SCAIRA

Territorial and Industrial Challenges in the Automotive and Aeronautic Sectors

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Overview of the Purpose and Scope

Automotive and Aeronautic Perspective

In recent years, there has been an increase in depopulation and deindustrialization in rural areas, leading to a 0.1% annual decrease in the resident population (Eurostat 2023). This has resulted in a 0.4% annual population increase in large cities (Eurostat 2023) and a negative impact on rural areas. Simultaneously, the industry must reinvent itself to become more resilient, sustainable, and appealing to younger generations. Consequently, the SUDOE region faces pressing challenges in addressing the environmental crisis, unbalanced economic growth, deindustrialization, and depopulation, particularly affecting rural areas.

The SUDOE region (Southwestern Europe), encompassing parts of Spain, Portugal, and southern France, is a hub of industrial and technological innovation. Known for its strong aerospace and automotive sectors, the region plays a critical role in Europe's economic and industrial landscape. These industries drive innovation, foster cross-border collaboration, and contribute to the transition toward sustainable technologies. With a focus on advanced manufacturing, research, and development, the SUDOE region is well-positioned to lead the way in tackling global challenges such as decarbonization, digitalization, and circular economy practices.

To ensure a cohesive narrative, this white paper highlights the critical contributions of both the automotive and aeronautical industries, recognizing their shared relevance in advancing sustainability and circularity within the SUDOE region. While the primary focus lies on analyzing and optimizing the innovation ecosystems in Portugal, Spain, and France, the insights presented here integrate findings from SCAIRA project, bridging both sectors to reflect their mutual impact and interconnected goals. This initiative identifies obstacles and opportunities for developing a circular and local value chain in the aeronautical sector, particularly within regions like Occitanie, Nouvelle-Aquitaine, Auvergne, and neighboring territories.

The present report examines the strategic orientations and challenges related to territorial and industrial development, with a specific focus on two high-value and economically significant sectors: automotive and aeronautics. These industries play a key role in the economic and technological transformation of the regions involved while facing major challenges in competitiveness, sustainability, and territorial integration.

By addressing both sectors, this white paper underscores the interconnected objectives of sustainable transformation, the enhancement of territorial and industrial capacities, and the integration of circular economy principles across regional value chains. Together, these efforts provide a systemic framework for understanding and shaping the future of mobility and industrial innovation

Key Findings and Conclusions

The SUDOE region, encompassing Spain, Portugal, and France, stands at a pivotal moment of transformation in both the automotive and aeronautical sectors. These industries face significant challenges and opportunities as they adapt to a low-carbon future shaped by stringent environmental goals, evolving customer expectations, and technological advancements.

Shared Challenges and Opportunities in the Automotive and Aeronautic Sectors

Sustainability and Circularity:

Both the automotive and aeronautical sectors must address dual challenges: achieving corporate sustainability and ensuring the sustainability of their products and services. These efforts are crucial for meeting ambitious decarbonization targets such as those outlined in the European Green Deal.

Technological Paradigm Shifts:

The automotive industry is undergoing a rapid transition driven by electrification, connectivity, and autonomous mobility. By 2030, electric vehicles are expected to make up over 50% of global new vehicle sales. Similarly, the aeronautical sector faces the need for innovation in sustainable aircraft design, production processes, and operational efficiencies.

Collaboration and Integration:

Cross-sectoral collaboration between automotive, aeronautics, and other mobility sectors such as rail and sea transport are essential. Integrated frameworks like simultaneous engineering and circular economy principles must replace traditional "customer-supplier" relationships to ensure a sustainable future.

The Role of the Iberian Sustainable Mobility Ecosystem (ISME)

This white paper introduces the **Iberian Sustainable Mobility Ecosystem (ISME)** as a transformative framework to address these challenges:

- **Technological Innovation**: Encouraging advancements in electrification, automation, and green manufacturing.
- **Value Chain Transformation**: Promoting circular economy practices to reduce resource dependence and waste.
- **Smart Infrastructure Development**: Building resilient, energy-efficient infrastructure to support new mobility solutions.
- **Adaptive Regulation**: Aligning policies to foster cross-border collaboration and innovation.

Projected Impacts of ISME:

- Economic Growth: Enhancing the competitiveness of the region's automotive and aeronautical sectors by 15-20% by 2030 and creating over 100,000 new high-skilled jobs.
- Environmental Sustainability: Reducing CO_2 emissions by 55% in the automotive sector by 2030 and by 90% by 2050.
- Investment Potential: Attracting over €50 billion in green investments by 2030, positioning the Iberian Peninsula as a global hub for sustainable mobility innovation.

Aeronautical Sector Challenges and Actions

The aeronautical industry, a highly specialized and demanding sector, must restructure to meet sustainability goals, particularly in reducing its dependence on fossil fuels. Current roadmaps propose ambitious actions, but success will require:

- Implementing collaborative systems based on trust among value chain stakeholders.
- Revising corporate accounting frameworks to prioritize respect for planetary boundaries over short-term economic performance.
- Leveraging digital technologies and best practices to ensure decarbonization from production to end-of-life.

Call to Action

The SUDOE region's strong industrial bases, political commitment to sustainability, and thriving innovation ecosystems position it to lead the global transition toward sustainable mobility. However, achieving this leadership will require urgent, bold, and integrated action. By aligning the automotive and aeronautical sectors under frameworks like ISME, the region can become a benchmark for economic growth, environmental stewardship, and resilience in a low-carbon future.

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Introduction

Background and Context

Automotive and Aeronautic Sectors

The automotive industry, historically a key driver of the global economy, is now at a critical inflection point. Growing concerns over **climate change, the scarcity of natural resources, and the demand for more sustainable mobility solutions** require profound and immediate transformation within the sector. This landscape presents significant **challenges**, such as the **shift to electric vehicles**, which increases **dependency on critical materials** like lithium, cobalt, and rare earths, as well as the need to adapt **charging infrastructure** and manage complex **global supply chains**.

