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A Strategic Action Plan to Advance Circular Economy Practices in the Automotive Industry Based on Sector Insights to Support Sustainable Development

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ABSTRACT

The circular economy is gaining traction as a transformative approach to address climate change and the shortcomings of the linear economic model, which is defined by unsustainable production and consumption patterns. This study explores the implementation of circularity principles in the Spanish automotive industry, with particular attention to the sector's ongoing transition toward sustainability in alignment with the United Nations Sustainable Development Goals and broader sustainable development objectives. The evolution of electric vehicles exemplifies this shift, underscoring the need to redesign production systems and manage resources more efficiently. Using a survey-based methodology complemented by expert panel input, and applying Principal Component Analysis, the research identifies critical challenges such as resource consumption, eco-design, technology development, and waste generation. The findings reveal a pressing need for a comprehensive green transition, highlighting specific deficiencies that require targeted action. To address these gaps, the study proposes a strategic action plan rooted in the principles of circularity, offering guidance for industry stakeholders and policymakers to accelerate the adoption of sustainable practices and foster long-term resilience in the automotive value chain.

1 | Introduction

The European Commission, in its *Circular Economy* document (EC 2021a), warns that urgent decisions are required to address climate change and biodiversity loss, implying a necessary transformation of the prevailing economic model toward one that prioritizes sustainability. Continued economic growth is incompatible with an extractive production model under conditions of finite planetary resources. In response to these challenges, societal action can be broadly structured around two complementary approaches: mitigation and adaptation. Mitigation strategies aim to reduce net greenhouse gas emissions, whereas adaptation strategies seek to optimize the use of water and natural resources, minimize vulnerabilities, and enhance resilience to the impacts of climate change (Zibell et al. 2022).

The linear economy is the prevailing economic model, characterized by high energy consumption throughout production and the unlimited exploitation of resources, following the "extract-produce-use-dump" approach (Grdic et al. 2020). In contrast, the circular economy (hereafter, CE) aims to minimize raw material and energy consumption on a macro scale through recycling and recovery (Gordon et al. 2019). The circular model is built on three core principles: designing products to avoid negative environmental impact or waste, maintaining products and materials at their highest value, and regenerating natural systems (EMF 2024). Furthermore, the CE influences all stakeholders through systemic thinking, fostering a universal capacity to meet societal needs. Despite its potential, the Circularity Gap Report (CE 2024) highlights that the global economy is only 7.2% circular. This statistic underscores that over 90% of materials are either wasted, lost, or rendered unavailable for reuse for extended periods, often locked within long-lasting stock such as buildings and machinery. Alarmingly, this situation continues to deteriorate annually due to increasing rates of material extraction and consumption.

The aim of this research is to assess the current application of the CE model in the Spanish automotive industry, based on the opinions of an expert panel in the sector. Limited prior analysis has been conducted on this topic. To fill this gap, this paper explores the conceptual framework of the CE alongside the key characteristics of the global automotive industry, with a particular focus on Spain. The automotive sector is especially suitable for CE research due to its material- and energy-intensive nature, its highly regulated environment, and its ongoing experimentation with circular business models. Consequently, the potential environmental and economic impact of adopting CE practices in this sector is substantial. The goal is to identify a commitment to the CE among companies striving for sustainability and trying to achieve fully circular organizations. Based on these insights, a strategic plan is formulated to guide companies in this purpose.

This study seeks to answer the following research questions (RQs):

RQ1. What is the level of awareness and understanding of CE principles, and how does it relate to their adoption in the automotive industry?

RQ2. What internal organizational and operational deficiencies limit the automotive industry's capacity to implement CE practices?

RQ3. What external barriers and enabling factors (e.g., regulatory, market, technological, and supply-chain related) influence the adoption of CE practices in the automotive industry?

RQ4. What economic benefits are associated with the implementation of CE strategies in the automotive industry?

RQ5. What strategies can support a successful transition of the automotive industry toward CE practices?

The research holds significant managerial and societal relevance. By systematically identifying knowledge gaps, sectoral challenges, and the critical barriers and enablers of CE implementation, this study provides actionable insights for industry stakeholders. The findings will inform corporate strategies and policy frameworks, facilitate the adoption of circular practices, and support the sector's alignment with the United Nations Sustainable Development Goals (SDGs). Ultimately, these contributions are expected to enhance the competitiveness and sustainability of the automotive industry in Spain, while delivering broader benefits for society through progress toward sustainable development.

The paper is organized into six sections. Section 1 serves as an introduction. Section 2 provides the background, including a literature review, the conceptual framework, and an overview of the current state of the automotive industry. Section 3 details the research methodology, based on a survey conducted with an expert panel from the automotive sector. Section 4 presents the analysis of the research results. Section 5 proposes a strategic action plan. Finally, Section 6 presents the conclusions and outlines directions for future research.

2 | Background

2.1 | Literature Review

The CE has evolved from its conceptual origins in industrial ecology and environmental economics to a practical framework implemented in national and industrial policies. Early large-scale implementation efforts in China contributed to its diffusion and generated a growing body of literature on CE strategies, indicators, and applications. In Europe, foundational contributions have focused on system-level approaches, product service systems, and the role of design and innovation in enabling circularity. More recent studies have addressed the integration of CE principles into specific sectors, including the automotive industry, highlighting national experiences such as Spain, where policies and industrial frameworks are increasingly incorporating CE-related metrics and practices.

The literature review that follows adopts a chronological structure to capture the progressive evolution of CE concepts, methodologies, and applications, thereby providing a coherent foundation for the present study. Although some studies predate 2011, this analysis focuses on publications from that year onward, widely regarded as a pivotal moment in the evolution of the CE, when the concept began gaining global attention and was later consolidated in the Ellen MacArthur Foundation's seminal report *Towards the Circular Economy* (EMF 2013), catalyzing policy, business, and academic interest. From this point, the concept gained momentum through key policy initiatives, such as the European Union's roadmap for resource efficiency, and the literature increasingly emphasized applied research, including empirical studies and circular business models. This approach illustrates how theoretical foundations, methodological developments, and policy frameworks have progressed over time, culminating in recent initiatives relevant to Spain and covering works primarily from that period to the present. Additionally, the theoretical framework explicitly connects with the Spanish automotive sector, providing a clear justification for the design of the study.

Hu et al. (2011) explore the impact of the CE on eco-efficiency through 4R mechanisms (reduce, reuse, recycle, recover), emphasizing the crucial role of industry despite scaling challenges, with outcomes like improved resource productivity. Building on this, Chun-rong and Jun (2011) use DEA (Data Envelopment Analysis) to evaluate regional development, identifying Beijing as a "Good Circle" (efficient waste utilization) versus Sichuan's "Basic Circle" (input redundancies), revealing uneven outcomes. Liu et al. (2012) present a pilot project aimed at achieving zero emissions, showcasing closed-loop mechanisms for sustainable development but noting scale barriers. Collectively, these studies provide early empirical metrics on China's CE initiatives, offering a coherent view of implementation mechanisms, regional challenges, and efficiency outcomes.

Geng et al. (2013) develop environmental indicator systems designed to measure and manage the CE effectively. Their framework includes metrics for resource efficiency, waste reduction, and material circularity, providing a systematic approach to assess circularity performance. This approach is particularly relevant in Spain, where several industrial and policy frameworks are beginning to incorporate CE-specific indicators, especially in the automotive sector, which is the focus of this research. Reh (2013) examines industries with extensive experience in recycling, assessing both their achievements and limitations, an analysis that resonates with ongoing efforts by Spanish automotive suppliers to integrate high-recovery materials while facing logistical and regulatory constraints. Lahl and Zeschmar-Lahl (2013) introduce the "risk cycle," describing how hazardous chemical additives circulate in closed-loop material flows, generating new environmental and health risks. They emphasize the role of European Union legislation in mitigating these risks. Although Spain aligns with these directives, challenges remain in traceability and hazardous substance management. Webster (2013) contrasts CE principles with traditional reverse engineering and emphasizes a systems-thinking approach. He argues that real circular transformation requires holistic, adaptive, and regenerative economic systems, rather than isolated technical fixes, highlighting the importance of dynamic flows of materials, energy, and information and the risks of reducing the CE to familiar engineering tasks.

The Ellen MacArthur Foundation (EMF 2013) proposed a pioneering CE model that conceptualized the economy through two interlinked cycles: the natural (biological) life cycle, in which resources were finite, and a circular (technological) process that reintegrated materials into production systems. This dual-cycle model was later reflected in Spanish public policy, particularly in initiatives such as the Strategic Plan for Comprehensive Support for the Automotive Sector promoted by the Ministry of Industry and Tourism (MINTUR 2024), which aligned national strategies with European Union regulations on vehicle design, recycling, and sustainable mobility. This policy orientation is consistent with the optimistic perspective adopted by Bonciu (2014), who, based on a historical analysis of human productive activity, argues that the implementation of the CE within the European Union and its subsequent diffusion at the global level represents a feasible and progressive evolution of economic systems.

Pan et al. (2015) review the literature on product service systems, highlighting their pivotal role in supporting the transition toward a CE. Andrews (2015) critically examines the unsustainability of the linear economic model and introduces the CE as a framework for systemic transformation, emphasizing the role of designers as key contributors to this shift. He further argues that the CE not only promotes education for sustainability but also enhances employability. Stahel (2016) conceptualizes the CE as an economic model aimed at extending product lifecycles and converting end-of-life goods into resources for new production, with positive effects on greenhouse gas emission reduction and labor force growth. Building on these contributions, Ghisellini et al. (2016) analyze the origins and implementation of the CE, identifying its roots in ecological and environmental economics and industrial ecology. Their analysis highlights contrasting governance approaches, with China promoting the CE as a top-down national policy objective, while in other contexts, such as Spain, Japan, and the United States, it is mainly applied through bottom-up environmental and waste management policies.

Geissdoerfer et al. (2017) clarify that the CE and sustainability are closely connected but not interchangeable concepts. Through a bibliometric analysis, they show that both share a focus on systemic change, innovation, and stakeholder collaboration. However, they emphasize that the CE is a means to support sustainability goals rather than an end in itself, and its contribution depends on alignment with broader social and environmental objectives. Mcdowall et al. (2017) present evidence of the CE implementation in China and Europe. China's approach is broad, addressing pollution and other environmental challenges in addition to waste and resource management, framed as a response to the environmental impacts of rapid growth and industrialization. In contrast, the European view is narrower, addressing waste, resource management, and business opportunities.

