo Zarazua de Rubens, Benjamin K. Sovacool, Lance Noel, and Johannes Kester, represent another well-established and highly collaborative network between scholars in Denmark and UK. In Austria, Melanie Pichler, Nora Krenmayr, and Ulrich Brand, have a strong internal collaboration and Krishnan, V. Vijai represent a solitary node, suggesting limited or no direct co-authorship connections within this particular dataset. Mainly, the co-authorship map highlights that research on EV adoption, maintenance, and after-sales services is fragmented into several distinct collaboration networks, with minimal cross-linkages between clusters, as observed in Figure 4.

Figure 4. The co-authorship link between the authors of the 91 papers.

This pattern suggests the existence of isolated research communities rather than a single, highly integrated scholarly network within the field.

3.4. Citation Distribution and Country Affiliation

The bibliometric evidence reveals a highly unequal citation distribution, with a small subset of publications accounting for a disproportionate share of total citations. Prominent among these are the UK [11] with 562 citations, [12] a France/Netherlands collaboration with 475 citations and [13] from Spain with 397 citations, which constitute cornerstone studies in the domain. These papers primarily examine consumer behavior in EV adoption, systemic transformation processes, and innovative business models, highlighting their central role in shaping scholarly discourse and theoretical advancement in the field.

The citation distribution reveals a strong geographical concentration of highly influential studies in Europe, particularly among publications exceeding 300 citations, which predominantly establish foundational frameworks on electric vehicle adoption, business models, and service systems. Mid-

range citation groups (50–299 citations) exhibit increasing regional diversity, with growing contributions from Asia, North America, and cross-regional collaborations, reflecting the globalization of EV-related research. In contrast, the majority of papers fall within the low-citation and zero-citation categories, representing recent, specialized, or region-specific studies across Asia, Africa, the Middle East, and South America. This pattern indicates both the rapid expansion of the field and a temporal lag in citation accumulation for emerging topics such as digital maintenance, workforce reskilling, and EV after-sales services.

Table 4 presents a hierarchy of the papers, listed according to their influence in the field. Papers having more than 300 citations were considered the founding studies, between 299 -100 citations, papers were considered highly influential, between 100 – 50 citations, papers were deemed influential, under 50 citations, papers were considered emerging contributions and papers with no citation index, but relevant content.

Table 4. The hierarchy of papers according to their Citation Index.

Citation Index	Author or Authors and Year of Publication	Region
Over 300 citations	[12,14,15],	<i>Europe</i>
	[16]	<i>Asia</i>
Between 299-100 citations	[17,18]	<i>Asia</i>
	[19–21]	<i>Europe</i>
	[22]	<i>Asia</i>
Between 99 - 50 citations	[23–28]	<i>Europe</i>
	[29,30]	<i>North America</i>
	[31,32]	<i>South America</i>
	[33–35]	<i>Europe and Asia</i>
	[36]	<i>Europe, Middle East, North America</i>
	[37]	<i>Europe and Africa</i>
Under 50 citations	[10,38–67]	<i>Europe</i>
	[33,68–82]	<i>Asia</i>
	[83–85]	<i>North America</i>
	[86]	<i>South America</i>
	[87,88]	<i>Middle East</i>
	[89]	<i>Australia</i>
	[90]	<i>Africa</i>
	[91,92]	<i>Europe and Asia</i>
	[93]	<i>Europe and Australia</i>
	[94]	<i>North America and Asia</i>
[95]	<i>Asia and Middle East</i>	
No citation	[96–100]	<i>Asia, Africa, Middle East</i>

The observed citation pattern highlights a structural imbalance in the literature: while highly cited, early studies focus on EV adoption, business models, and macro-level transitions, more recent and regionally diverse research addressing after-sales services, maintenance practices, workforce readiness, and organizational adaptation remains weakly cited and fragmented. This disparity suggests that knowledge production has prioritized technological performance and market diffusion over operational, human, and service-oriented dimensions, particularly in the context of electric vehicle maintenance. The concentration of low- and zero-citation studies in emerging regions further indicates that context-specific challenges related to skills, repair infrastructure, and service governance are underrepresented in dominant theoretical frameworks, reinforcing the need for integrated, cross-disciplinary research that bridges economic, technological, and ergonomic perspectives—an explicit gap addressed by the present study.

As far as the country of affiliation is concerned, below, Figure 5 illustrates the geographical distribution of authors' institutional affiliations contributing to research on electric vehicle (EV) adoption, maintenance, and after-sales services.

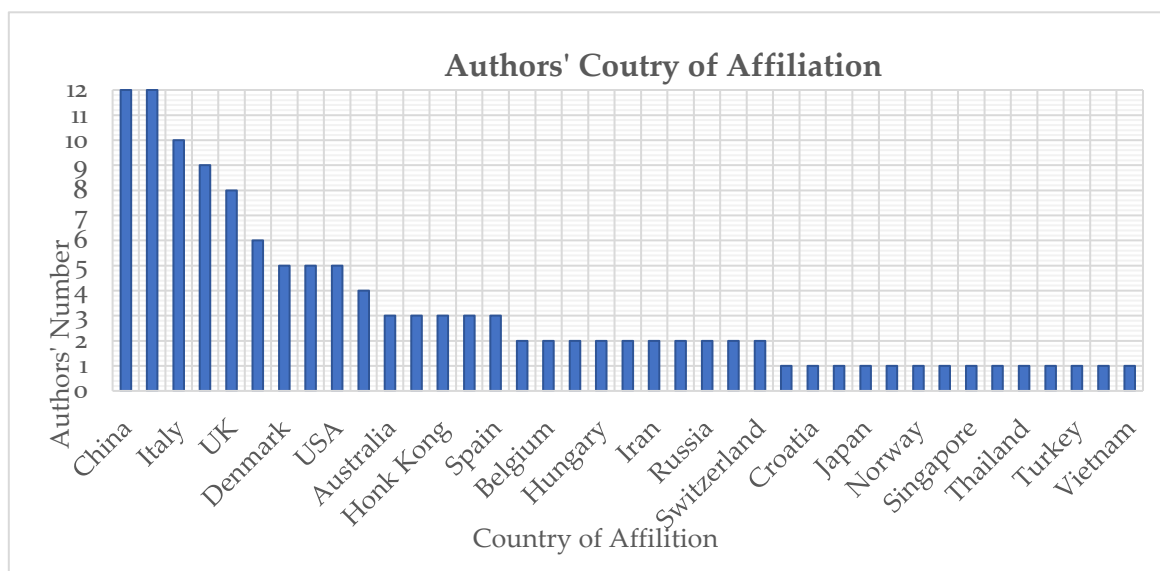


Figure 5. The authors' country of affiliation.