Simultaneously, the industry faces unprecedented challenges driven by **climate urgency, energy transition**, evolving consumer expectations, and rapid technological advancements. In markets like Portugal, Spain, and France, these challenges are compounded by the need to adapt to regional specificities and the dynamics of local industrial clusters. The integration of **sustainable and innovative practices** has become essential for the sector's survival and growth, particularly in rural areas, where restructuring value chains can revitalize local economies and promote more balanced development.

In this context, strategies such as embracing the **circular economy** and leveraging **advanced technologies**—like blockchain for component traceability—are critical to overcoming value chain constraints and fostering a more integrated and efficient transformation. A detailed analysis of the automotive ecosystem is fundamental to identifying sustainability trends, challenges, and opportunities for innovation. The study aims to provide strategic recommendations to support decision-makers in navigating the transition toward a more sustainable, competitive, and inclusive future.

With increasing regulatory pressures and shifting consumer preferences, the ability to adapt and innovate will be a key success factor for automotive companies in the years ahead.

The analysis for the aeronautic industry has been developed with a focus on its value chain, identifying the obstacles, challenges, and key drivers essential for promoting sustainable development and guiding the industry's transition toward sustainability, all within a local circularity framework.

The intensification of climate change and the depletion of non-renewable resources raise many questions about the future of the aviation sector.

The global challenge of carbon neutrality requires an acceleration of actions to meet the challenges with all stakeholders, in a context for the aviation sector of traffic growth and tension in the value chain resulting from the health, climate and geopolitical crises.

How can we act today to continue flying tomorrow?

The purpose of this document is to list some levers to answer this question throughout the aeronautics value chain in terms of the decarbonization of energy, the use and the production system of the aircraft.

The environmental issues related to the means of production of aircraft (machines, tools, manufacturing processes) as well as the difficulties of producing in a finite world are rarely addressed in the literature, which is why this document proposes to carry out a more in-depth study on:

- Reducing the impact of production systems on the environment,
- And the future of an aircraft's production system in a world under energy and material constraints.

To achieve carbon neutrality, environmental, economic and social aspects must be considered at all stages of the life cycle of the aircraft and the associated infrastructure by each of the players in the aviation sector.

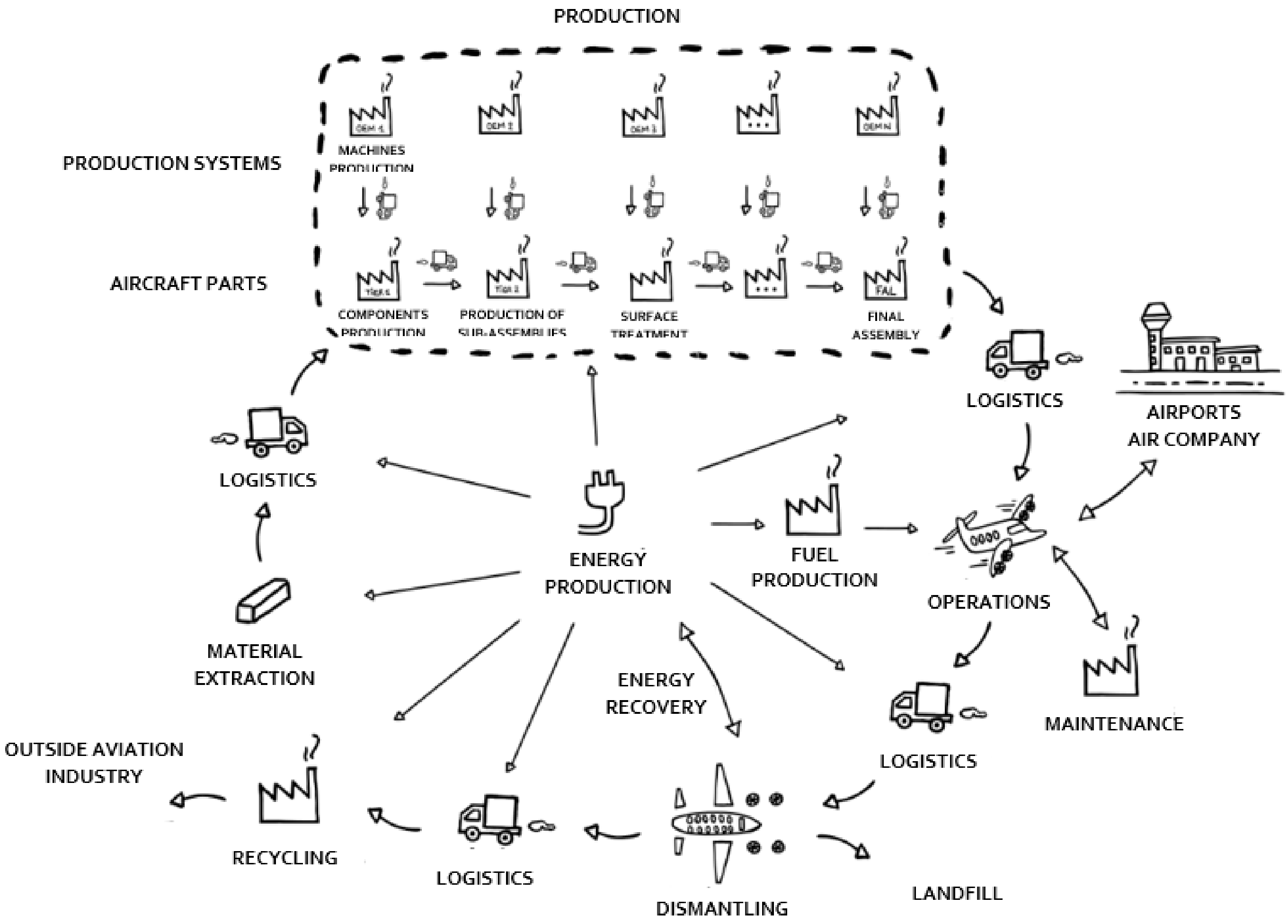


Figure 1: *Main stages and actors in the life cycle of the aircraft*

Objectives of the White paper

To provide a detailed overview of the automotive ecosystem with an emphasis on sustainability and innovation, this study **maps critical value chains in the markets of Portugal, Spain, and France**, highlighting **key trends, opportunities, and challenges** for a more sustainable future. The European automotive sector is undergoing profound transformations driven by global factors such as climate urgency, digitalization, and shifting consumer preferences. This study aims to comprehensively **analyse the automotive innovation ecosystem in Europe**, with a particular focus on **sustainability** and the **energy transition**, adoption of **sustainable materials**, and in production processes **digitalization**. The objective is to present a clear view of emerging trends, identify areas that require urgent innovation, and propose strategic recommendations to help the automotive sector adapt and thrive in an increasingly regulated and competitive environment. Additionally, the document aims to support the economic system by fostering conditions that enable local startups to thrive and contribute to the region's sustainable growth.