Korhonen et al. (2018) analyze the concept of the CE from an environmental sustainability perspective, identifying two key contributions: the importance of maintaining high-value, high-quality material cycles and the potential for achieving a collaborative economy alongside sustainable production, fostering an environmentally friendly production, consumption culture. Kirchherr et al. (2018) examine a representative sample of stakeholders to identify the barriers to the CE implementation in the European Union, with companies and policymakers citing the lack of consumer interest and awareness, along with a hesitant business culture, as the main cultural obstacles. These barriers resonate with the Spanish context, particularly within the automotive value chain and among SMEs, where limited investment capacity, low demand for secondary raw materials, and insufficient consumer engagement hinder the transition. Hopkinson et al. (2018) demonstrate that sustainable circular practices can lead to significant new revenues, improved resource productivity, and enhanced business continuity, an area still underdeveloped in many Spanish companies. Managers and practitioners need to develop new competencies to navigate the complex and dynamic challenges of rapid technological change and market volatility. Milios (2018) discusses three key policy areas for the CE: policies to promote reuse, repair, and remanufacturing; green public procurement and public procurement for innovation; and policies to strengthen secondary materials markets. However, Spain's fragmented and regionally variable policy execution often limits their full deployment.

Gupta et al. (2019) investigate the application of big data warehousing in decision-making processes within value chain networks that support the CE. They conclude that effective stakeholder relationship management is key to successfully applying big data analytics in this context. Barreiro-Gen and Lozano (2020) emphasize the need for organizations to enhance their efforts in applying the 4Rs (reduce, reuse, recycle, repair) to better align theory with practice and contribute more meaningfully to the CE. They also advocate for a holistic implementation of the CE beyond organizational boundaries, through improved collaboration with external stakeholders. Van Loon and Van Wassenhove (2020) analyze four company case studies to provide recommendations on the necessary steps before initiating the transition to a circular model. Patwa et al. (2021) highlight the strong influence of factors such as consumer behavior on the acceptance of remanufactured products and the use of products as a service to encourage the adoption of circular practices in emerging economies. According to Maldonado et al. (2021), the CE is a model applicable in any industrial sector, analyzing the Mexican automotive sector in terms of ecological innovation of products, processes and management. While the geographical context differs, the industrial dynamics and environmental pressures are comparable to those in Spain. Their findings offer valuable insights into how circular strategies can be implemented, inform policy, support industrial decision-making, and serve as a benchmark within Spanish automotive firms. In this regard, ernández de Arroyabe et al. (2021) establish how the shift to circular business models could provide significant competitive advantages over companies that still operate under the linear model, reinforcing the urgency of overcoming existing implementation barriers in Spain.

Bradley and Persson (2022) mention the existence of the "right to repair" movement, which allows consumers to repair and modify products. They highlight how the transition to future and more circular economies can be enacted and directed in a way that allows different roles and powers for citizen consumers. Figge et al. (2023) review extensive literature to identify the most appropriate definition of the CE. They propose the following definition: "CE is a multilevel resource use system that stipulates the complete closure of all resource loops. Recycling and other means that optimize the scale and direction of resource flows contribute as supporting practices and activities. In its perfect conceptual form, all resource loops are closed. In its imperfect, realistic form, some use of virgin resources is inevitable." Babkin et al. (2023) introduce an algorithm for estimating what they call the "circularity index" for industrial cluster ecosystems, a measure of sustainable performance based on: Environment, Society, and Governance (ESG). Ghinoi et al. (2024) define the so-called Municipal Indicator of the CE, a new composite indicator based completely on environmental variables, grouped into the five areas of green enterprise, sustainable mobility, sustainable energy, biodiversity, emissions and pollution and applicable to local territories such as municipalities. Together, these analytical and practical tools offer valuable models that could inform the development and implementation of more robust circularity metrics and governance strategies in Spain, both at the industrial and municipal levels, although they are not currently applied in a systematic manner within the Spanish context. Kiefer et al. (2024) analyze the role of corporate environmental culture in enabling firms' transition toward the CE through eco-innovation. The study shows that a strong environmental culture fosters internal capabilities, employee engagement, and learning processes that facilitate the development and implementation of circular solutions. The findings highlight that cultural factors within organizations act as a critical micro-level driver of CE adoption, complementing technological and regulatory approaches. Arroyave et al. (2025) demonstrate that internal environmental commitment alone is not sufficient; rather, relational capabilities and stakeholder engagement play a central role in moving from environmental intentions to concrete circular practices. The study offers important implications for managers and policymakers, suggesting that fostering collaborative networks can accelerate the adoption of CE strategies, especially in resource-constrained SMEs. Schultz et al. (2025) revisit the relationship between business and moral rationales for corporate engagement in the CE. Departing from static trade-off perspectives, they propose a co-evolutionary framework in which moral considerations are progressively integrated into CE business cases via innovative governance mechanisms. This approach conceptualizes profitability and ethical responsibility as dynamically aligned over time.

Building on the chronological analysis presented above, the reviewed literature can be further synthesized by identifying two broad thematic lines that cut across the temporal evolution of CE research. While the chronological perspective captures how the concept has expanded and matured over time, this complementary synthesis highlights the substantive focus of the contributions and the specific dimensions through which knowledge on the CE has been developed. Table 1 provides an overview of

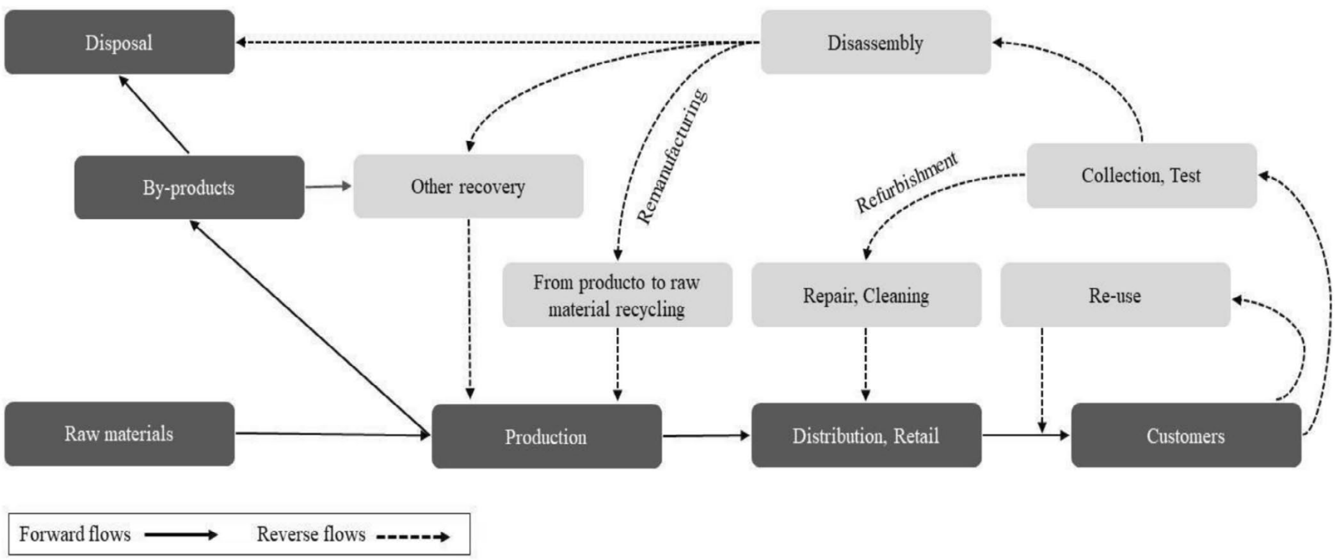

FIGURE 1 | Production cycles in the CE. *Source:* Suzanne et al. (2020).

TABLE 1 | Thematic synthesis of the CE literature reviewed.

Thematic line	References	Main contribution
Conceptual foundations, challenges, and opportunities of the CE	Hu et al. (2011)	Identifies eco-efficiency and resource productivity as key industrial drivers of the transition toward circular models.
	Andrews (2015)	Frames the CE as a fundamental break from linear production and consumption systems.
	Figge et al. (2023)	Defines the CE as a multilevel closed-loop resource system, highlighting the systemic nature of circularity.
	Geissdoerfer et al. (2017)	Clarifies the conceptual relationship between CE and sustainability, emphasizing innovation, regulation, and stakeholder cooperation.
	Kirchherr et al. (2018)	Identifies cultural, organizational, and market-related barriers hindering CE implementation.
	Lahl and Zeschmar-Lahl (2013)	Introduces the “risk cycle” concept, highlighting environmental and health risks linked to hazardous substances in closed-loop systems.
	Reh (2013)	Analyzes logistical and operational challenges in material recovery and recycling systems.
	Milios (2018)	Highlights policy fragmentation and governance challenges affecting circular material flows.
	Stahel (2016)	Demonstrates macro-level environmental and employment benefits of circular economic models.
	Hopkinson et al. (2018)	Shows how circular practices enhance firm-level performance, resilience, and resource productivity.
	ernández de Arroyabe et al. (2021)	Establishes circular business models as a source of sustained competitive advantage.
	Bradley and Persson (2022)	Emphasizes consumer empowerment through the right to repair as a social enabler of circularity.
	Schultz et al. (2025)	Demonstrates the role of trust, transparency, and behavioral incentives in consumer acceptance of circular products and services.
	Maldonado et al. (2021)	Provides sectoral evidence from the automotive industry on how CE strategies drive eco-innovation in products, processes, and management.
	Chun-rong and Jun (2011)	Applies DEA to assess regional CE efficiency, revealing uneven implementation outcomes.
	Liu et al. (2012)	Evaluates a zero-emissions pilot project, highlighting both implementation potential and scale-up limitations.
	Ghisellini et al. (2016)	Compares top-down and bottom-up CE policy approaches across regions, including Europe and China.
	Mcdowall et al. (2017)	Analyzes regional differences in CE policy implementation between China and Europe.
	Bonciu (2014)	Frames the CE as a progressive and feasible evolution of economic systems within the EU and globally.
	Ellen MacArthur Foundation (2013)	Introduces the dual biological and technological cycle model underpinning modern CE frameworks.
	Pan et al. (2015)	Highlights the role of product-service systems as key enablers of circular transitions.
	Korhonen et al. (2018)	Emphasizes high-quality material cycles and collaborative consumption as pillars of environmental sustainability.