The data indicate that China and India are the leading contributors, each with 12 affiliated authors, followed by Italy [10], Germany [9], and the United Kingdom [8]. This highlights the dominant role of Asian and European researchers in advancing EV-related scholarship.

Moderate contributions are observed from Poland, Denmark, France, and the USA, while a wider group of countries—including Brazil, Australia, Malaysia, and the Netherlands—show limited but notable participation. Representation from regions such as Africa, the Middle East, and Southeast Asia remains marginal, suggesting a geographically uneven distribution of research activity. Overall, the figure reflects a concentration of EV research expertise in a few industrialized and emerging economies, underscoring the need for broader international engagement in the field.

The bibliometric analysis provides a comprehensive overview of the research landscape on electric vehicle (EV) adoption, maintenance, and after-sales services, revealing a rapidly expanding yet unevenly distributed field. Scholarly output has increased significantly since 2019, driven by global sustainability initiatives and policy support for electric mobility. The analysis highlights strong collaboration networks, primarily concentrated in Europe and Asia, with China, India, and several European countries leading in publication volume and citation impact.

4. EV Aftersales and Maintenance Services—The Scientific Literature Approach

The global shift toward sustainable transportation has placed electric vehicles (EVs) at the centre of both environmental and technological debates. As countries intensify efforts to reduce greenhouse gas emissions and decrease reliance on fossil fuels, EV adoption has emerged as a key strategy for advancing climate objectives and enhancing energy security. Nonetheless, the diffusion of EVs is influenced by a complex set of drivers and constraints that differ across socioeconomic, geographic, and infrastructural contexts [101]. However, considering the global economy at the end of the year 2025: the constant war threats in Europe, the escalating conflict between Ukraine and Russia, the rise of Chinese economy and the equivocal foreign politics of USA, it seems that European Union is seriously considering to delay or to lift the 2035 ban of on sales of new combustion-engine cars [102].

In their latest report, [103] has ascertained the following relevant facts: less than 4% of EU cars are electrically chargeable and the average age of EU car fleet is 12.5 years, with an upward trend; meanwhile, [104] has reported that BEVs have recorded a minor setback, in 2024, the sales dropping by 1.14%, in comparison with the previous year. Plug-in hybrid electric vehicles (PHEVs), which combine the environmental benefits of battery electric vehicles with the reliability of conventional gasoline engines, have not achieved the anticipated market success. After sales peaked in 2022, a steady decline followed by in their market share. Hybrid electric vehicles (HEVs) dominate the market for alternative propulsion systems. Their sales have increased steadily since 2020, and by 2024, they represented nearly one-third of all new cars sold in the European Union.

Data presented by ACEA (The European Automobile Manufacturers' Association) have been further analyzed in Figure 6, illustrating the comparative evolution of new electric vehicle (EV) sales—including battery electric vehicles (BEVs), plug-in hybrids (PHEVs), and hybrid electric vehicles (HEVs)—and internal combustion engine (ICE) car sales in Europe from 2020 to 2024. The data reveal a clear and sustained shift toward electrified mobility over the observed period.

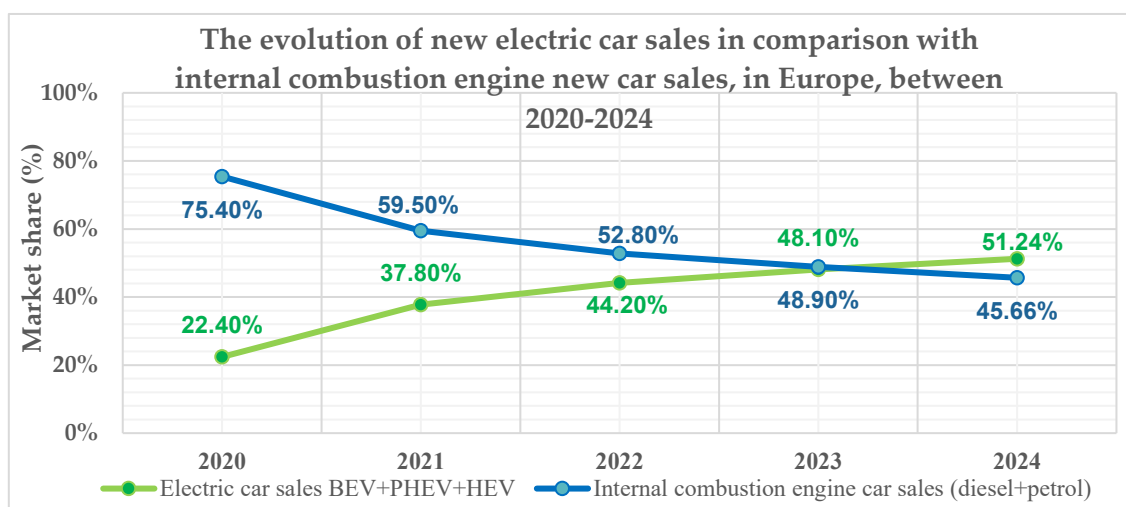


Figure 6. The evolution of new electric car sales in comparison with internal combustion engine new car sales, in Europe, between 2020-2024.

In 2020, ICE vehicles dominated the market, accounting for 75.4% of new car sales, while electric vehicles represented only 22.4%. However, the trend shows a steady decline in ICE sales and a consistent increase in EV adoption, with the two market segments reaching near parity in 2023 (48.9% ICE vs. 48.1% EVs). By 2024, electric vehicles surpassed conventional models for the first time, achieving a market share of 51.24%, compared to 45.66% for ICE vehicles.