The study further seeks to highlight the specific characteristics of automotive clusters in France, Spain, and Portugal, acknowledging that each country faces unique challenges and opportunities. It also places special emphasis on rural areas, where the energy transition may encounter specific obstacles but also significant opportunities for sustainable development. Thus, this study aims to serve as a strategic tool for **policymakers**, **business leaders**, and **other stakeholders**, guiding the transformation of the European automotive sector in an efficient and sustainable manner.

The primary areas of focus encompass a comprehensive examination of **sustainability, innovation**, and **adaptation** within the automotive sector. This includes identifying the **main trends** shaping the industry's future, such as the **transition to electric vehicles**, the **adoption of sustainable materials**, and the role of **digitalization** in transforming production and operations. A critical part of the analysis involves assessing the needs for innovation and adaptation across products, processes, organizational structures, and marketing strategies to ensure that the sector remains competitive and aligned with sustainability goals.

To provide a comprehensive synthesis of the obstacles and levers within the aeronautic industry. The study conducts an in-depth analysis to identify structural, economic, regulatory, and organizational challenges, along with strategic opportunities, aimed at promoting circularity and territoriality.

Another key dimension is **mapping** critical decisions along the value chains, with a particular focus on understanding the regional impacts of industry shifts, especially in rural areas. This includes exploring opportunities for **local innovation** that can drive the energy transition while fostering **economic and social inclusion**. To support this transformation, strategic recommendations are formulated to facilitate the energy transition and promote innovation within the automotive sector, addressing both corporate strategies and public policy frameworks.

Finally, the analysis considers the specific challenges and opportunities for **rural areas**, including the need for enhanced **charging infrastructure, resilient supply chains, and inclusive economic policies**. It also delves into the **unique characteristics** of automotive clusters in **France, Spain, and**

Portugal, evaluating how these clusters are adapting to meet the demands of sustainability and innovation, thereby positioning themselves as key players in the transition to a more sustainable future.

This comprehensive approach offers an integrated framework to understand the challenges, overcome obstacles, and identify opportunities to promote circularity and territoriality in both the aeronautic and automotive industries, ensuring their effective transition toward sustainability.

Sectors Overview

Automotive & Aerospace Industry

Automotive Industry

Europe is at the forefront of automotive innovation, particularly regarding sustainability. With the European Union setting ambitious targets for reducing greenhouse gas emissions and promoting initiatives like the European Green Deal, the automotive sector finds itself at a decisive crossroads, as by 2035, all new vehicles in the EU will have to be zero emissions. (Guillaume Ragonnaud, 2024) The transition to electric vehicles (EVs) is not just a technological choice but a necessity to meet environmental standards and maintain global competitiveness.

Innovation in the automotive industry extends beyond electrification, with investments exceeding €250 billion, it created an opportunity to produce a diverse range of electric cars and vans. (SPIN 360, 2024) Digitalization and connectivity are transforming how vehicles are designed, manufactured, and used. Technologies such as 5G, cloud computing, and artificial intelligence are redefining mobility by introducing new paradigms like autonomous vehicles and Mobility as a Service (MaaS). These advancements are creating a complex ecosystem where the integration of various technologies and business models will be crucial for success.

Moreover, the automotive sector increasingly relies on robust interconnections with other industries, such as energy and information technology (IT). The shift to a **sustainable model** requires close collaboration with the energy sector for the integration of renewable sources like solar and wind, both in automotive production and charging infrastructure. Simultaneously, digitalization driven by the IT sector is fundamental for developing connected vehicles and implementing smart mobility solutions. This interdependence fosters synergies that can accelerate innovation but also presents challenges in terms of strategic alignment and regulatory coordination.

Furthermore, **global value chains are being restructured** to meet sustainability requirements, as Draghi Report suggests, to EU develop a specific industrial action plan, covering all stages of the value chain. (Guillaume Ragonnaud, 2024) These trends have altered the fundamentals of the industry, which has been undergoing the biggest structural transformation in its history. (Guillaume Ragonnaud, 2024). The focus on circular economy principles, the use of recycled materials, and waste reduction have become priorities as companies strive to minimize their carbon footprint throughout the entire product lifecycle. In this context, Europe has the opportunity to lead the transition toward a more sustainable and digitized automotive future. However, achieving this will require a coordinated and innovative approach that integrates other critical sectors to maximize positive impact.

The global automotive industry is experiencing a period of profound transformation marked by challenges and needs that are often overlooked or underestimated. These challenges emerge in a landscape of rapid technological advancements, changing consumer behaviours and its expectations, environmental pressures, and new regulatory demands.

Climate Urgency: The transportation sector accounts for approximately 24% of global energy-related CO_2 emissions, with road vehicles representing the largest share of this total. The Paris Agreement and subsequent national commitments to emission reduction are placing unprecedented pressure on the industry to rapidly decarbonize.

Technological Revolution: The convergence of advances in electrification, connectivity, autonomous driving, and artificial intelligence is redefining the concept of the "automobile." According to BloombergNEF, electric vehicles are projected to account for over 50% of global new vehicle sales by 2030.

Shifting Mobility Patterns: Increasing urbanization, combined with the rise of the sharing economy, is altering attitudes toward vehicle ownership, particularly among younger generations. The concept of "Mobility as a Service" (MaaS) is gaining traction, challenging the traditional business model focused on vehicle sales.