(Continues)

TABLE 1 | (Continued)

Thematic line	References	Main contribution
	Geng et al. (2013)	Proposes environmental indicator systems for assessing and managing CE performance.
	Webster (2013)	Contrasts CE principles with traditional reverse engineering, reinforcing the systemic logic of circular design.
	Barreiro-Gen and Lozano (2020)	Advocates holistic CE implementation through the 4Rs and enhanced stakeholder collaboration.
	Gupta et al. (2019)	Demonstrates how big data analytics support CE decision-making in value chain networks.
	Patwa et al. (2021)	Examines how consumer behavior affects adoption of circular practices, focusing on remanufactured products and product-as-a-service models.
	Van Loon and Van Wassenhove (2020)	Identifies key organizational steps required to initiate successful CE transitions.
	Babkin et al. (2023)	Develops an ESG-based circularity index for industrial cluster ecosystems.
	Ghinoi et al. (2024)	Proposes a municipal-level CE indicator based on environmental variables.
	Kiefer et al. (2024)	Shows how corporate environmental culture enables eco-innovation and CE adoption.
	Arroyave et al. (2025)	Highlights the importance of relational capabilities and stakeholder engagement in translating CE commitment into practice.

Source: Own elaboration.

this thematic consolidation by grouping the reviewed studies according to their primary analytical emphasis, distinguishing between works that contribute to the conceptual foundations, challenges, and opportunities, and those that focus on policy frameworks, measurement systems, and organizational drivers underpinning its practical implementation. The references are organized according to their specific focus.

Overall, the literature confirms the growing relevance of the CE, particularly in industrial contexts, and identifies the automotive sector as a highly relevant area of analysis. In the case of Spain, however, empirical evidence remains limited, which highlights a clear research gap. This gap justifies the focus of the present study and supports the research questions formulated.

2.2 | Conceptual Framework

Progress has traditionally been framed as being driven by unlimited production and consumption. However, the unprecedented climatic impacts caused by the linear economic model have revealed a critical flaw. The future now depends on adopting a model that rationalizes production and consumption within a circular framework that promotes sustainability and involves all of society. British economists David W. Pearce and Kerry R. Turner introduced the concept of the CE in the 1980s. In their seminal book *Economics of Natural Resources and the Environment*, Pearce and Turner (1995) defined the concept of the CE and articulated its core principles, laying the foundations for subsequent theoretical and empirical developments. Building on this contribution, later research has expanded, refined, and operationalized these principles across diverse analytical perspectives and economic contexts. As synthesized in the preceding literature review, this body of work provides the conceptual foundations that underpin the contemporary understanding of the CE. In line with the research objectives and questions outlined in the introduction, the present conceptual framework draws on these insights to organize the key dimensions and relationships characterizing the CE. While the framework is formulated at a general level, it is explicitly oriented toward its application to the automotive sector, which constitutes the industrial focus of this study and is examined in detail in a subsequent section.

Since the beginning of this century, the term CE has prominently appeared in the titles of numerous articles across various fields, including energy, engineering, science, and resource management. To emphasize how the CE redefines the traditional linear production model, it is crucial to view waste management as a new input within production systems. Figure 1 illustrates this concept (Suzanne et al. 2020). The dotted arrows represent the reverse cycle back into the system, indicating production activities associated with the CE that intersect and disrupt the direct flows of the conventional production process.

The goal of the CE is to ensure that resources are used for as long as possible, which encourages companies to adopt alternative business practices and models, thereby reducing the need for increased extraction of raw materials (Muranko et al. 2019). Additionally, the product life cycle is extended through activities such as reuse and remanufacturing (Preston 2012), both of which are included in the "10 Rs" of the CE: reject, rethink, reduce, reuse, repair, recondition, remanufacture, repurpose, recycle, and recover as energy (Potting et al. 2018). According to Kirchherr et al. (2018), economic prosperity is also a key objective, along with improving environmental quality. Thus, the CE is an economic system that benefits society, businesses, and the environment (Primc et al. 2020). These three elements are encompassed in the term ESG (environmental, social, and governance), which is essential to ensure that industrial companies operate in a socially and environmentally responsible manner. Sustainability is a long-term goal that requires balancing economic, social, and environmental dimensions, and the CE contributes to this by reducing waste and pollution (Babkin et al. 2023).

Implementing the circular model in industry is complex, with literature identifying the main barriers and drivers of the transition from a linear economy to a CE. These are classified as cultural, regulatory, economic, and technical (De Jesús and Mendonça 2018; Kirchherr et al. 2018). One cultural driver of change is the growing public awareness of environmental issues (Baldassarre et al. 2022). Almeida Neves and Cardoso Marques (2022) suggest that education and youth are drivers of CE, while older age is often a barrier. People with higher education levels tend to be more aware of circular practices. In terms of regulatory barriers, there are divergent opinions among governments and organizations on how to manage resource consumption. Studies such as Agovino et al. (2016) demonstrate that regulation can aid in improving waste separation, as seen in Italy. Given the importance of economic factors, investment in the CE is necessary for success, as confirmed by Salmenperä (2021). Technical aspects have been examined in studies such as Pheifer (2017) and Shahbazi et al. (2016), with the latter highlighting that overcoming technical barriers increases opportunities for the transition to the CE.

The CE also serves as a tool to help achieve the SDGs set by the 2030 Agenda adopted by the United Nations (UN 2024). Currently, the International Organization for Standardization (ISO) is developing the ISO 59000 series of CE standards. These standards will provide frameworks, guidance, support tools, and requirements for organizations to implement the CE and maximize their contribution to sustainable development and to the SDGs (ISO 2024).

The shift toward the CE is a strategic priority for many nations. The European Commission published an ambitious Action Plan in 2022, with measures focused on "Closing Resource Loops" by promoting sustainable products, empowering consumers for the green transition, achieving carbon neutrality, and striving for an environmentally sustainable, toxic-free, fully CE by 2050 (EP 2022). In Spain, the government is aligning its strategies with European measures. A recent initiative is the Recovery, Transformation, and Resilience Plan, adopted by Spain in 2021 and funded by the European Union's Next Generation initiative, which aims at sustainable growth, a green transition, and the digitization and modernization of SMEs and industry. Since 2020, the Spanish CE strategy "Spain Circular 2030", led by the Ministry for Ecological Transition and the Demographic Challenge (MITECO 2023), has been in place. This strategy establishes the foundations for a new production and consumption model that maintains the value of products, materials, and resources in the economy for as long as possible, minimizes waste generation, and maximizes the use of unavoidable waste. The Spanish CE strategy identifies six priority sectors: construction; agri-food, fishing, and forestry; industry; consumer goods; tourism; and textiles and clothing. To support the strategy's implementation, the CE council is responsible for collaborating on implementation, monitoring, reviewing, and preparing annual proposals. It includes representatives from social and economic sectors. In contrast, countries such as China, Japan, and the United States are in different stages of their CE efforts. China follows a top-down approach, designing a regulatory framework at three levels: macro (legislation), meso (policies), and micro (regulations). Its primary objectives include sustainability and carbon neutrality by 2060. Notably, China passed the CE Promotion Law, which legally commits to advancing CE, protecting the environment, and optimizing resource efficiency (Shang et al. 2022). Japan has a cooperative system involving society, businesses, and the public sector. The country has an extensive track record in recycling, resource reduction, and reuse (ME 2014). The United States has historically prioritized waste reduction and reuse. However, it lacks a federal level CE policy initiative. Countries such as Denmark, the Netherlands, Sweden, Germany, the United Kingdom, Austria, or Finland are actively advancing circular strategies, particularly through strict waste treatment regulations (Ghisellini et al. 2016). Europe's leadership in sustainability and the CE is evident on a global scale. Policies depend on the strategic decisions of each nation. However, there is a clear vision of the benefits that can be achieved through a successful transition to the circular model. According to McGinty (2021), there are five main conclusions: better utilization of the planet's finite resources, protection of human health and biodiversity, creation of more and better jobs, reduction of emissions, and stimulation of economies.

In recent years, there are industrial sectors where the CE methods or principles are being applied on a large scale. Some of the most prominent cases are shown in Table 2.

2.3 | An Overview of the Automotive Sector

The automotive sector plays a major role in the GDP and employment of industrialized countries. As noted by the European Commission (EC 2022), its contributions include: (i) *economic impact*: 7% of the GDP of the European Union, amounting to approximately €1015 billion euros, with 17,300 companies operating; (ii) *employment generation*: 13.8 million jobs, accounting for 6.1% of total employment in the European Union; and (iii) *connections with other sectors*: multiplier effect on the economy due to its strong links with sectors such as chemicals, iron and steel, ICT, textiles, repair, or mobility services.

This sector is also vital to the Spanish economy and is considered a global benchmark due to its level of automation and innovation. According to the Spanish Association of Automobile and Truck Manufacturers (ANFAC 2023), the automotive industry accounted for 8.1% of Spain's GDP in 2022, including vehicle and component manufacturers. The sector's direct and indirect employment share was 9%. Spain's production capacity is notable, with over 2.2 million vehicles produced in 2022, making the country the second-largest vehicle producer in Europe and the ninth largest globally, behind China, the United States, Japan, India, South Korea, Germany, Mexico, and Brazil. Most of this

TABLE 2 | Analysis of the CE applications in various sectors.

References	Sectors and country	Results	Benefits
Anh et al. (2011)	Fishing industry (Vietnam)	There is the possibility of developing an eco-industrial cluster that includes aquaculture, fish processing companies, product plants and wastewater treatment units.	Socials, economic and environmental
Hu et al. (2011)	Leather industry (China)	Reduced consumption of raw materials, water and energy in manufacturing processes.	Economic and environmental
Kayal et al. (2019)	Water industry (Jordan)	Total project cost of US$907 million in the case of no circular development.	Economic and environmental
Maher et al. (2023)	Textile industry, organic industry and construction industry (Australia)	Waste reduction. Expansion of customers, supply chain partners, range of products and services, and performance of its operations. Increased awareness and culture of waste trends and their impact on the environment.	Environmental, economic and social
Ferreira et al. (2023)	Manufacturing industry (Portugal)	Cooperative network to reduce waste with the help of Blockchain technology application.	Economic and environmental

Source: Own elaboration.

production is destined for export, with Germany, France, Italy, and the United Kingdom being the primary markets. Spain leads Europe in the manufacturing of commercial vehicles, ranks second in passenger car production, and is fourth in component manufacturing (Montoriol and Díaz 2021).