This evolution, although less rapid than desired, underscores a structural transition in the European automotive market, driven by policy incentives, technological advancements, and changing consumer preferences. The data suggest that Europe is approaching a tipping point in the decarbonization of road transport, with electric vehicles emerging as the new market norm rather than an alternative niche.

For the reasons mentioned above, it can be concluded that the number of electric cars (BEV, PHEV, HEV) is growing, constantly, perhaps not at the pace envisaged by the EU authorities or required by the reversal of the climate change consequences, but advancing in the right direction. Considering the upward trend of all types of electric cars, it is reasonable to explore the readiness of the OEMs to deal with issues and challenges brought by the technology within the electric cars.

The purpose of this systematic review is to ascertain whether the academic and scientific community have addressed the aftersales problems risen by the use of electric cars, in a quantitative and qualitative fashion. Only with thorough researches and analysis have the technological development progressed, the limitations and the concerns approached by the scientific work is the foundation on which evolution is achieved.

During the first stages of the literature review, while searching the databases, a lot of papers expressed interest for the three phases of a car lifecycle: raw materials sourcing, production and end of life, neglecting the 'here and now' phase: use and exploitation, [105,106], as shown in Figure 7.

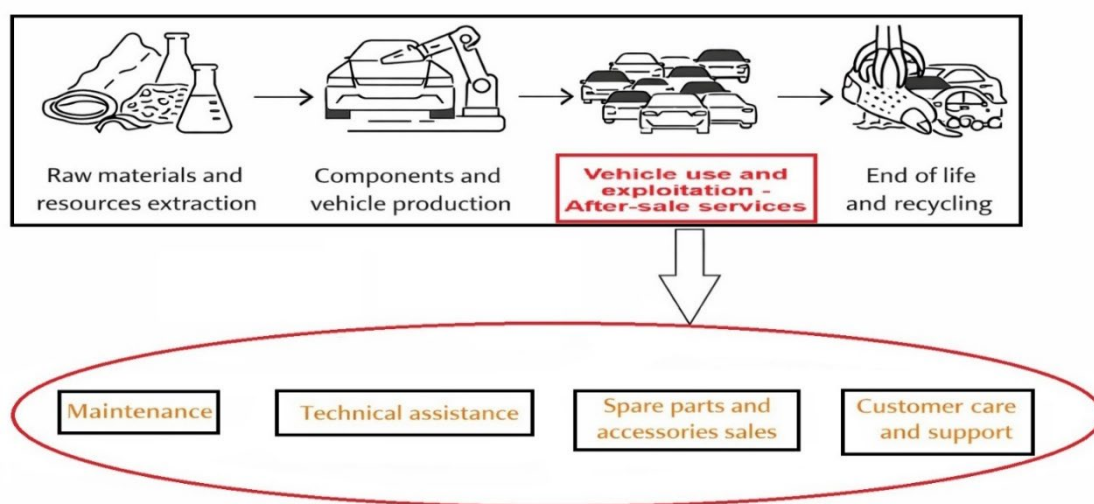


Figure 7. The life cycle of vehicles and the components of the use phase.

The papers [107] and [108] define the aftersales services as service activities performed during and after the warranty period, encompassing product maintenance, technical assistance, provision of spare parts and accessories, as well as customer care and support. After-sales services are critical for ensuring product reliability, customer satisfaction, and brand loyalty. These services extend the operational lifespan of products, reduce failure rates, and enhance perceived value, thereby influencing repurchase intentions and overall market competitiveness. Moreover, in the context of electric vehicles, effective after-sales management supports technological adaptation, user confidence, and the sustainability of the mobility ecosystem through efficient resource utilization and lifecycle management [109].

Clearly, efficient and professional after-sales services can only be provided by qualified personnel, and despite the fact that out of 250,000,000 million passenger cars on European roads, approximately 7,1% are electric cars (HEVs, PHEVs, BEVs)[103], it can reasonably be concluded that maintenance and repair workshops [either dealerships or independent] must be equipped with trained and skilled workers able to address issues regardless of the powertrain. The professional workforce problem, the fundament of all after-sales service, has been approached before in the scientific literature, but without the proper impact [10,110,111]. Given, possibly, that in 2014, it was too early to seriously research this matter, this paper aims to establish the current state of knowledge concerning after-sales services.

Selecting the relevant papers for this literature review was not an easy task, due to the fact that there are few documents approaching this theme directly, and the most merely mentioning it, in other contexts.

VOSviewer was a very useful tool employed to facilitate the systematic organization of the literature. By generating co-authorship and co-occurrence, the tool enabled the identification of thematic clusters that represent major research streams within the field. These clusters provided a data-driven basis for grouping articles according to shared conceptual orientations and methodological approaches. Through this mapping process, the literature review was structured around interconnected areas of interest. Thus, VOSviewer played a major role in enhancing the objectivity, transparency, and coherence of the review's analytical framework.

Figure 8 presents the key-word co-occurrence network and their density map, which reveals several dominant thematic clusters. The first, centred around terms such as "system," "service," "industry," and "business model," reflects research focusing on service systems, industrial transformation, and business model innovation in the EV sector. A second prominent cluster, represented by terms like "maintenance," "repair," and "replacement," corresponds to studies addressing technical and operational aspects of EV maintenance and lifecycle management. A third major cluster—organized around "EV adoption," "intention," "perception," and "user"—captures research on consumer behaviour, adoption intentions, and socio-psychological determinants of EV uptake. The subsections of this paper will be structured according to the clusters identified by VOSviewer.