Reconfiguration of Global Value Chains: The COVID-19 pandemic exposed vulnerabilities in global supply chains, prompting a reevaluation of production and sourcing strategies. The transition to electric vehicles is creating new dynamics in the value chain, with new players emerging and incumbents needing to adapt rapidly. Chinese car exports overtook South Korea in 2021 and Germany in 2022, in a context of over-capacity issues on its national market. China is the main source of car imports for the EU with total EU cars imports from this country, by nearly 40% from 2022 to 2023. (Guillaume Ragonnaud, 2024)

Regulation and Public Policies: Governments worldwide are implementing increasingly stringent policies related to emissions, safety, and vehicle recycling. In the European Union, for instance, the European Green Deal sets ambitious targets for emission reductions in the transportation sector.

Evolving Consumer Expectations: Environmental awareness is growing among consumers, particularly in developed economies. Additionally, there is a demand for vehicles that are more connected, personalized, and technologically advanced.

To remain competitive and sustainable, the industry must adopt a strategic and innovative approach capable of addressing a complex set of technological, social, environmental, and geopolitical issues. The following sections will explore the key challenges, needs, and opportunities that define the future of the automotive sector.

Geopolitics and Economic Nationalism

Rising geopolitical tensions and increased economic nationalism could severely impact global supply chains and access to key markets. The automotive industry must prepare for scenarios involving the fragmentation of global trade, including restrictions on technology transfers and shifts in import/export policies. Diversifying supply chains and strengthening local partnerships will be crucial to mitigate these risks, along with implementing circular economy strategies to enhance operational resilience.

Dependence on Critical Materials and Vulnerable Supply Chains

The shift to electric vehicles intensifies the dependence on materials such as lithium, cobalt, nickel, and rare earths, which are concentrated in a few countries. In 2023, 14 million electric vehicles were sold worldwide, representing 18% of all cars sold globally. (Guillaume Ragonnaud, 2024) This dependence makes the industry vulnerable to supply disruptions and unsustainable mining practices. Investing in recycling, the development of alternative materials, and supplier diversification are essential strategies to create more resilient and sustainable supply chains. Urban mining for recovering metals from discarded electronic products and bio-mining are emerging as innovative solutions to mitigate these risks.

Underestimation of Software Complexity and Cybersecurity

The increasing digitalization of vehicles exposes the industry to significant cybersecurity risks. Advanced software integration heightens vulnerability to cyberattacks, necessitating more secure software development and robust data protection protocols. Competing with tech companies for talent and establishing security standards are critical challenges. Furthermore, digital transformation requires the establishment of ethical guidelines that balance security and fairness in automated vehicle decision-making, especially in unavoidable risk scenarios.

Mass Customization

Advances in additive manufacturing, such as 3D printing, and artificial intelligence open new opportunities for mass customization of vehicles. This enables manufacturers to offer highly personalized vehicles, fundamentally changing production and distribution models and requiring greater flexibility in assembly lines.

Vehicles as Service Platforms

Vehicles are evolving beyond mobility into digital service platforms. This transformation presents new revenue streams, such as in-car entertainment, occupant health monitoring, and connectivity services. Automakers face the challenge of reinventing themselves as providers of experiences and services, rather than just vehicle manufacturers.

Technological Aging and Legacy Infrastructure

Modernizing production infrastructure is essential for integrating new technologies like electrification and automation. Many automakers still operate with outdated processes that limit efficiency and the ability to adapt to innovations. Upgrading production lines and incorporating Industry 4.0 practices are necessary steps to maintain competitiveness despite high modernization costs.

Social and Labor Impacts of Automation and Digitalization

The increasing automation in the industry poses a risk to traditional jobs, potentially leading to social tensions. It is imperative to invest in reskilling and developing new competencies for workers, balancing productivity gains with social responsibility and maintaining strong relationships with unions. However, the recent Draghi Report pointed out that EU car industry is suffering from higher production costs, lagging technological capabilities (...) recommending measures to lower energy costs, and increasing automation in the sector. (Guillaume Ragonnaud, 2024)

Integration with Smart Cities

The development of smart cities presents an opportunity for the automotive industry to integrate vehicles with intelligent urban infrastructures, such as traffic management systems. This integration can enhance efficiency, reduce emissions, and transform urban mobility, but requires close collaboration with governments and other sectors.

Ethical Challenges of AI

The development of autonomous vehicles raises significant ethical dilemmas, particularly concerning safety decisions in unavoidable risk situations. The industry must address these issues transparently and develop robust ethical standards to ensure social acceptance of autonomous vehicles.

Circular Economy

Adopting circular economy principles is crucial to reducing environmental impact throughout the vehicle lifecycle. This includes battery recycling, designing vehicles for easy disassembly and component reuse, and minimizing the carbon footprint across the value chain.

Occupant Health and Well-Being

With more time being spent in vehicles, there is an opportunity to develop technologies that monitor and enhance occupant health and well-being. Integrating health sensors, advanced air purification systems, and comfort features can transform the in-vehicle experience.

Data Regulation

Increased vehicle connectivity brings challenges related to user data collection, usage, and protection. Automakers must navigate globally varying data regulations and establish standards that ensure privacy and security while maintaining consumer trust.

Vehicles Adapted for an Aging Population

With the aging population in developed countries, there is a growing need for vehicles tailored for older drivers. Advanced assistance systems, intuitive interfaces, and technologies that improve accessibility are essential to meet this expanding market segment.

Adaptation to New Materials

Beyond recycling, adapting to new sustainable materials such as bioplastics and advanced composites is crucial. These materials require significant changes in production processes but offer substantial environmental benefits and can enhance vehicle sustainability.

With regard to sustainability ...

What concerns to sustainability, and the major tendencies we can look at the automotive sector at a global level, as it is undergoing a rapid transformation, driven by increasingly stringent environmental regulations and a growing demand for cleaner technologies. Key trends shaping the industry include:

Transition to Electric and Hybrid Vehicles: Challenges and Opportunities - The electrification of vehicles is accelerating across Europe, driven by stringent decarbonization policies, ambitious CO_2 emission reduction targets, and government incentives. This trend is reshaping the automotive industry, presenting both opportunities and challenges that demand innovative strategies.