In Spain, the automotive industry comprises 17 vehicle manufacturing plants, 15 technology centers, 10 automotive clusters, and more than 1000 equipment and component manufacturing companies. The industry's turnover reaches €32,085 million (Sernauto 2023). The sector is currently undergoing technological transformation, supported by the European Union and the Spanish Government, including a strategy for safe, sustainable, and connected mobility; a mobility and transport financing law; and a plan to renew the vehicle fleet.

For Spain, the 2030 targets include reducing the vehicle fleet from 25 million in 2021 to 20; lowering the fleet's average age from 13.5 years to 9; and cutting CO_2 emissions from 78.4 million tons in 2021 to 36 million tons (ANFAC 2023). Spain holds a relevant position in R&D&I, but like the rest of Europe, it is stagnating in patent registrations (DGT 2023). Europe leads R&D&I investment in the automotive sector with €62.6 billion euros, ahead of the United States (27.6), Japan (33.2), and China (18) (EC 2021b). Paradoxically, this investment does not correspond with its global standing in registered patents. China stands out with 126,000 patents (70% of the global total), securing its industrial sovereignty (PONS 2023). This imbalance is partly due to companies' lack of awareness regarding the benefits of patent protection. Many companies generate innovative ideas but do not prioritize securing industrial property (DGT 2023). Table 3 shows a comparison of the trends and similarities of the leading companies in terms of production versus the development of companies in Spain.

China is the world's leading power in the automotive sector, with a strong technological and commercial commitment. In 2022, it manufactured 27 million vehicles. In addition to focusing on growth in all branches of the sector, especially electric vehicles, China is heavily investing in intelligent vehicles, with the government aiming to lead their adoption by 2025 (Statista 2023). The US has the second-largest automotive industry globally, contributing 3% to its GDP. The country produced more than 10 million vehicles in 2022 (ANFAC 2023) and is also focusing on electric vehicle adoption, supported by government initiatives. Japan, the third-largest vehicle producer in the world, manufactured 7.8 million vehicles in 2022 (Statista 2023). Toyota accounts for nearly half of this production, with other significant players like Honda and Mazda also contributing (MarkLines 2023). The Japanese government and automotive industry believe the shift to electric vehicles will have a profound impact on the sector and society. They aim to leverage Industry 4.0 to integrate various productive sectors under the "Connected Industries" project, aspiring to create a "Vehicle and Society Integration" process known as "Society 5.0" (Castelltort Claramunt 2020). India produced 5.6 million vehicles in 2022, with a large portion destined for export (OICA 2023). By the end of 2024, India aims to double the size of its automotive industry. The National Electric Mobility Mission Plan promotes the use of electric vehicles, enhances manufacturing capacity, and addresses issues related to pollution and energy security (Balani and Pritwani 2023). South Korea ranked as the world's fifth-largest vehicle producer in 2022, with 3.75 million vehicles (OICA 2023). The Hyundai and Kia brands stand out in the country's vehicle exports. Electrification is attracting significant investment, and autonomous vehicles are positioned to be a key focus in South Korea's strategy compared to other countries (ICEX 2023). Germany leads vehicle production in Europe, with 3.7 million vehicles and 800,000 jobs in 2022 (Statista 2023). According to the IFO Institute (2023), while the sector is performing well, there are signs of pessimism regarding future expectations. The German government is closely monitoring industry trends, such as digitalization and autonomous driving. It seeks to capitalize on the sector's potential by promoting R&D&I using Artificial Intelligence to create a more versatile, safe, eco-friendly, and efficient mobility system for the future (AUTO 2020). Mexico

TABLE 3 | Comparative analysis of Spanish companies and global industry leaders.

Company	Status of the company	Trend	Comparison to the Spanish manufacturing companies
Volkswagen	European leader with strong investment in electric mobility and battery recycling.	Adopts the closed-loop model for rare metals and components.	Although Spain is home to key plants such as SEAT, the infrastructure for battery recycling is still incipient. Requires greater incentives and public investment (ANFAC 2023).
Toyota	Global pioneer in sustainability; "lean + green" approach.	Efficient production, use of recycled materials, elimination of waste, long vehicle service life.	Their model still clashes with the programmed obsolescence of the secondary market. Regulation that favors durability is needed (Barreiro-Gen and Lozano 2020; Almeida Neves and Cardoso Marques 2022).
Mercedes-Benz	Leader in sustainable premium mobility; zero-emission plants.	Use of green steel, electrification with a circular approach, indoor circularity and batteries.	Mercedes strategies require advanced collaborations throughout the chain; Spanish companies have not yet achieved this systematic integration in their supply networks (PwC 2023; Walker et al. 2022).
Stellantis	Multinational Group (Peugeot, Citroën, Opel, Fiat).	CE on a large scale: reuse, recycling, remanufacturing with own unit.	The SUSTAINera initiative offers a replicable model; however, many supplier companies in Spain have not internalized circular business models, except in cases induced by corporate requirements (Maldonado et al. 2021).
BMW	Global leader in the premium sector; comprehensive sustainability strategy ("Circularity by Design").	Strong focus on circular design, recycling of materials, digital traceability (blockchain, IoT).	BMW drives better digital integration and waste management compared to Spain. Digitalization for material traceability is not yet common (Sapigiuc 2022; Sernauto 2023).

Source: Own elaboration.

TABLE 4 | Comparison of the automotive sector in different countries.

Country	Status of the sector	Trend	Comparison to the Spanish sector
China	First world power with more than 27 million vehicles in 2022.	Leading the smart vehicle market by 2025.	The percentage of electrified passenger cars in 2022 was 9.6%, comparable to the level in Spain
United States	10 million vehicles manufactured in 2022. It accounts for 3% of GDP.	Shift the focus to electrification. Government incentives.	Spain also has incentives for electrification such as the Incentive Program for Efficient and Sustainable Mobility.
Japan	Major brands support the country's production. Third largest producer in the world.	Government and industry focus on electric vehicles.	There is greater diversification in production. Electric vehicles are not advancing at the same pace as in Japan.
India	5.4 million vehicles were manufactured in 2022.	Doubling the vehicle fleet by 2024.	Spain aims to reduce its vehicle fleet to 20 million, decrease the average age of vehicles, and lower CO_2 emissions by 2030.
South Korea	Major automobile manufacturer and exporter.	High investment in electrification and autonomous vehicle.	The manufacturing volume is higher than in Spain and so is the investment, particularly in autonomous vehicles.
Germany	Consolidated automotive industry, but with pessimistic expectations.	Boosting R&D&I through the application of new technologies, such as AI and autonomous driving.	The Spanish automotive equipment and components sector is one of the top investors in R&D&I. Its suppliers invest more than 4% of their revenue, three times the Spanish industrial average.
Mexico and Brazil	An industry with great potential due to investments from manufacturing brands.	Growth in employment and production following the Covid19 crisis	The data shows some similarity to Spain in terms of vehicle production. Focus on electrification.

Source: Own elaboration.

and Brazil are also significant automotive producers, with 3.5 million and 2.4 million vehicles produced in 2022, respectively ranking them seventh and eighth worldwide (ANFAC 2023). The sector in both countries shows stable growth in terms of production and employment (OICA 2023).

Table 4 summarizes the comparison between the countries analyzed.

New trends in the automotive sector are driven by five key vectors of change (PWC 2023): digital revolution; ecosystem-based supply chain; sustainability; new business and collaboration models; and transforming urban environments and infrastructure. The sector's renewal hinges on the implementation of strategic government measures and objectives. For instance, the Euro 7 regulation aims to end the sale of combustion engine vehicles by 2035, with the goal of achieving a carbon-neutral footprint by 2050 (RACE 2023). Novel aspects include: limits for non-exhaust emissions like particulate emissions from brakes and tire abrasion; minimum performance requirements for battery durability in electric cars, with stricter standards for vehicle lifetimes; and the use of advanced technologies and emission monitoring tools.

TABLE 5 | Profile of the experts participating in the study.

Experts	Field of work
1–13	Managers in vehicle and component manufacturers
14–20	Automotive sector associations
21–22	Project management and business strategy
23–25	Operational excellence and continuous improvement
26–29	Auditing and advice for manufacturers in the sector
30–31	Mobility development and use of renewable energies
32–38	University academic (sustainability and environmental research)
39–40	Automotive technical press
41–44	Factory supplier
45–46	Electric vehicle development
47–52	Quality and improvement strategies
53–55	Innovation in battery and charging technologies
56–59	Electric vehicles, sustainability, and innovation
60–68	Social responsibility, climate change, eco-design, SDGs
69–72	CE management
75–78	Sustainable development, energy efficiency, and transition
79–84	Consultancy on energy and social transition

Source: Own elaboration.

The transformation of vehicles encompasses several areas: new electric propulsion systems, hydrogen-based systems, and autonomous vehicles (Cristeto 2023). The tipping point for electric passenger vehicle adoption occurred in the second half of 2020. The continued acceleration of electrification has increased pressure on original equipment manufacturers (OEMs), their supply chains, and the electric vehicle ecosystem to meet regulatory targets. In Europe, regulatory frameworks have driven progress, while in China, consumer demand is strong despite reduced incentives. In contrast, electric vehicle adoption in the United States has been slower due to low consumer interest and weaker regulatory pressure. Hydrogen-powered vehicles offer advantages such as zero emissions, greater autonomy compared to electric vehicles, and faster refueling times similar to conventional fossil fuels. However, commercialization faces challenges, particularly the limited availability of hydrogen refueling stations and higher costs compared to conventional vehicles. Autonomous vehicles have the potential to revolutionize mobility, making driving safer, more convenient, and enjoyable. This innovation could add significant value to the automotive industry.

The incorporation of the CE principles is transforming core elements of the automotive industry, particularly through vehicle reuse and parts renewal. This also includes converting thermal engine vehicles into electric ones. Reuse and recycling of batteries hold significant development potential. When a battery's charge capacity falls below 70%, it is no longer suitable for powering electric vehicles but can be repurposed for less demanding applications, such as supplying energy to homes, businesses, or public facilities. Alternatively, batteries can be recycled to recover raw materials for new battery production (ISTAS 2021). The value chain must now consider new components such as centers for treating elements and components, shredding and recovering materials, and reconditioning vehicles for a second life.