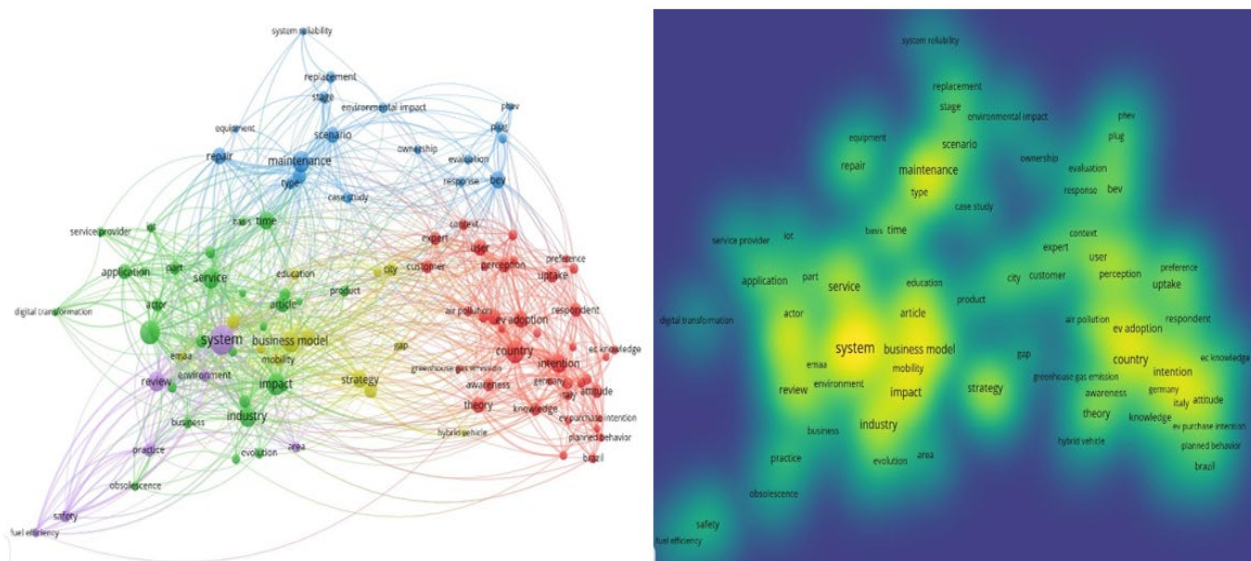


Figure 8. Keyword Co-occurrence Network and Keyword Co-occurrence Density Map.

4.1. Factors That Hinder EV Adoption

In their literature review, [16] mention that consumer priorities increasingly centre around safety, comfort, and maintenance issues associated with electric vehicles and aftersales service quality, in terms of readiness and presence, should be improved, due to the fact that it has a considerable influence on the EV market.

In papers [17,71], the authors have classified the barriers to EV adoption in four categories, divided, themselves into sub-barriers: living with technology (four sub-barriers), lack of trust (five sub-barriers), sales conversion inability (two sub-barriers), desirability (seven sub-barrier). Of course, the issue of maintenance could easily fall under three categories:

- Living with technology - sub-barrier cost of purchase and ownership
- Sales conversion inability- dealers
- Desirability – repair and lack of fun and emotional attachment.

The authors introduce a unique perspective, when considering the engagement in automobile maintenance and repair as a widely appreciated activity among individuals, with many deriving personal satisfactions from independently repairing and modifying vehicles. There exists a prevalent perception that conventional internal combustion engine (ICE) vehicles are less complex to repair compared to electric vehicles (EVs), leading consumers to favour vehicles that allow for self-maintenance and reduced dependence on professional service centres. A significant portion of vehicle owners advocate for the right to repair their own vehicles, a stance often at odds with the restrictive policies adopted by many EV manufacturers. These policies are viewed as strategic limitations on repairability, intended to foster reliance on official service providers and, consequently, increase revenue streams, to the detriment of the “I can do it myself” repair culture.

4.2. EV Era - Introducing New Business Models, New Technologies and Continuous Challenges

The automotive industry is undergoing a profound technological and organizational transformation driven by the global push for decarbonization and digitalization. Electric vehicles (EVs) have emerged as both a technological innovation and a socio-economic disruptor, reshaping production structures, labour requirements, and value chains. The after-sales services of electric cars entail multidisciplinary transformation and adaption, they cannot be reinvented within themselves. A transition period that addresses all the challenges and clears the path for new business models, must combine the old and the new practices and knowledge, in order to make the EV adoption successful. The technological, digital, human, and institutional dimensions interact within a dynamic system in which technology provides the infrastructure, the digital dimension facilitates data exchange and analysis, the human component ensures skills and adaptability, and the institutional dimension establishes the regulatory and governance framework. Together, these dimensions reinforce one another, generating innovation and sustainable transformation within organizations and society. This interdependence becomes particularly evident when progress in one dimension (e.g., technological advancement) requires the alignment of values, policies, and behaviours across the others, in order to produce a coherent impact. Figure 9 illustrates the interdisciplinary dimension of electric cars after-sales.

Maintenance and lifecycle implications approached by several studies [10,40,93,97] converge on the finding that EVs entail lower maintenance costs than internal combustion engine vehicles (ICEVs), primarily due to their reduced number of moving parts, simpler drivetrains, and fewer consumables. However, this apparent efficiency conceals a growing complexity in diagnostic systems, electronic architectures, and battery management, creating new demands for specialized skills and technologies leading to a major concern that ensuring the profitability of dealerships and related business units in the context of a transition toward electric vehicles, uncertainties, also, exist regarding activities carried out by sales and aftersales actors, such as traditional vehicle maintenance, which are expected to decline, when electric vehicle will be adopted on a larger scale, [15,67]. While the mechanical workload decreases, the cognitive and technical load increases — shifting the centre of expertise from traditional mechanics to high-voltage, software, and systems engineers [48,86].

Across the literature, there is consensus that the transition to electric mobility demands substantial workforce adaptation. Studies from Europe [62,65,66] and Asia [61] underline a critical gap between existing technician skillsets and the emerging requirements of electrified and digitalized vehicle platforms. [59] pointed to deficits in formal education and safety training among repair workers. [52,53] noted limited research on vehicle maintenance modelling, calling for expanded study on environmental and operational impacts of EV servicing and proposed lifecycle optimization models for vehicle replacement, linking maintenance data with sustainability and resource management. [87] discussed requalification challenges as the workforce shifts from ICE to EV production; emphasized reskilling programs for job continuity. The scarcity of high-voltage qualified technicians, limited training capacity, and slow curriculum reform in vocational systems represent systemic bottlenecks. Universities and training centres are increasingly positioned as key actors in

bridging these skills divide, yet current reskilling initiatives remain fragmented and reactive rather than strategic.