Growing Adoption of Electric Vehicles (EVs) - Countries like Portugal, Spain, and France are at the forefront of this transition, showcasing significant growth in EV and plug-in hybrid electric vehicle (PHEV) sales. In 2023 alone, EV sales grew by 58% in Portugal, 46% in Spain, and 39% in France. This rapid adoption is supported by expanding charging infrastructure, with increases of 32%, 28%, and 35%, respectively, in these nations. These advancements have not only facilitated sustainable mobility but also contributed to an average CO_2 emission reduction of 7% across EV fleets in the region.

However, challenges remain, particularly in less developed regions, where limited access to charging stations and slower infrastructure development hinder widespread adoption. Addressing these disparities is essential for ensuring a truly inclusive transition.

Overcoming Charging Infrastructure Barriers - The expansion of charging infrastructure is critical to supporting EV growth, especially in rural areas where accessibility is limited. Innovative solutions, including mobile charging units and community-driven initiatives, are being explored to address these barriers. Additionally, governments and private stakeholders are investing in fast-charging networks to enhance convenience for users, driving further adoption.

Supply Chain Resilience Amid Critical Material Shortages - The shift to EVs has profoundly impacted the automotive supply chain, increasing demand for critical materials like lithium, cobalt, and nickel, which are essential for battery production. Europe's reliance on external suppliers for these materials has created vulnerabilities, exacerbated by geopolitical tensions and rising global demand.

To mitigate these risks, the industry is pursuing several strategies:

Diversifying Supply Sources: Europe is securing agreements with resource-rich countries and exploring sustainable mining opportunities within its borders.

Focusing on Recycling and Circular Economy: Advanced battery recycling technologies are enabling the recovery of valuable materials like lithium and cobalt, reducing reliance on virgin resources and supporting a more sustainable lifecycle for EVs.

Developing Alternative Battery Technologies: Research is advancing in alternative batteries, such as sodium-based and solid-state batteries, which require fewer critical materials while offering improved sustainability and cost efficiency.

Ensuring a Sustainable Future

The transition to electric and hybrid vehicles is a cornerstone of Europe's efforts to achieve climate neutrality. While significant progress has been made, addressing challenges such as material shortages, infrastructure gaps, and supply chain vulnerabilities remains crucial. By adopting innovative strategies and fostering international cooperation, Europe can lead the way in creating a resilient and sustainable EV ecosystem.

Sustainable Materials, Eco-Design and Recycling - The automotive industry is increasingly adopting recyclable materials and circular economy practices into production processes. Eco-design principles, which emphasize sustainability throughout the product lifecycle, are becoming integral to these efforts. Advanced recycling technologies, such as battery reuse and component remanufacturing, not only reduce the sector's carbon footprint but also open new business opportunities in the recycled parts market. For instance, battery recycling and the use of biocomposites have achieved up to a 20% reduction in carbon footprint in some French automotive plants. Additionally, Spain has made notable advancements in recycled metals, with a 15% increase in their use within production lines over the past two years. By integrating eco-design into material selection and production strategies, the industry ensures that sustainability is considered from the initial design stage to end-of-life management.

Development of Alternative Energy Sources - Emerging technologies like green hydrogen are gaining traction, particularly for heavy vehicles and long-haul transportation. France has invested €2 billion in hydrogen infrastructure over the past five years, positioning itself as a European leader. In Portugal, hydrogen projects in industrial areas are advancing, while Spain focuses on developing advanced biofuels to reduce reliance on fossil fuels.

Digitization and Connectivity - Digitization is reshaping the automotive sector, from manufacturing to aftermarket services. Technologies such as blockchain, big data, and IoT are enhancing efficiency, component traceability, and supply chain optimization while promoting transparency and compliance with environmental standards. These technologies also improve cybersecurity and data protection for consumers.

Global Challenges in the Automotive Sector

The global automotive sector faces a series of interconnected challenges that are fundamentally reshaping the industry:

Decarbonization

Status Quo	Challenge
The sector accounts for approximately 15% of global CO_2 emissions. Stricter regulatory targets demand a significant reduction in emissions, such as the EU's goal of a 55% reduction in CO_2 emissions from new cars by 2030.	Challenge: Rapidly transitioning to electric propulsion and other low-emission technologies while maintaining competitiveness.

Electrification

Status Quo	Challenge
Electric vehicles (EVs) are projected to account for 58% of global passenger car sales by 2040	Developing more efficient and sustainable batteries, expanding charging infrastructure, and managing critical material supply chains.

Digitalization and Connectivity

Status Quo	Challenge
By 2030, an estimated 95% of new vehicles sold globally will be connected	Investment in software and electronics, cybersecurity, and consumer data management.

Autonomy

Status Quo	Challenge
The global autonomous vehicle market is expected to grow at a CAGR of 39.47% from 2021 to 2028.	Technological development, regulation, ethical considerations, and consumer acceptance.

New Business Models

Status Quo	Challenge
Mobility-as-a-Service (MaaS) is disrupting the traditional vehicle ownership model. The global MaaS market is projected to reach $52.6 billion by 2027.	Adapting to new revenue models and consumption patterns.

Sustainable Supply Chains

Status Quo	Challenge
Increasing pressure to adopt circular economy practices and reduce environmental footprints. The EU has proposed regulations requiring due diligence throughout the value chain	Ensuring transparency, traceability, and sustainability in complex, global supply chains.

Spain, France and Portugal Automotive specific challenges

Workforce Transition

Status Quo	Challenge
The sector directly and indirectly employs over 2 million people across the three countries.	Reskilling the existing workforce and attracting new talent in fields like software, electronics, and green technologies.

Global Competition

Status Quo	Challenge
Growing competition from emerging markets, particularly in Asia. Europe's global market share in automotive production fell from 30% in 2000 to 22% in 2020.	Maintaining competitiveness through innovation and enhanced productivity

Dependence on SMEs

Status Quo	Challenge
SMEs account for a significant portion of the automotive supply chain in the region. In Portugal, for instance, SMEs represent 70% of sector employment.	Supporting SMEs in transitioning to new technologies and sustainable business models.

Charging Infrastructure

Status Quo	Challenge
Rapid expansion of charging infrastructure is needed to support EV adoption. The region must install over 3 million charging points by 2030 to meet electrification targets.	Coordinating public and private investments to build an efficient and comprehensive charging network.