3 | Research Methodology

To assess the current state of the CE in the Spanish automotive sector, a survey was designed and distributed to a panel of experts. This panel comprised managers from leading vehicle and component manufacturing companies in Spain, as well as other professionals in the automotive industry. The survey method is widely used due to its ability to efficiently gather and analyze data while incorporating subjective perspectives from respondents (Casas Anguita et al. 2003). This method has been validated by numerous scientific studies, such as Böttcher and Müller (2015), Severo et al. (2015), Díaz-Garrido et al. (2016), Adebanjo et al. (2016), and Held et al. (2018), all of which applied surveys to the automotive sector in countries like Germany, Brazil, China, and Spain. Consequently, the survey is a well-established method for industry analysis.

The list of manufacturing companies surveyed was derived from the annual report of ANFAC (2023). Spain has 17 vehicle manufacturing plants nationwide, some of which belong to the same manufacturer. These include major players such as Ford, Iveco, Mercedes-Benz, Nissan, Stellantis, Renault, Seat, and Volkswagen. In addition to manufacturers, the survey included experts from other organizations within the automotive sector.

TABLE 6 | Survey designed for the research.

Section 1: overview of the circular economy	
P1.1.	Easy to understand the circular economy model.
P1.2.	Necessity of transitioning from the current linear model to the circular model.
P1.3.	Promotes the reuse of raw materials and resources.
P1.4.	Contributes to environmental protection.
P1.5.	Encourages R&D&I and the development of new technologies.
P1.6.	Enhances the competitiveness of companies.
P1.7.	Foster the creation of new business models.
P1.8.	Benefits the economy, employment, and local industry.
P1.9.	Extends the life cycle of products.
P1.10.	Difficult to implement within the current economic model.
P1.11.	Government policies exist to facilitate its development.
P1.12.	Companies are motivated to transition to the circular model.
P1.13.	Need for more sustainable and responsible consumption habits.
P1.14.	Numerous barriers to accessing financing.
P1.15.	Lack of technological and infrastructure development.
Section 2: barriers to the adoption of the circular economy	
P2.1.	User or consumer incentives are ineffective.
P2.2.	Excessive bureaucratic barriers.
P2.3.	Unclear rules and regulations.
P2.4.	Warranty does not cover the quality of component, machine or vehicle with extended lifespan.
P2.5.	Insufficient consumer awareness.
P2.6.	Unavailable or inadequate financing options.
P2.7.	Lack of consistent criteria for the use of recyclable materials.
P2.8.	Insufficient development of key transition technologies.
P2.9.	Lack of a collaborative culture across different areas of the company.
P2.10.	High investment costs.
P2.11.	High shareholder expectations.
P2.12.	Marketing does not focus on promoting the circular economy.
P2.13.	Short-term vision when setting company objectives.
P2.14.	Insufficient training.
Section 3: enablers in the adoption of the circular economy	
P3.1.	New batteries for electric vehicles.
P3.2.	Traceability using technologies like Blockchain.
P3.3.	3D printing.
P3.4.	Use of robotics for process optimization.
P3.5.	Platforms for collection, separation, recycling and valuation of resources and materials.
P3.6.	Artificial Intelligence (AI), Internet of Things (IoT), and Big Data.
P3.7.	Development of infrastructure necessary for electric mobility.

(Continues)

TABLE 6 | (Continued)

Section 3: enablers in the adoption of the circular economy	
P3.8.	Regulations on greenhouse gas emissions.
P3.9.	Extending the useful life of products, equipment, and raw materials.
P3.10.	Use of energy from renewable sources.
P3.11.	Extended Producer Responsibility.
P3.12.	Waste disposal and treatment.
P3.13.	Use of sustainable, recycled, or recovered materials.
P3.14.	VAT reductions for recovered or renewable materials, or VAT increases and imposition of "green taxes" on non-recovered or non-renewable materials.
P3.15.	Special taxation for products from competing countries that do not apply Extended Producer Responsibility.
P3.16.	Subsidies and soft credits for investments in enabling technologies for the transition to the circular economy.
P3.17.	Reduction of National Health Systems contributions in exchange for penalties on the purchase of non-renewable materials.
Section 4: benefits of the circular economy in companies	
P4.1.	Helps achieve strategic objectives on sustainability.
P4.2.	Establishes guidelines for better resource utilization.
P4.3.	Reduces production costs.
P4.4.	Increases profitability and competitive advantage.
P4.5.	Enhances employee engagement.
P4.6.	Reduces greenhouse gas emissions.
P4.7.	Boost local employment rates.
P4.8.	Reduces dependence on external suppliers
P4.9.	Increases security of supply of raw materials.
P4.10.	Improves market share.

Source: Own elaboration based on Sapigiuc (2022).

These professionals were selected based on their specialized knowledge and expertise. Table 5 presents the details of all the experts included in the study panel.

The survey was designed with a dual focus, targeting both corporate managers and external experts, in order to capture comprehensive perspectives at two levels: within companies and across the value chain. This design allows for the inclusion of insights from experts in diverse organizations, including public administration, certification bodies, consultancies, and specialized publications, thereby enhancing the depth and reliability of the data collected.

The survey is divided into four sections, each addressing research questions related to CE: general aspects, barriers, enabling factors, and benefits. Each section contains multiple questions, with responses measured using a Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Table 6 provides a detailed description of the survey structure and the questions included (Sapigiuc 2022).

After sending the virtual survey link via email, a total of 84 responses were received: 13 from company experts out of a possible 17, and 71 from other experts out of a possible 98. This resulted in a response rate of 73.04%, which is significantly higher than the typical 10%–12% value reported in similar studies (Plaza et al. 2011). Given that data were collected from a single respondent in each case, there was a possibility of common method bias. To address this, data were collected at different times (Podsakoff and Organ 1986). The means and correlations of early and late respondents were compared, and no significant differences were found between the two groups. Additionally, tests were conducted to detect non-response bias, a key concern when assessing whether the response rate affects the validity of the analysis. Following the approach of Díaz-Garrido et al. (2016), two groups were selected: one consisting of 50% of the experts who responded early, and another with 50% who responded late. The means of the variables were compared for each group, and Levene's test, along with the *t*-test for equality of means, showed significance levels exceeding 5% in all cases. This indicates that non-response bias was not an issue, and the respondents can be considered representative of the population.

The data were analyzed using the Principal Component Analysis (PCA) to delve into latent characteristics and relationships among survey variables. The PCA follows three

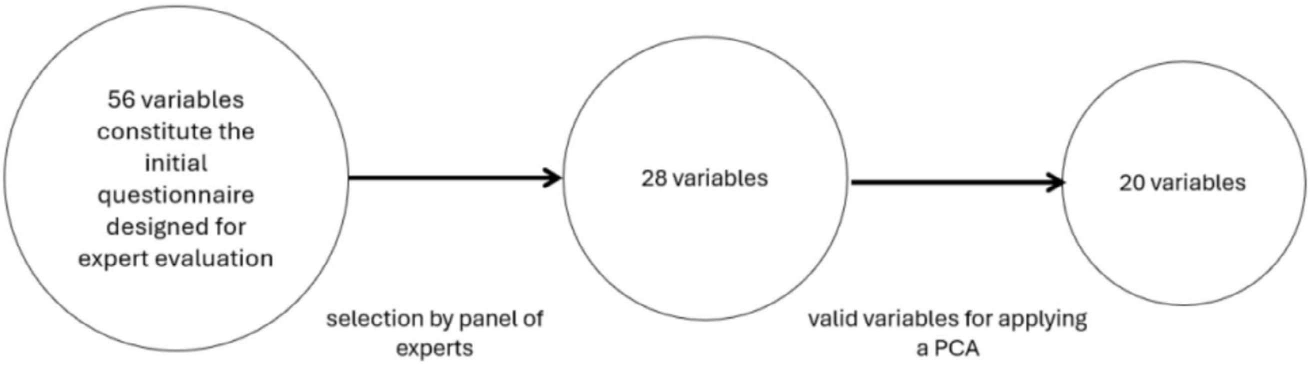

FIGURE 2 | Selection of variables for PCA. *Source:* Own elaboration.

TABLE 7 | Measures of adequacy and reliability of data.

Adequacy and reliability measures	Value obtained	Reference value
Number of variables	20	—
Cronbach's alpha	0.845	> 0.700
Kaiser–Meyer–Olkin measure of sampling adequacy	0.657	> 0.500
Bartlett's test of sphericity	0.000	< 0.001

Source: Own elaboration.

procedures (Shrestha 2021): First, assessing the suitability of the data for factor analysis; second, extracting the principal components to reduce the complexity of the dataset; and third, rotating and interpreting the factors.

To examine participants' attitudes toward the CE and to reduce the complexity of the PCA model, the number of initial variables was reduced. This technique (Hair 2010; Tabachnick and Fidell 2013) allows the elimination of conceptual redundancies and ensures that the included variables are representative for our research. The questionnaire used in this study was submitted to a panel of experts who assessed the relevance of the 56 variables regarding the CE. A Likert scale (1–5) was designed, where 1 represented very low relevance to the CE and 5 indicated high relevance. After collecting the experts' opinions, the 28 items with the highest scores were selected. The next step was to check the suitability of these 28 variables for PCA analysis. For this purpose, variable informativeness was assessed, and those with low communalities (< 0.4) or low factor loadings (< 0.3) were removed (Malhotra et al. 2020). This process resulted in a final selection of 20 variables meeting the established criteria. Figure 2 illustrates the variable selection process carried out.

The data's reliability was confirmed by Cronbach's alpha, reaching a value of 0.845, exceeding the threshold of 0.700, ensuring that the dataset was suitable for analysis (Field 2005; Rajput and Singh 2019). The Kaiser–Meyer–Olkin (KMO) measure for sampling adequacy yielded a value of 0.657, which is above the 0.500 minimum for this sample size (Field 2005; Child 2006). Additionally, Bartlett's test of sphericity produced a value of 0.000, which is lower than the 0.001 requirement, confirming the data's appropriateness for factor analysis (Rajput and Singh 2019). Table 7 provides the values obtained for measures of adequacy and reliability.