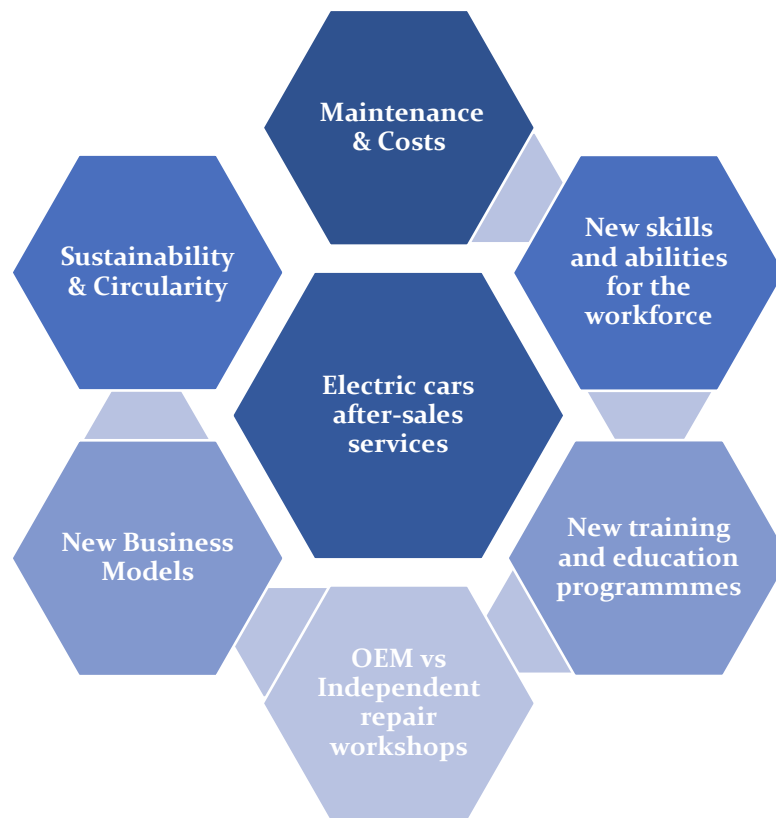


Figure 9. Interrelated Drivers of Transformation in Electric Cars After-Sales Services.

The emergence of electric cars has been closely linked to industrial reconfiguration and digital systems. EV architecture reduces the number of traditional mechanical components but introduces complex electronic control units (ECUs), IoT (Internet of Things)-based monitoring, and over-the-air (OTA) software updates [36,48]. This integration of digital technologies transforms maintenance into a data-driven process. As a positive model of this kind of industrial evolution [30] researched the rise of Tesla Motors and analysed its electric vehicle commercialization strategy. Predictive maintenance models, enabled by artificial intelligence (AI), can anticipate component failures and minimize downtime, aligning with principles of cleaner production. However, these systems also increase dependency on OEM-controlled data and software platforms, reinforcing asymmetries between manufacturers and independent service providers.

Older research [60], but also recent studies [34,63] emphasize that although the automotive sector is integrating circular economy principles, these remain largely confined to recycling rather than holistic lifecycle management. Battery recycling, remanufacturing, and component reuse are underdeveloped, and sustainable maintenance practices—such as reparability and modular component design—are not yet systematically implemented, also [49] explain that their E/IT components often have much shorter lifecycles than the vehicles themselves, making cars increasingly vulnerable to the obsolescence of these parts and in the meantime vulnerable to unpredictable failures. The limited institutional focus on workforce adaptation, end-of-life management, and local supply chain resilience continues to undermine the social and economic dimensions of sustainability.

Overall, the literature indicates that while technological progress in EV systems supports environmental objectives, it also generates new organizational and labour vulnerabilities. The skills gap, digital dependence, and uneven institutional readiness constitute major challenges for achieving a just and sustainable automotive transition.

The diffusion of electric mobility is not only transforming vehicle technology, but also reconfiguring the business logic of the automotive industry. Traditional models centred on ownership, sales margins, and after-sales servicing, are being replaced by service-based, digital, and platform-oriented paradigms.

The shift from product to service orientation reflects a fundamental transformation in industrial strategy, where value creation increasingly derives not from the physical product itself but from integrated, service-based solutions that enhance customer experience. Early frameworks [12,43,112] anticipated the emergence of service-centric business models integrating mobility, charging, and energy services. Subsequent research [23,67] confirmed this trajectory, highlighting how reduced maintenance needs in EVs disrupt the traditional revenue streams of dealerships and independent garages. With maintenance representing up to half of dealership profits, electrification compels a strategic pivot toward subscription-based, digital, and value-added services such as mobility-as-a-service (MaaS) [44], vehicle-to-grid (V2G) integration, and “functions on demand” [83].

The consumer’s requirements and the service reorientation, subsequently led to the development of new business models. The transition to electric vehicles (EVs) necessitates the development of innovative business models that redefine value creation, delivery, and capture across the automotive ecosystem. These models increasingly emphasize digitalization, service integration, and sustainability shifting profitability from traditional manufacturing and maintenance toward data-driven services, mobility platforms, and circular economy solutions: [27] identified subsystems (vehicle, infrastructure, electronics, energy) and critical success factors in PSS (Product-Service System) for EVs, [88] found that free maintenance programs boost EV market share; tied maintenance strategy to pricing and adoption, [75] proposed innovative warranty models balancing manufacturer–customer reliability risks, [113] explored optimization of after-sales services by balancing spare parts use and service quality, [79] showed how production and pricing decisions depend on after-sales capacity; EV manufacturers like Tesla and BYD illustrate this dynamic.