Regulatory and Subsidiary Harmonization

Status Quo	Challenge
Differences in regulations and incentives across the three countries can create inefficiencies.	Coordinating policies and regulations to create a cohesive and competitive regional market, complemented by government subsidies that actively shape market dynamics.

Innovation and R&D

Status Quo	Challenge
Increased investment in R&D is essential to maintain global competitiveness. Europe's automotive R&D intensity (5.8% of revenue) lags the US (7.1%) and Japan (6.3%). EU firms operating in the automotive value chain, are the most important investors in R&D (32% of total industrial investment) (Lamia Kamal-Chaoui, 2024)	Boosting R&D investment and enhancing collaboration among industry, academia, and government.

Adapting Industrial Infrastructure

Status Quo	Challenge
Many factories in the region are optimized for internal combustion engine vehicle production.	Modernizing production facilities to support EV manufacturing and related components.

Proposed Solution: The Iberian Sustainable Mobility Ecosystem (ISME)

To address these challenges and capitalize on emerging opportunities, we propose the establishment of the Iberian Sustainable Mobility Ecosystem (ISME). This holistic and integrated approach aims to transform the automotive sector in Spain, France, and Portugal, positioning the region as a global leader in sustainable mobility and innovation.

Aeronautics Industry

The European Union has implemented several ambitious policies to drive sustainability and ensure the sector's competitiveness. Notable among these is the *European Green Deal*, which aims to achieve climate neutrality by 2050. This has direct implications for the aeronautical industry, including the adoption of stricter CO2 emission reduction targets under initiatives such as the *ReFuelEU Aviation* program, promoting the use of sustainable aviation fuels (SAF). Additionally, the *EU Emissions Trading System (EU ETS)* mandates airlines to purchase allowances for their carbon emissions, creating financial incentives for cleaner operations.

The *Single European Sky* initiative is another regulatory framework that seeks to optimize air traffic management across the EU, reducing fuel consumption and emissions by streamlining flight routes. Furthermore, safety regulations remain paramount, with strict adherence to the standards set by the European Union Aviation Safety Agency (EASA) to ensure passenger and operational safety.

The aeronautics value chain, from aircraft design to end-of-life, involves a multitude of interconnected players and stages. In the SUDOE area (South-Western Europe, mainly France, Spain and Portugal), this chain is part of a regional dynamic that mobilizes cutting-edge companies, academic institutions and end-users such as travelers.

The aeronautical value chain is based on continuous interaction between major groups (such as Airbus and Safran), specialized SMEs, suppliers, airlines, public institutions and competitiveness clusters, travelers, etc. Closer collaboration between these players is essential to meet environmental challenges, particularly in regions such as SUDOE, which boasts a high concentration of industry and a network of aeronautical clusters.

For each stage—**R&D**, **Manufacturing**, **Assembly**, **Use (Operation)**, **Maintenance, Repair, and Overhaul (MRO)**, and **End-of-Life (Dismantling and Recycling)**—various challenges, obstacles, and key drivers will be presented.

Research and Development (R&D)

R&D is a key stage in aircraft design, focused on innovation and performance. It includes feasibility studies, digital modeling and prototyping, with the aim of producing more efficient aircraft that comply with environmental standards. This stage involves aircraft and equipment manufacturers, research centers, etc.

Manufacturing

The production of aircraft parts, subsystems and systems (engines, landing gear, electronic systems, cabin interiors, etc.) involves many different stages. Tier 1 suppliers (major equipment manufacturers) work with subcontractors to produce systems such as them. Manufacturing relies on strict quality control and coordination between all players in the chain.

Assembly

Assembly steps are carried out throughout the production chain (e.g. to assemble engine, fuselage and wing components). Final assembly creates complete structures. Here again, numerous tests are carried out to verify conformity and performance.

Use (Operation)

Once assembled, the aircraft enters the commercial operation phase. The aircraft is wholly or partly owned by the airlines. This phase is based on continuous optimization of operations: flight planning, optimized maintenance operations, etc.

Maintenance

Maintenance ensures the safety and reliability of aircraft throughout their life cycle. It includes regular inspections (preventive maintenance), immediate repairs (corrective maintenance) and major overhauls. Maintenance, repair and overhaul (MRO) companies play a key role in ensuring aircraft operational availability. This stage also involves spare parts management, reconditioning and, in some cases, recycling.

End-of-life (dismantling and recycling)

At the end of their life cycle, aircraft are dismantled and reusable parts, such as engines or electronics, are reconditioned or resold. Aircraft end-of-life varies widely around the world. This contributes to the full integration of aeronautics in a circular economy approach.

The Importance of Automotive Clusters in France, Spain, and Portugal – the SUDOE Region

France, Spain, and Portugal play pivotal roles in the European automotive landscape, each hosting significant industrial clusters that drive innovation and production across the continent. These clusters are not only centres of manufacturing but also hubs of technological advancement, fostering synergies among various actors in the value chain. These three countries share unique characteristics that position them advantageously to lead the transition toward a more sustainable and innovative future.

Robust Industrial Base:

- Spain is the second-largest car manufacturer in Europe, producing 2.8 million vehicles in 2020 despite the pandemic's impacts.
- France is home to two of the world’s largest automotive groups, Stellantis and Renault, and has a long-standing tradition of innovation in the sector, with a rich legacy of innovation and advanced engineering.
- Portugal has seen remarkable growth in its automotive industry, with a 30% increase in production between 2015 and 2019, and is rapidly expanding its role in the European Market.

Commitment to Sustainability:

- All three countries have set ambitious goals for emission reduction and renewable energy transitions. For instance, Spain aims for 74% renewable energy in its electricity grid by 2030.
- France has been a leader in promoting electric vehicles, offering substantial incentives and planning to ban the sale of combustion vehicles by 2040.
- Portugal has been a pioneer in electric mobility initiatives, including an extensive charging network.

Growing Innovation Ecosystems:

- Barcelona, Paris, and Lisbon are emerging as technology and startup hubs, attracting investment and talent to the mobility sector.
- There is increasing collaboration among universities, research centres, and industry in all three countries, fostering automotive innovation.

Strategic Geographic Position:

- The region serves as a bridge between Europe, Africa, and Latin America, offering significant logistical advantages.