Although the sample size, 84, is slightly below the recommended threshold of 100 cases for this study, corresponding to a ratio of at least 5 cases per variable (Hair 2010), PCA was considered methodologically appropriate for several reasons. The KMO measure of sampling adequacy was acceptable and Bartlett's test of sphericity was highly significant, indicating sufficient correlation among variables. Furthermore, communalities were high (see Table 8), and the analysis revealed a clear and coherent structure. As noted by MacCallum et al. (1999) and Fabrigar et al. (1999), when communalities are high and factors are well defined, smaller sample sizes can be acceptable without compromising the validity of the analysis. Finally, the internal consistency of the item set, as indicated by Cronbach's alpha, was high, thereby reinforcing the reliability of the results. The difficulty in obtaining a larger sample, due to the specialized expertise required, represents a reasonable limitation that does not compromise the quality of the analysis conducted.

4 | Analysis of Results

The results obtained from the expert panel are presented, focusing on the initial variables and final components, as well as their relationship with the survey items. After confirming the reliability and suitability of the survey data, a factor analysis was conducted using the PCA with Varimax rotation (Park et al. 2002). Twenty variables were selected based on the experts' opinions, as they were asked to identify the most significant questions. The first step in the analysis was to assess the communalities of these variables, which indicate how much of an original variable is shared with the other variables in the analysis. This method was previously used to discard variables with low communalities.

Table 8 presents the communalities of the previous variables. None of them has a communality value below 0.500, indicating that they are appropriate for PCA (Field 2005).

The PCA performed resulted in a matrix of principal components extracted based on the variance explained. To enhance the interpretability of the data, a Varimax rotation was applied (Park et al. 2002). Six components were extracted (see Table 9). The variance explained by each component is as follows: the

TABLE 8 | Communalities. Extraction method: principal component analysis.

Variable	Initial	Extraction
P1.2. Need for transition from the current linear model to the circular model	1.000	0.861
P1.3. Promotes the reuse of raw materials and resources	1.000	0.689
P1.4. Contributes to the protection of the environment	1.000	0.898
P1.5. Promotes R&D&I and new technologies	1.000	0.656
P1.9. Extends the life cycle of products	1.000	0.730
P1.13. Need for more sustainable and responsible consumption habits	1.000	0.842
P1.15. Lack of technological and infrastructure development	1.000	0.892
P2.5. Insufficient consumer awareness	1.000	0.854
P2.10. High investment costs	1.000	0.715
P3.1. New batteries for electric vehicles	1.000	0.832
P3.5. Platforms for collection, separation, recycling and valuation of resources and materials	1.000	0.701
P3.7. Development of infrastructure necessary for electric mobility	1.000	0.652
P3.9. Extension of the useful life of products, equipment and raw materials	1.000	0.590
P3.10. Use of energy from renewable sources	1.000	0.727
P3.12. Waste disposal and treatment	1.000	0.759
P3.13. Use of sustainable, recycled, or reclaimed materials	1.000	0.733
P4.1. Helping to meet strategic sustainability objectives	1.000	0.712
P4.4. Increased profitability and competitive advantage	1.000	0.831
P4.6. Reduces greenhouse gas emissions	1.000	0.861
P4.9. Increased security of supply of raw materials	1.000	0.804

Source: Own elaboration.

first principal component (PC1) accounts for 19.274% of the total variance; the second one (PC2) 17.314%; the third one (PC3) 11.597%; the fourth one (PC4) 11.300%; the fifth one (PC5) 8.969%; and the sixth one (PC6) 8.242%. The cumulative proportion of variance criterion indicates that the extracted components should collectively explain at least 50% of the total variance (Field 2005). In this analysis, 76.695% of the total variance was explained, which validates the results obtained and supports their interpretation.

The next step involves examining the factor loadings of each variable across the six principal components extracted. For this purpose, the rotated component matrix is constructed (see Table 10). In this table, the variables with a factor loading greater than 0.500, considered the minimum value for analyzing each component, are highlighted in bold.

A critical examination of the relationships between the variables in each component aids in interpreting the underlying dimensions of the principal components. From the original 20 variables, six new uncorrelated variables have been derived, explaining 76.695% of the total variance. Each component reveals a grouping of variables, enabling us to identify the nature of the grouping or, in other words, the aspects related to the CE that it explains. The following relationships are derived for each of the six principal components in comparison with the study variables included in the survey.

PC1 brings together all variables from the first section of the survey, which captures CE experts' awareness and overarching understanding of CE principles. This component reflects a shared cognitive and normative orientation toward circularity, indicating broad consensus on the need to integrate CE principles within firms as a fundamental step in the transition toward a green economy. Rather than being associated with specific operational actions or measurable outcomes, this component represents a foundational layer of alignment in which awareness and strategic recognition of circularity precede implementation. The consistency observed in experts' perceptions is in line with prior literature (Kirchherr et al. 2018; Baldassarre et al. 2022) and with the narratives promoted by major international initiatives such as the World Circular Economy Forum, the Ellen MacArthur Foundation, the European Parliament, and the United Nations, all of which emphasize the role of shared understanding as a prerequisite for effective CE adoption.

PC2 incorporates five survey variables related to the technological core of the automotive sector's transition toward electric mobility: the development of new batteries for electric vehicles and the expansion of electric mobility infrastructure, together with

TABLE 9 | Total variance explained and extraction of principal components.

Component	Initial eigenvalues			Sums of squared extraction charges			Sums of loads squared by rotation		
	Total	% of variance	% accumulated	Total	% of variance	% accumulated	Total	% of variance	% accumulated
PC1	6.442	32.211	32.211	6.442	32.211	32.211	3.855	19.274	19.274
PC2	2.603	13.015	45.226	2.603	13.015	45.226	3.463	17.314	36.588
PC3	2.015	10.075	55.301	2.015	10.075	55.301	2.319	11.597	48.185
PC4	1.716	8.582	63.883	1.716	8.582	63.883	2.260	11.300	59.485
PC5	1.318	6.589	70.472	1.318	6.589	70.472	1.794	8.969	68.454
PC6	1.245	6.224	76.695	1.245	6.224	76.695	1.648	8.242	76.695
PC7	0.792	3.960	80.655						
PC8	0.669	3.345	84.000						
PC9	0.600	2.999	86.999						
PC10	0.521	2.604	89.603						
PC11	0.466	2.331	91.934						
PC12	0.352	1.758	93.692						
PC13	0.327	1.635	95.327						
PC14	0.263	1.314	96.642						
PC15	0.213	1.067	97.709						
PC16	0.164	0.819	98.528						
PC17	0.143	0.715	99.243						
PC18	0.068	0.340	99.583						
PC19	0.047	0.234	99.817						
PC20	0.037	0.183	100.000						

Source: Own elaboration.

increased profitability and competitive advantage, reduction of greenhouse gas emissions, and enhanced security in raw material supply. The first two variables belong to the third section of the survey (Enablers in the adoption of the CE), while the last three are part of the fourth section of the survey (Benefits of the CE in companies). The fact that these benefits are associated specifically with these enablers suggests that this component captures a technology-driven value creation mechanism within the CE transition. In this dimension, economic and environmental benefits emerge primarily when firms engage in capital-intensive, infrastructure-based investments that directly affect production systems and supply chains. Other CE enablers, such as organizational or regulatory factors, appear to operate more indirectly and therefore do not load significantly on this component. This explains why the benefits identified in this component are linked to a specific subset of enablers rather than to the full range of CE drivers considered in the analysis. This connection has been analyzed by Lu et al. (2024), who emphasize the benefits of advancements in battery technology, charging infrastructure, and energy efficiency, while also highlighting the critical role of government policies in accelerating electric vehicle adoption and its positive effects on both the environment and the global economy. Similarly, Zaino et al. (2024) examine how the transportation sector has embraced electric vehicles as a key solution for reducing fossil fuel dependence and mitigating CO_2 emissions.

PC3 groups three variables that capture an operational pathway toward CE value creation. On the enabler side (third section of the survey), it includes the establishment of platforms for the collection, separation, recycling, and valorization of resources and materials. On the benefits side (fourth section of the survey), it is associated with supporting companies' strategic sustainability objectives and with reducing greenhouse gas emissions. The fact that these benefits load specifically on this enabler suggests that this component reflects a process-oriented circularity mechanism, in which improvements in resource management practices translate directly into measurable environmental outcomes and strategic sustainability performance. Unlike broader regulatory or organizational enablers, these operational platforms have an immediate and tangible impact on material flows, which helps explain why the associated benefits are limited to emissions reduction and sustainability goal alignment rather than to a wider range of economic or competitive outcomes. This interpretation is consistent with Walker et al. (2022), who show that firms primarily perceive CE practices as a means to advance

TABLE 10 | Rotated component matrix.

Variable	Component					
	PC1	PC2	PC3	PC4	PC5	PC6
P1.2. Need for transition from the current linear model to the circular model	**0.870**	−0.061	0.278	0.027	0.084	0.119
P1.3. Promotes the reuse of raw materials and resources	**0.736**	0.309	−0.086	−0.059	0.197	−0.045
P1.4. Contributes to the protection of the environment	**0.838**	0.168	0.208	0.284	0.100	0.183
P1.5. Promotes R&D&I and new technologies	**0.614**	0.103	0.132	−0.086	−0.052	0.491
P1.9. Extends the life cycle of products	**0.531**	0.384	0.279	0.141	0.233	−0.385
P1.13. Need for more sustainable and responsible consumption habits	**0.798**	0.205	−0.025	0.134	0.205	−0.320
P1.15. Lack of technological and infrastructure development	0.182	−0.322	−0.019	0.074	**0.864**	0.060
P2.5. Insufficient consumer awareness	0.219	0.302	0.148	0.127	**0.796**	0.210
P2.10. High investment costs	0.056	0.015	−0.104	0.094	0.275	**0.785**
P3.1. New batteries for electric vehicles	0.017	**0.758**	0.352	−0.187	−0.033	−0.312
P3.5. Platforms for collection, separation, recycling and valuation of resources and materials	0.199	0.066	**0.796**	−0.122	0.018	0.088
P3.7. Development of infrastructure necessary for electric mobility	0.213	**0.625**	0.123	0.302	0.229	−0.239
P3.9. Extension of the useful life of products, equipment and raw materials	−0.088	0.043	−0.124	**0.739**	0.086	0.106
P3.10. Use of energy from renewable sources	0.288	0.119	0.210	**0.705**	0.258	−0.148
P3.12. Waste disposal and treatment	−0.100	−0.273	0.490	**0.628**	−0.159	0.070
P3.13. Use of sustainable, recycled, or reclaimed materials	0.369	0.388	−0.045	**0.666**	−0.011	−0.038
P4.1. Helping to meet strategic sustainability objectives	0.152	0.183	**0.674**	0.147	0.104	−0.410
P4.4. Increased profitability and competitive advantage	0.331	**0.823**	0.133	0.126	−0.075	0.073
P4.6. Reduces greenhouse gas emissions	0.072	**0.544**	**0.710**	0.191	0.098	−0.102
P4.9. Increased security of supply of raw materials	0.117	**0.850**	−0.038	0.061	−0.074	0.239
Extraction method: PCA. Rotation method: Varimax with Kaiser normalization. The rotation has converged in nine iterations						

Source: Own elaboration.

sustainability objectives, while remaining less convinced about their short-term economic and business impacts. Similarly, Pilipenets et al. (2025) emphasize core process elements such as materials, energy, water, and waste management, as central to achieving cleaner manufacturing practices, reinforcing the role of operational circularity in delivering environmental rather than purely economic benefits.