The competition between OEM control vs. independent repair follows the electric car’s theme, as well. A recurring pattern across studies [15,37,100] is the growing dominance of OEMs over repair and service networks. Through proprietary software, exclusive access to technical data, and standardized service protocols, manufacturers increasingly monopolize after-sales activities. Independent garages face declining access to diagnostic tools and technical documentation, limiting their ability to compete. This centralization enhances quality control and safety compliance for high-voltage systems but also raises concerns about market concentration and the erosion of small enterprise viability. Their rivalry, also, extend to workforce and institutional adaptation. While OEMs invest heavily in digital and high-voltage training programs, smaller workshops lack the resources to retrain technicians or purchase specialized equipment. The literature identifies a widening gap between OEM-affiliated and independent repair networks — a divide that risks reinforcing inequalities in employment quality and regional economic resilience [25,65]. Despite these risks, few studies have proposed structured frameworks for managing this duality. Only a limited number of business model analyses [20,44] acknowledge maintenance as a key variable in sustainable business model design.

Emerging digital and platform models—such as e-Mobility-as-a-Service (eMaaS) or subscription-based functionalities—offer new opportunities for profitability and customer engagement. However, they often externalize maintenance responsibilities or obscure them within bundled services, leaving gaps in liability, workforce inclusion, and sustainability measurement. This contradiction highlights a broader tension between technological innovation and social equity, underscoring the need for integrative approaches that connect product innovation with sustainable labour and service ecosystems.

In synthesis, the literature reveals a clear trend: EV-related business models are diversifying rapidly, yet the ownership, governance, and sustainability of after-sales services remain unresolved. The industry’s success will depend on its ability to balance digital control with open, fair, and adaptive service networks.

4.3. EV After-Sales Services, Old and New Concerns: Will Maintenance and Repairs Activities Be on the Verge of Extinction?

After-sales activities are increasingly recognized as central to competitiveness and long-term profitability. They influence customer trust, brand loyalty, and lifecycle sustainability [21,45,96]. Paper [64] highlighted the need for early integration of after-sales considerations in product design to optimize total cost of ownership (TCO). However, academic research continues to prioritize manufacturing and design, leaving maintenance and service systems underexplored. This oversight is critical, as the EV transition reshapes service demand, labour requirements, and safety standards.

The maintenance of EVs introduces new complexities, safety risks, and skill requirements and the development of new, improved occupational abilities theoretical and practical. Studies [59] on maintenance risk identify high-voltage exposure, inadequate training, and data access limitations as primary safety challenges. Traditional mechanics, often trained through apprenticeships, are insufficiently prepared for HV systems and software diagnostics. The literature consistently calls for standardized qualification frameworks and tiered certifications for EV maintenance personnel. While ISO 6469 and SAE J2344 provide safety guidelines, no globally harmonized occupational standard currently defines competency for EV electricians. Paper [94] developed a reliability model incorporating human error and repair imperfections, focusing on battery systems. Research [54] distinguished between certified vs. self-service maintenance; stressed that EV maintenance must occur in authorized facilities, due to its tools and HV knowledge requirements. [100] found that after-sales services generate 54% of profitability; identified the absence of maintenance standards for EVs.

EVs' reliance on electronic control systems and embedded software makes maintenance increasingly dependent on digital diagnostics and AI-based fault detection [41,48,68]. [81] investigated failure mechanisms in battery and charging systems, emphasizing environmental conditions and charge rate, while [114] analysed the costs, risks, and safety aspects across EVs, HEVs, and ICEVs and concluded that battery failure as the most frequent issue. Predictive maintenance enabled by condition-based monitoring and data analytics has emerged as a key pillar of sustainable service systems. Yet, integration between human technicians and digital maintenance platforms remains incomplete, limiting efficiency gains and worker agency.

Lower maintenance frequency reduces recurring revenues for dealerships and independent garages [23,100]. This decline pressures firms to compensate through extended warranties, digital subscriptions, or service packages embedded in the Product–Service System (PSS). Concurrently, cost structures evolve: while EVs reduce mechanical servicing, they increase costs related to battery diagnostics, software updates, and obsolescence management [49].

Despite clear recognition of EVs' transformative impact, major research gaps remain. Few studies quantify the long-term employment effects of reduced maintenance activity, and even fewer examine the sustainability of independent service networks. Environmental assessments often neglect the life-cycle impacts of maintenance and repair activities, focusing narrowly on battery recycling or production emissions [52]. Furthermore, the absence of consistent policy frameworks for reskilling technicians and certifying EV service facilities constrains the sector's readiness for large-scale electrification.

The reviewed literature portrays a sector at an inflection point: as mechanical complexity declines, digital and organizational complexity rises. After-sales services are transitioning from manual, component-based repair toward data-driven, predictive, and platform-managed ecosystems. This evolution aligns conceptually with cleaner production and circular economy objectives but remains hindered by institutional inertia, fragmented training standards, and unbalanced value capture between OEMs and independent actors. Despite significant advancements in electric vehicle (EV) technology, current research continues to prioritize technical performance while overlooking the equally vital human and organizational dimensions necessary for a sustainable transition. The lack of standardized maintenance protocols across countries further exacerbates disparities in service quality, safety, and workforce training, hindering the establishment of a cohesive global framework for EV after-sales services. Additionally, the literature reveals a scarcity

of integrative approaches that combine economic, ergonomic, and technological perspectives, resulting in fragmented insights and insufficient guidance for aligning innovation with workforce readiness, operational efficiency, and long-term industry resilience.

4.4. Consumer's Behaviour and Preferences - a Major Influencer on EV Markets

The transition to electric vehicles (EVs) represents one of the most transformative shifts in modern transportation, driven by global efforts to reduce emissions, improve energy efficiency, and promote sustainable mobility. In the EV era, customer satisfaction is increasingly shaped by service quality and experiential value, not just product performance [57]. However, beyond technological innovation, consumer behaviour and preferences play a decisive role in shaping the pace and scale of EV adoption. [45] highlighted the fact that long-term relationships are sustained through consistent after-sales experiences. Factors such as purchase cost, range anxiety, charging accessibility, maintenance expectations, and environmental attitudes strongly influence decision-making [74,77,80]. Understanding these behavioural dynamics is therefore essential for designing effective policies, business models, and educational strategies that support widespread EV acceptance and long-term sustainability in the automotive sector.