Supportive Government Policies:

- The governments of these three countries have implemented supportive policies for the automotive sector, including tax incentives for R&D and backing the transition to electric vehicles.

Skilled Workforce and Talent:

- The region boasts a highly skilled workforce with a strong tradition in automotive engineering and design.

The ongoing transition from a globalized economy to a more regionally focused model presents a unique opportunity for Spain, France, and Portugal to position themselves as leaders in the transformation of Europe's automotive sector toward sustainability and innovation. This shift is driven by the need to reduce supply chain vulnerabilities, enhance local production capabilities, and accelerate the adoption of green technologies. By leveraging their complementary strengths, these three countries are well-placed to establish a robust and competitive regional cluster that aligns with Europe's strategic priorities.

In these markets, global sustainability trends are adapted to distinct regional characteristics:

Portugal: Over the past year, Portugal's EV charging infrastructure has grown by 32%, supported by tax incentives that have made EVs more accessible. The country stands out for its circular economy initiatives, such as battery reconditioning in rural areas, which have reduced reliance on virgin materials. Public policies have prioritized modernizing value chains, with targeted investments in underdeveloped areas aimed at integrating sustainable practices into local economies.

Spain: As one of Europe's largest automotive production hubs, Spain has invested heavily in industry digitalization and modernization. The country's 28% increase in EV charging infrastructure in 2023 reflects its commitment to sustainability. Innovation clusters are being developed to advance sustainability, with an emphasis on producing batteries and recyclable components.

France: A leader in sustainable mobility, France has implemented aggressive policies supporting electrification and green hydrogen development. The French government has made significant investments in workforce reskilling, boosting employability in areas tied to sustainable automotive technologies. Regional clusters play a key role in driving innovation and the adoption of sustainable practices, particularly in less developed areas.

In France, the automotive cluster is defined by the presence of major manufacturers such as Renault and the PSA Group, both of which have heavily invested in electrification and digitalization. The country leads in sustainable mobility initiatives, supported by fiscal incentives for EVs and substantial investments in charging infrastructure.

Spain, as one of Europe's largest vehicle producers, has a robust network of suppliers specializing in automotive components. The industry is adapting rapidly to market demands, focusing on EV production and modernizing factories to reduce emissions.

Portugal, while smaller in terms of production, has demonstrated remarkable innovation capacity, particularly in electric mobility. The country has made significant progress in EV infrastructure development and actively promotes renewable energy use in automotive manufacturing.

Shared Challenges and Opportunities for SUDOE region Countries

Despite their unique strengths, these three countries face shared challenges, including the need to modernize infrastructure and upskill the workforce for emerging technologies. According to the region's slower EV infrastructure growth, solutions like mobile charging units and fast-charging corridors could offer practical insights. However, they also possess competitive advantages that position them to lead the transition toward a more sustainable and innovative automotive sector.

A systemic and strategic approach to optimizing the automotive innovation ecosystem in these markets will be essential. By mapping and evaluating value chains, identifying critical innovation areas, and adopting advanced technologies such as blockchain for component traceability, these clusters can tackle future challenges while fostering balanced regional development.

Through targeted investments, regional synergies, and a commitment to sustainability, France, Spain, and Portugal have the potential to set a benchmark for a competitive, inclusive, and future-ready European automotive industry.

Sustainability in Rural Areas and Its Implications for the Automotive Sector

Rural Sustainability as a Pillar of Balanced Automotive Development

Sustainability in rural areas is critical for achieving balanced growth in the automotive sector. These regions face challenges such as limited infrastructure and restricted access to advanced technologies but also present significant opportunities for local innovation:

Developing Sustainable Mobility Infrastructure: Establishing charging points in rural areas is essential to support electric mobility and integrate these regions into the energy transition. In Portugal, the number of rural charging stations has grown by 20% in the last two years. Meanwhile, Spain is investing in charging corridors that connect urban and rural areas, providing rural residents with access to critical infrastructure.

Local Innovation and Economic Revitalization: Creating green jobs and fostering new business opportunities related to sustainable technologies is transforming rural economies. In France, electric mobility and renewable energy initiatives have revitalized rural areas, leading to a 15% increase in green employment. The integration of renewable energy with electric mobility, such as combining solar panels with vehicle chargers, is helping to reduce operational costs while promoting more inclusive economic development.

Impacts on Value Chains: Including local suppliers in value chains reduces logistical costs and carbon footprints while strengthening local economies. Spain is leading efforts to incorporate rural SMEs into supply chains, promoting a circular economy through automotive part reuse. In Portugal, supportive policies are driving the digitalization of rural value chains, facilitating the integration of these regions into the green economy of the automotive sector.

Enhancing Regional Supply Chains Through Material Innovation - Reducing Europe's dependency on critical materials for EV batteries requires a dual approach: diversifying material sources and fostering regional innovation. Sodium-ion batteries, for instance, present a promising alternative to lithium-ion technology, utilizing more abundant and locally sourced materials. Investing in R&D for such innovations can mitigate supply risks while creating opportunities for local industries to become pivotal players in the green mobility transition. By prioritizing local sourcing and processing of alternative materials, countries like Portugal, Spain, and France can strengthen their regional supply chains, lowering transportation costs and minimizing environmental impacts. Additionally, cross-border collaborations in material science can accelerate breakthroughs, reinforcing Europe's leadership in sustainable battery technologies.

Circular economy and advanced battery recycling - The circular economy is fundamental to ensuring the sustainability of the automotive sector, particularly in regions where resources are limited. Advanced battery recycling technologies are emerging as critical enablers of this approach, allowing valuable materials such as lithium, cobalt, and nickel to be recovered and reused in new battery production. These technologies not only reduce reliance on virgin materials but also create opportunities for local economic development, especially in rural areas.

Rural mobility and the future of EV Adoption - Rural areas will continue to rely heavily on private vehicles due to limited public transportation options and greater distances between key destinations. Integrating this insight into policymaking is crucial for promoting the adoption of electric vehicles (EVs) and enhancing charging infrastructure in less developed regions. Tailored solutions, such as mobile charging units and fast-charging stations, could address infrastructure gaps and support EV transition in these areas. Furthermore, shared mobility services, like robo-buses, offer innovative potential to address rural accessibility challenges, providing efficient, cost-effective alternatives to private car use and enhancing overall mobility in underserved regions.