PC4 captures four enabler variables from the third section of the survey: extending the useful life of products, equipment, and raw materials; using energy from renewable sources; waste disposal and treatment; and using sustainable, recycled, or recovered materials. Together, these variables reflect an integrated operational pathway toward sustainable production within the CE. Three of them focus on material life-cycle management through proper handling, recovery, and recycling of resources, while the fourth, using energy from renewable sources, complements and enhances circularity by reducing the environmental footprint of production systems, as discussed in Kandpal et al. (2024). Conceptually, the co-occurrence of these variables indicates that companies implementing one circular practice are more likely to adopt complementary measures, forming a coherent operational strategy. This interpretation is supported by theoretical frameworks emphasizing the interdependence of CE practices: material recovery, recycling, and energy efficiency function together to optimize resource use and minimize environmental impacts (Geissdoerfer et al. 2017; Kirchherr et al. 2018). By integrating these practices, firms can reduce overall resource consumption and align with sustainability targets, for example lowering greenhouse gas emissions, as evidenced by European initiatives showing reductions of up to 56% in emissions linked to material production (McKinsey 2024).

PC5 reflects two variables linking the first section of the survey (Overview of the CE) with the second section (Barriers in the adoption of the CE): lack of technological and infrastructure development, and insufficient consumer awareness. It is the only principal component that incorporates barriers affecting the implementation of CE practices. While at first glance these variables may seem misaligned, they can be interpreted as a feedback relationship: insufficient consumer awareness regarding sustainable consumption reduces demand for products that would positively impact resource use and environmental outcomes, which in turn diminishes companies' incentives to develop new technologies and infrastructures that enable faster and more efficient circularity. This interpretation suggests that consumer behavior and technological development are interdependent in shaping CE adoption. Empirical evidence supports this view: for instance, Da Silva et al. (2022) show that companies that actively engage and empower consumers, and society in general, can build sustainable markets, enhance value creation, generate returns for shareholders, and safeguard broader societal interests. This value creation, in turn, provides a feedback loop that motivates further investments in technology and infrastructure, explaining why these two variables are grouped in this component.

PC6 represents a single variable from the second section of the survey (barriers in the adoption of the CE): high investment costs. Although it does not strongly correlate with other variables in the survey, this does not imply it is entirely unrelated to factors captured in other principal components. For example, high investment costs can affect drivers of R&D&I and new technologies, the development of platforms for collection, separation, recycling, and valorization of resources and materials, greater security in raw material supply, waste disposal and treatment, and the extension of product life cycles. As such, high investment costs may act as a limiting factor for CE adoption, particularly when perceived as an expense rather than a long-term strategic investment, which aligns with the philosophy of circularity. Saarinen and Aarikka-Stenroos (2023) corroborate this perspective, highlighting that the investments required for circular models often involve costly and risky structural changes, especially for SMEs, thereby constraining CE adoption despite its potential long-term benefits in terms of resource efficiency and sustainability.

Table 11 summarizes how the five research questions are addressed through the six principal components identified in the statistical analysis made.

The correspondence between the proposed research questions and the extracted principal components serves as the analytical foundation for designing a strategic action plan. This plan aims to provide a structured roadmap for implementing the CE principles within the Spanish automotive sector. Each principal component reflects different key dimensions identified through the analysis, which directly aligns with specific research questions. This alignment ensures that the strategic plan is both data-driven and designed to cope with the critical factors influencing CE adoption. Moreover, the methodology enables scalability and adaptability, facilitating the extension of this action plan to the automotive sector in other countries with similar industrial and regulatory contexts.

TABLE 11 | Relationship between RQs and PCs.

Research question	Principal component
RQ1	PC1, PC2
RQ2	PC1, PC6
RQ3	PC2, PC3, PC4, PC5, PC6
RQ4	PC3, PC4, PC6
RQ5	PC1, PC3, PC4, PC6

Source: Own elaboration.

5 | Strategic Action Plan

Based on the results of this study, a strategic action plan has been developed to guide managers and practitioners in the automotive sector toward the CE. The proposed plan is tailored to address both the general challenges identified and the specific needs of the sector, such as the development of new sustainable technologies, materials management, and potential long-term benefits in terms of resource efficiency. It is structured into five interconnected pillars: (1) Defining clear sustainability objectives across the automotive value chain; (2) Conducting a detailed cost–benefit analysis for the automotive transition to circularity; (3) Developing modular designs for automotive components; (4) Implementing closed-loop systems for critical automotive materials; and (5) Promoting awareness and capacity building among automotive stakeholders. These pillars are aligned with strategies established by the European Commission (EC 2024), the European Automobile Manufacturer's Association (ACEA 2024), and the Spanish Government (MINTUR 2024). In the following, related principal components, proposed actions, and expected impact for each pillar are described.

5.1 | Defining Clear Sustainability Objectives Across the Automotive Value Chain

5.1.1 | Related PCs

PC1 highlights the importance of awareness and a sound understanding of circularity principles as a foundation for transition. PC3 underscores how setting strategic sustainability objectives helps align CE practices with reducing greenhouse gas emissions and managing resources effectively.

This awareness and the establishment of strategic sustainability objectives should be integrated from the earliest stages of vehicle design, manufacturing, and supply chain management. In the automotive sector, this implies promoting the "circular car" approach, as championed by the World Economic Forum in 2019, which connects all stakeholders, from raw material suppliers to vehicle manufacturers, component producers, and recyclers, to align design, production, and end-of-life processes with CE principles (WEF 2020). This integration calls for new business models based on remanufacturing, reuse, and material recovery, fostering greater resource efficiency and reducing environmental impact across the entire automotive value chain.

5.1.2 | Proposed Actions

- Establish measurable objectives to drive organizational commitment and accountability across the automotive value chain. These targets should be explicitly aligned with the European Union Taxonomy criteria for climate change mitigation and CE in the manufacture of vehicles and automotive components, as well as with relevant UN SDGs on sustainable industry, responsible consumption, and climate action.

- Strengthen governance by creating dedicated sustainability committees at board or executive level in automotive manufacturers and major suppliers. These committees should oversee the integration of CE principles into vehicle design (e.g., ease of disassembly and component reuse), procurement policies (e.g., sourcing low-impact and recycled materials), production processes (e.g., closed-loop recycling in plants), and end-of-life strategies (e.g., take-back schemes and partnerships with authorized treatment facilities). By monitoring taxonomy-aligned activities, reviewing progress against circularity and emissions targets, and coordinating cross-functional initiatives, these bodies ensure that the transition toward the "circular car" becomes a core element of corporate decision-making.

5.1.3 | Expected Impact

Grounded in PC1 and PC3, this action ensures organizations address both awareness and environmental impact through clearly defined goals.

5.2 | Conducting a Detailed Cost–Benefit Analysis for the Automotive Transition to Circularity

5.2.1 | Related PCs

PC2 emphasizes the economic and environmental benefits of transitioning to CE, such as increased profitability and emissions reduction. PC6 highlights high investment costs as a significant barrier, necessitating thorough financial evaluation.

While the anticipated benefits, such as reduced raw material costs through closed-loop recycling, lower life-cycle emissions from remanufactured components, and compliance with stringent European Union regulations on vehicle recyclability, may drive profitability, the high upfront investments in eco-design tools, disassembly robotics, and battery remanufacturing facilities represent significant barriers, particularly for SMEs in the supply chain. Studies highlight the critical role of targeted funding mechanisms, such as green bonds or European Union recovery funds, to overcome these hurdles and accelerate the shift from linear to circular models in vehicle production and end-of-life management (Kirchherr et al. 2018; Ozkan-Ozen et al. 2020).

5.2.2 | Proposed Actions

- Quantify long-term cost savings associated with energy efficiency in manufacturing plants, material recovery from end-of-life vehicles, and reduced waste disposal costs through remanufacturing of high-value components such as batteries and engines.
- Address PC6 by framing investments in the CE as opportunities for innovation and long-term growth. For example, analyzing the ROI of closed-loop recycling for components can help quantify cost reductions in raw material procurement. Similarly, evaluating the financial impact of remanufacturing electric vehicle batteries, considering their extended lifecycle and reduced dependence on critical raw materials, can guide investment decisions.
- Leverage European Union funding mechanisms, such as the Innovation Fund and Horizon Europe, to help mitigate initial costs (EU 2025).

5.2.3 | Expected Impact

This action tackles both economic concerns and high investment barriers, paving the way for financially sustainable CE adoption.

5.3 | Developing Modular Designs for Automotive Components

5.3.1 | Related PCs

PC3 connects modular design with reducing waste and achieving sustainability objectives. PC4 highlights the importance of extending product lifecycles and using materials sustainably. Eco-design plays a key role in achieving this objective.

Panda et al. (2025) demonstrate that modularity holds out the great promise of improving circularity through product design, highlighting that modular components, which are independently replaceable, repairable, and reusable, play a key role in extending product life cycles, reducing waste, and conserving resources. Modularity is identified as an enabler for implementing the CE in industrial sectors such as automotive manufacturing. Several leading car companies are actively incorporating modularity into their design strategies. For instance, the Renault-Nissan-Mitsubishi Alliance employs modular vehicle architecture, which enables the reuse of components across different models. This approach reduces part diversity, facilitates remanufacturing, and supports efficient end-of-life disassembly. Volkswagen Group has implemented modular platforms for electric vehicles to standardize key structural and electronic components, allowing for scalable production and easier refurbishment, upgrading, and recycling. This configuration allows for battery and hardware upgrades, thus extending the product lifecycle and reducing electronic waste. BMW is also committed to modularity, minimizing part complexity and enabling disassembly. Components are designed to be plug-and-play and made from mono-materials to facilitate material recovery and reuse.