Research on electric vehicle adoption emphasizes the complex interplay between economic, psychological, and infrastructural factors shaping consumer decisions. Early studies [14,40,89] show that while EVs reduce CO₂ emissions and lifecycle impacts, high purchase prices and perceived technological immaturity deter mass adoption. Key barriers include range anxiety, charging convenience, and cost perception though first-hand experience tends to improve consumer attitudes toward EV reliability and maintenance savings [56]. Studies highlight that environmental concern alone does not ensure adoption, as comfort, performance, and convenience remain dominant factors [47]. Knowledge and education gaps persist across markets [50,92], with vocational training and early e-mobility education insufficient to meet workforce and consumer needs. Socioeconomic variables such as GDP per capita, energy costs, and policy incentives significantly influence adoption rates [32,58]. Recent works [46,51,95] underscore the role of personal norms, perceived usefulness, and financial risk in shaping purchase intentions, alongside the importance of trust and after-sales service quality in building long-term consumer confidence. Overall, the literature converges on the finding that maintenance accessibility, cost, and skilled service availability remain decisive for consumer trust and EV market expansion, while integrated policies and digital mobility models are essential to overcome behavioural and infrastructural barriers.

The reviewed literature in this sub-section demonstrates that while battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) hold significant promise for reducing emissions and lowering ownership costs, their widespread adoption remains hindered by a multifaceted set of technical, economic, and behavioural barriers. Consumer decisions are primarily influenced by purchase cost, charging infrastructure, range anxiety, and after-sales service quality, as well as psychological factors such as habit, perceived usefulness, and social norms. Across studies, maintenance and after-sales services emerge as critical determinants of consumer confidence, with concerns centring on battery longevity, repair accessibility, and skilled labour availability. Ecological motivation alone is insufficient to drive adoption without parallel improvements in convenience and affordability.

At the policy level, the evidence suggests that financial incentives, infrastructure investment, and consumer education must be integrated to achieve large-scale diffusion. Emerging business models—such as e-mobility services, car-sharing, and digital maintenance platforms—offer new opportunities, but require consumer trust and institutional coordination. Ultimately, the transition to electric mobility represents a technological, behavioural, and systemic transformation that demands coordinated action among industry, policymakers, and academia.

5. Discussion

Current academic research lacks an integrated, standardized framework defining occupational requirements for electric vehicle maintenance and repair technicians. While existing studies recognize emerging challenges including high-voltage hazards, battery handling protocols, advanced diagnostics, and software-intensive architectures the evidence base remains scattered and predominantly observational. Scholarly work tends to address isolated dimensions such as workplace safety risks, competency deficits, training inadequacies, or labour market transitions, rather than synthesizing these elements into a cohesive, globally relevant standard that encompasses technical skills, credentialing pathways, certification tiers, ergonomic considerations, and occupational health safeguards. Furthermore, standardization initiatives vary widely by jurisdiction, and much existing guidance derives from industry conventions rather than rigorous academic consolidation. In sum, the literature identifies the challenge without delivering a unified solution, underscoring a significant knowledge gap. The clearest evidence of this trend is that studies on these topics have generated no subsequent research and zero citation impact.

Moreover, the literature has yet to develop or empirically validate comprehensive business management frameworks that systematically support the simultaneous operation and integration of ICEV and electric cars service lines within automotive aftermarkets. Although few studies explore Product–Service Systems (PSS), service-centric strategies, and digital or subscription-based, these contributions typically frame the transition as unidirectional rather than acknowledging an extended hybrid coexistence period. Empirical research commonly recognizes reduced EV maintenance volumes, dealership revenue challenges, and heightened OEM influence, but rarely delivers operationally models addressing dual ICEV –EV service workflows, shared facility utilization, technician deployment, financial architectures, or governance dynamics between authorized and independent repair networks. Consequently, existing frameworks remain largely theoretical, technology-focused, or market-analytical, offering insufficient guidance for practical aftermarket integration.

In response to this gap, this study advances a Dual Service Transition Model (DSTM) that conceptualizes the coexistence of ICEV and EV after-sales operations as a structured, multi-layered system rather than a linear replacement process. The model comprises five interdependent dimensions, as presented in Table 5. The infrastructure layer addresses the physical configuration of workshops, including fully or partially segregated ICE and EV service zones, high-voltage equipment, safety isolation measures, and diagnostic stations. The workforce layer captures the composition and evolution of human resources, distinguishing between conventional technicians, high-voltage specialists, and hybrid roles, while emphasizing structured upskilling and reskilling pathways. The workflow layer defines the operational sequence from vehicle intake and triage to high-voltage risk assessment, specialist allocation, software diagnostics, intervention, validation, and delivery. The business layer reflects the divergence of revenue streams, with ICE services centred on frequent maintenance and mechanical interventions, and EV services increasingly focused on diagnostics, software, battery systems, predictive maintenance, and service contracts. Finally, the governance layer encompasses data access, OEM–independent repair relationships, certification requirements, safety standards, and audit mechanisms.

Table 5. Dual Service Transition Model (DSTM) for ICEV–EV After-Sales Systems.

Layer	Dimension	Key Elements	Function
A	Infrastructure Layer	Segregated ICE/EV zones, HV equipment, safety isolation, diagnostic stations	Enables safe and efficient coexistence of ICE and EV service operations
B	Workforce Layer	ICE technicians, HV specialists, hybrid roles, reskilling/upskilling programs	Ensures availability of appropriate competencies across service types

C	Workflow Layer	Reception, triage, HV risk assessment, specialist allocation, diagnostics, intervention, validation	Defines operational processes for handling hybrid vehicle service demands
D	Business Layer	ICE (mechanical maintenance, consumables), EV (diagnostics, software, battery, predictive services, contracts)	Captures differentiated revenue models and service logic
E	Governance Layer	Data access, OEM-independent relations, certification, safety standards, audits	Regulates system interactions, compliance, and standardization

Taken together, the proposed competency framework and the Dual Service Transition Model provide a systemic and operational response to the limitations of the existing literature, offering both a structured approach to workforce qualification and a practical model for managing hybrid service ecosystems. These contributions shift the perspective from fragmented analysis toward integrated system design, thereby supporting a more coherent and sustainable transition of the automotive aftermarket in the context of electrification.

Nevertheless, this study presents several limitations that should be acknowledged. First, the research is based on a systematic and bibliometric review of existing literature, and is therefore constrained by the availability, scope, and quality of published studies. Given the fragmented and underdeveloped nature of research on EV after-sales services, particularly in relation to workforce requirements and repair activities, the findings are inherently limited by gaps in the existing evidence base.

Second, the analysis relies on a corpus of 91 peer-reviewed articles, which, despite a rigorous selection process, may not capture all relevant contributions. Important insights from grey literature, industry reports, and proprietary OEM data may therefore be underrepresented.

Third, the study adopts a global perspective, which may overlook regional differences in regulatory frameworks, training systems, and market structures, potentially limiting the generalizability of the findings.

Fourth, the research is primarily conceptual and does not include empirical validation. As such, the proposed competency framework and Dual Service Transition Model require further testing in real-world contexts.

These limitations highlight the need for future research incorporating empirical methods, regional analyses, and closer collaboration with industry stakeholders.

6. Conclusions

This article set out to assess the state of scientific knowledge on electric vehicle (EV) after-sales services, with a particular focus on maintenance and repair activities, workforce requirements, and emerging business models within the automotive aftermarket. By conducting a systematic literature review covering the period 2001–2025 and analysing a final corpus of 91 peer-reviewed studies, the paper provides a structured synthesis of how this research field has evolved and where critical gaps persist.

The findings indicate that the transition to electric mobility is profoundly reshaping after-sales services, yet academic research remains unevenly developed. While substantial attention has been devoted to technological performance, cost structures, and market diffusion of EVs, considerably less emphasis has been placed on human, organizational, and operational dimensions. In particular, the review demonstrates that the literature has not yet produced a comprehensive, standardized occupational framework defining the skills, qualifications, safety protocols, and ergonomic

requirements for EV maintenance and repair personnel. Existing contributions are fragmented, often country-specific, and focus on isolated risks or training needs rather than integrated occupational standards.

Similarly, although numerous studies discuss Product–Service Systems (PSS), service-oriented strategies, and digital or subscription-based business models, there is limited empirical or conceptual work addressing how internal combustion engine (ICE) and battery electric vehicle (HEV, PHEV, BEV) service operations can coexist and be operationally integrated during the prolonged transition phase. Most business model research implicitly assumes a linear shift toward full electrification, overlooking the practical realities faced by dealerships, independent workshops, and OEM service networks that must simultaneously support heterogeneous vehicle fleets.

From a sustainability perspective, the review highlights that after-sales services play a critical role in extending vehicle lifecycles, enabling circular economy practices, and maintaining consumer trust in electric mobility. However, these potential benefits can only be realized if workforce reskilling, training systems, and governance structures evolve in parallel with technological change. The growing concentration of knowledge and resources within OEM-controlled service ecosystems further raises concerns regarding market access, competition, and the long-term viability of independent repair actors.

Future research directions should consider the following issues: 1) the transition to EVs entails profound changes in spare parts logistics and availability, the reconsideration of diagnostic procedures and flat rate units (FRU), safety protocols, documentation systems, warranty management, and customer interaction processes. 2) administrative and office personnel—such as service advisors, parts managers, warranty clerks, and customer service staff—also face significant skills mismatches, as they must handle new components, software-driven maintenance schedules, high-voltage safety documentation, and evolving OEM-specific service requirements. Despite this systemic transformation, the literature largely neglects the retraining needs of non-technical staff, implicitly treating EV servicing as a purely mechanical or engineering challenge. 3) although the existing literature frequently emphasizes that electric vehicles require lower routine maintenance compared to internal combustion engine vehicles, it largely overlooks the repair dimension of after-sales services. Repair activities related to electric vehicles remain underexplored, weakly quantified, and predominantly treated as emergent phenomena, with limited empirical evidence, standardized metrics, or statistically grounded analyses. As a result, the complexity, frequency, and organizational implications of EV repair operations are insufficiently captured in current research. 4) resolve the structural misalignment between the evolving competence requirements of electric vehicle (EV) maintenance and repair and the qualifications currently prevalent within the automotive workforce. Addressing this gap requires the development of standardized, modular, and competency-based curricula aligned with established European skills and qualification frameworks, notably the European Qualifications Framework (EQF), the European Credit System for Vocational Education and Training (ECVET), and the European Skills, Competences, Qualifications and Occupations (ESCO) classification. Such curricula should support both the upskilling and reskilling of incumbent workers and the initial training of new entrants, by clearly defining learning outcomes related to high-voltage safety, EV-specific diagnostics, software-enabled maintenance procedures, and occupational health and safety risks. Harmonization at the EU level would enhance transparency, portability, and mutual recognition of qualifications, while facilitating workforce mobility and ensuring a consistent minimum standard of competence across the automotive aftermarket.

A holistic transition framework for electric vehicle after-sales services should integrate technological, digital, and human capital dimensions. The success of electrified mobility depends not only on innovation and infrastructure, but also on the equitable distribution of technical skills and service capabilities across the entire automotive value chain. The transformation of after-sales and maintenance services must be regarded as a central pillar of the electrification strategy rather than a secondary activity. As the mechanical complexity of vehicles decreases, the cognitive and digital dimensions of automotive service activities become increasingly significant. If implemented

coherently, this integrated approach will ensure that the transition to electric vehicles becomes not only a technological success but also socially, economically, and environmentally equitable, thereby supporting the long-term sustainability of the post-carbon automotive sector.

In conclusion, this study confirms that EV after-sales services constitute a strategic yet underexplored domain at the intersection of technology, labour, business models, and sustainability. By explicitly identifying unresolved gaps in occupational standardization and hybrid ICEV– HEV– PHEV– BEV service management, the article provides a clear rationale for future research and policy intervention. Advancing this field will require integrated frameworks that combine economic, ergonomic, technological, and organizational perspectives, as well as closer collaboration between academia, industry, and policymakers. Such efforts are essential to ensure that the automotive aftermarket remains resilient, inclusive, and aligned with broader sustainability and decarbonization objectives during the transition to electric mobility.

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