5.3.2 | Proposed Actions

- Integrate modularity into vehicle design by standardizing components to facilitate repairs, upgrades, and recycling (Soliman 2021).
- Design batteries with interchangeable modules to extend vehicle lifespan and reduce waste.

- Prioritize high-strength, easily separable materials, such as aluminum alloys and bio-based composites, to enhance component reuse and recyclability.
- Apply a "design for disassembly" approach to ensure that key elements, such as dashboards and electronic units, can be easily replaced or upgraded (Kręt and Baborska 2023).

5.3.3 | Expected Impact

Modular designs address both environmental and operational goals by enhancing sustainability while reducing waste, as emphasized by PC3 and PC4.

5.4 | Implementing Closed-Loop Systems for Critical Automotive Materials

5.4.1 | Related PCs

PC2 identifies the need for sustainable supply chain solutions, including securing raw materials. PC4 highlights proper management, recovery, and recycling of materials as key enablers of the CE.

Enhancing resource efficiency and supply chain resilience in the automotive sector requires the recovery and reintegration of high-value and critical materials into new production cycles. Closed-loop approaches enable the collection, separation, and reuse of materials such as aluminum, steel, copper, and increasingly lithium, cobalt, nickel, graphite, and rare earth elements from end-of-life vehicles and battery systems. Despite their environmental and economic benefits, significant challenges remain related to material purity, complex disassembly processes, and the substantial investments needed for dedicated recycling infrastructure and logistics networks. Several automotive manufacturers have begun to adopt such approaches, although their implementation remains uneven. For example, BMW integrates recycled materials into vehicle components, Ford prioritizes recycled plastics and closed-loop manufacturing processes to reduce production waste, and Škoda explores alternative sustainable materials for interior applications (Istrițeanu et al. 2024). In parallel, Audi and Renault are piloting advanced recycling models aimed at recovering critical materials, though large-scale deployment is still limited (Prochatzki et al. 2023).

5.4.2 | Proposed Actions

- Establish dedicated recycling systems for critical electric vehicle battery materials, such as lithium, cobalt, nickel, and graphite, covering both end-of-life batteries and production scrap to enable their reintegration into new battery manufacturing processes (Lehtimäki et al. 2024; Stefan and Chirumalla 2025).
- Foster collaboration across the automotive and battery supply chain, involving OEMs, battery manufacturers, recycling firms, and material suppliers, to develop closed-loop networks supported by appropriate collection, disassembly, and recycling infrastructure, thereby reducing dependence on virgin raw materials.
- Ensure that the transition toward closed-loop systems is market- and demand-driven by aligning CE solutions with viable business models, regulatory frameworks, and consumer expectations, in order to enhance economic feasibility, adoption rates, and scalability.

5.4.3 | Expected Impact

Closed-loop systems directly address the resource efficiency and emissions reduction objectives identified in PC2 and PC4.

5.5 | Promoting Awareness and Capacity Building Among Automotive Stakeholders

5.5.1 | Related PCs

PC1 underscores the importance of awareness as a driver of CE adoption. PC5 links insufficient consumer awareness with limited infrastructure development, highlighting the need for education and engagement.

Raising awareness and strengthening capabilities across the automotive value chain are essential to support the effective adoption of CE practices. While increasing environmental awareness among consumers and suppliers can exert pressure on companies to adopt circular solutions, persistent perceptions of recycled or remanufactured products as being of lower quality continue to hinder market acceptance. Beyond consumer awareness, capacity building across the automotive value chain, including original equipment manufacturers, suppliers, and recycling actors, is required to develop the technical, organizational, and managerial competencies necessary for implementing circular strategies. Effective communication and training initiatives that highlight the environmental, economic, and performance benefits of CE solutions are therefore crucial to overcoming resistance, improving stakeholder engagement, and facilitating large-scale adoption (Govindan and Hasanagic 2018).

5.5.2 | Proposed Actions

- Develop targeted training programs and awareness initiatives for employees, suppliers, and consumers aimed at closing knowledge gaps related to CE principles, material circularity, and product quality, thereby supporting capacity building across the automotive sector.
- Facilitate structured collaboration among automotive stakeholders to enable the exchange of best practices, technical knowledge, and lessons learned, reinforcing a shared understanding of CE principles.
- Promote coordinated engagement across the entire automotive value chain, including manufacturers, suppliers, recyclers, and service providers, to ensure consistent alignment with CE objectives and implementation strategies.
- At the institutional level, support coordinated medium- and long-term policy measures that enable capacity building and awareness raising for a new mobility model aligned with governmental sustainability commitments.

5.5.3 | Expected Impact

By addressing the barriers outlined in PC1 and PC5, awareness initiatives will create a well-informed stakeholder base capable of driving CE adoption.

To achieve the proposed actions in the automotive sector, coordinated efforts among manufacturers, suppliers, recyclers, policymakers, and consumers are required. Implementation mechanisms include the development of recycling infrastructure, adoption of modular design principles, targeted training programs, and structured stakeholder collaboration. Potential barriers include high investment costs, technological complexity in material separation, limited consumer acceptance of recycled products, and fragmented regulatory frameworks. These can be overcome through public-private partnerships, policy incentives, standardized CE guidelines, and awareness campaigns to build trust and capacity across the value chain. In the Spanish context, the ongoing transition toward sustainable mobility, the European Union Circular Economy Action Plan, and national regulations on battery recycling and vehicle end-of-life management provide both a framework and an opportunity to implement these measures effectively, while regional clusters of automotive manufacturing and research centers can serve as pilot sites for testing and scaling circular practices.

6 | Conclusions and Future Research Directions

The analysis of the automotive industry in the context of the CE has identified key aspects that define the current landscape and emerging strategies. The results achieved highlight the circular model, along with its barriers, enablers, and benefits.

The automotive sector is undergoing a profound transition, driven by the impact of new technologies, pressing environmental challenges, and the urgent need to adopt more sustainable practices, as seen in the rise of electric vehicles in response to societal demands. In this context, the CE has gained prominence as a key approach to mitigating the industry's environmental impact. Vehicle production and use generate substantial waste and greenhouse gas emissions, prompting the adoption of responsible measures that consider the entire life cycle of the automobile. Principal components 1 and 4 underscore this aspect.

Progress in the CE varies across major vehicle-producing countries. For instance, the adoption of electric vehicles as a primary axis of the green transition has not yet reached the desired level in some of the world's largest economies. China, Japan, and Germany are leading the way in electrification, driven by tax incentives and government policies. Automakers in each country take distinctive approaches: Germany focuses on engineering and design, while Japan excels in reliability and efficiency. Cultural factors and lifestyles further shape each nation's preferences and sustainability orientation. The development of new technologies, driven by R&D&I, is steering countries in different directions. Europe leads in automotive sector investment compared to the United States, Japan, China, and India. However, China stands as the global leader in automotive patents, with a strong focus on industrial protection. In Europe, Spain stands out for successfully implementing dismantling and recycling networks for end-of-life vehicles. Nevertheless, Spain lags behind countries like Germany and the Netherlands in technological innovation and CE policies. This aligns with principal components 2, 5, and 6.

The automotive sector confronts significant challenges, including the efficient management of resources and materials used in vehicle manufacturing and maintenance. Dependence on non-renewable resources and increased waste generation necessitate innovative solutions. At the same time, these challenges create opportunities to develop cleaner technologies, such as the adoption of electric vehicles, the use of recycled materials, and modular designs that facilitate recycling. This is where principal components 3 and 4 come into alignment.

Circularization strategies in the automotive sector range from vehicle designs aimed at easy recycling to the reconditioning and reuse of components, as well as extending the useful life of automobiles through remanufacturing practices. Notably, it is during the design phase that adaptation to a circularity strategy has the greatest impact, reducing the product's final environmental impact by 80%. Principal components 4 and 5 support this consideration.

The findings indicate that the success of the CE necessitates close collaboration among automakers, component suppliers, government authorities, researchers, and society. Furthermore, innovation is crucial in advancing new technologies and business models that foster circular practices, conserve natural resources, reduce environmental impact, and ensure substantial economic profitability.

A strategic action plan has been developed to facilitate the transition to a circular model, addressing the specific challenges and opportunities within the automotive sector. Advancing sustainability in this industry requires establishing clear objectives aligned with environmental, economic, and social priorities. These objectives provide a foundation for guiding subsequent efforts, including a detailed cost–benefit analysis to assess the feasibility and impact of proposed initiatives. Insights from this analysis can inform the development of modular designs for automotive components, enhancing efficiency, simplifying maintenance, and improving recyclability. In parallel, implementing closed-loop systems for critical materials optimizes resource use and minimizes waste through reuse and recycling. Additionally, raising awareness and building capacity among key stakeholders such as manufacturers, consumers, and policymakers is essential for fostering a shared commitment to sustainability and ensuring the effective execution of these strategies.

This study is subject to certain limitations that should be acknowledged. One such limitation is the partial response rate from the expert panel, as not all invited participants completed the questionnaire. This may have implications for the representativeness of the sample and the generalizability of the findings. Despite this constraint, the data collected enabled a robust statistical analysis through PCA. The analysis revealed six principal components that together account for a substantial proportion of the variance in the questionnaire responses. These components provide valuable insights into the key dimensions influencing the implementation of CE principles in the Spanish automotive sector.

Future research should aim to improve expert participation, potentially through more targeted engagement strategies or systematic follow-up mechanisms to ensure a more comprehensive and representative data set. Additionally, further studies may seek to validate the components identified in this analysis, extend the methodological framework to larger or more diverse samples, and undertake longitudinal assessments to monitor the evolution of CE adoption over time. Cross-national comparative research could also enhance the understanding of contextual differences and support the identification of best practices at an international level. An additional avenue involves the development of a balanced scorecard to accompany the strategic action plan. Such a tool would enable more precise monitoring of implementation progress and facilitate the alignment of key performance indicators with the sector's objectives.

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