Bridging Urban-Centric Innovation and Rural Potential

While much of the innovation in the automotive sector has focused on urban areas, rural regions must not be overlooked. These areas face unique challenges in the energy transition and technology adoption, such as a lack of charging infrastructure for electric vehicles and lower population density, which complicates the implementation of sustainable mobility solutions.

However, rural areas also present significant opportunities for the development of innovative solutions. Renewable energy sources like solar and wind can be particularly effective in these regions, contributing to the decarbonization of the automotive sector and fostering local economic growth. Additionally, the creation of green jobs and the development of sustainable infrastructure can help revitalize these areas, reduce regional disparities, and promote an inclusive energy transition.

This study aims to explore these dynamics, providing a detailed analysis of the challenges and opportunities in rural areas across France, Spain, and Portugal. By gaining a deeper understanding of the specific needs of these regions, we can develop strategic recommendations that not only advance sustainability in the automotive sector but also contribute to balanced and inclusive development across Europe.

Circularity in the Aeronautic Sector

Eco-design in the Aeronautic Sector

Eco-design in aeronautics is an approach that aims to integrate environmental criteria (including carbon) right from the design phase of aeronautical products (aircraft, engines, sub-systems, etc.). Its aim is to reduce environmental impacts at every stage of the product life cycle, from the selection of materials through production, use and recycling, to the end-of-life of equipment.

Responsible and involved actors

Responsible actors : R&D teams, engineers, designers

Involved actors : aircraft manufacturers and subcontractors

The challenges of eco-design for aeronautical equipment

The subject of eco-design has been emerging in the aeronautics industry for several years now and is of growing interest to a growing number of players, particularly in France.

Some major players, responsible for the design of their equipment, are already committed to this approach and are seeking to improve the design of their products. Their aim is to extend the approach to all their products, and gradually involve their suppliers.

However, implementing an integrated eco-design approach across the value chain (i.e. involving different players) remains complex. This is reflected in the specifications sent to suppliers. Life-cycle assessment (LCAs) provide a snapshot of current impacts, but do not commit to any change.

Today, the main challenge for the aerospace industry is to reduce its carbon footprint. Many eco-design initiatives focus on this indicator, but it is essential not to neglect other environmental issues in the process.

Decarbonizing and improving propulsion

One of the main challenges facing the aeronautical industry today is to reduce greenhouse gas (GHG) emissions, a key factor in the fight against climate change. Aircraft propulsion, traditionally dependent on fossil fuels, is a major source of greenhouse gas emissions. The challenge is therefore to find solutions to make engines cleaner and more efficient. The main avenues include:

SAF (Sustainable Aviation Fuel):

Aviation fuels that produce fewer GHGs than conventional fuels. They can be derived from renewable biological sources (biofuels) or synthetically manufactured from captured CO_2 and green hydrogen (e-fuels). Some SAFs are already used in aircraft, although usually in blends with conventional fuels.

Electrification and hydrogen (H2):

The integration of electric or hydrogen propulsion systems to partially or totally replace combustion engines could considerably reduce carbon footprints. The industry considers that these technologies will be mature by 2035.

Open Rotor technology: Improves aircraft propulsion efficiency by significantly reducing fuel consumption through the use of optimized shrouded propellers, thus lowering CO_2 emissions per passenger-kilometer (fuel consumption reduction of up to 20%).

Lighter equipment

Aircraft weight has a direct impact on fuel consumption: the heavier the aircraft, the more fuel it consumes, which in turn increases GHG emissions. Lightweighting is therefore a major eco-design issue in the sector.

The use of new alloys (e.g. lithium aluminum alloys) and composite materials, such as glass and carbon fibers, makes it possible to reduce aircraft weight while meeting the technical requirements of the industry. These materials are used for components such as rotor blades, vanes and fuselage and wing structures.

Improving aerodynamics

Finally, aerodynamics plays a key role in aircraft fuel efficiency. Better management of air resistance helps reduce drag - the force opposing the aircraft's forward motion - and thus save fuel. For example, boundary layer ingestion optimizes the way air around the wings and fuselage is ingested by the engines, reducing turbulence and drag, thus improving fuel efficiency. In another example, winglets, small extensions placed at the wingtips, reduce the vortices generated in flight, thus reducing induced drag and, consequently, fuel consumption.

Current and future standards and regulations

In the aerospace sector, there are no specific regulations or standards governing eco-design. The working group led by ASD (AeroSpace and Defence Industries Association of Europe) is working to establish a framework for the aerospace and defense sector, with no intention of creating a standard.

At present, the absence of satisfactory technical solutions adapted to the specific needs of the sector makes it impossible to set up standards dedicated to eco-design.

Main obstacles to eco-design deployment

Safety and certification requirements

Any change of material or process in the aeronautics industry requires rigorous testing and certification. These steps, essential to guarantee safety, can slow down the adoption of innovative ecological technologies identified through eco-design.

Development costs

Committing to an eco-design approach for all products requires a significant investment over a long period of time. This can be a deterrent for some players. Setting up an eco-design approach.

Supply chain complexity

The aeronautics value chain is complex and involves a large number of economic players. This can hinder the deployment of more global eco-design approaches: coordination between the various manufacturing stages, data sharing between principals and suppliers (at least tier 1), etc. Although some players are attempting to develop a more global approach, current efforts are mainly focused on sharing the results of life cycle analyses (LCAs), often limited to segments of the chain.

Long aircraft life

Aircraft often have a lifespan of 20 to 30 years, which slows down the transition to greener designs.

Key drivers for eco-design deployment

Growing awareness of environmental issues

Faced with this trend, the aerospace industry is seeking to preserve its image and competitiveness. Integrating eco-design approaches not only helps reduce environmental impacts, but also anticipates future developments in the industry, such as stricter regulations and increased stakeholder expectations in terms of sustainability.

Lower operating costs

A more sustainable design can, in the long term, lead to operational savings, notably through reduced fuel consumption, the use of more resistant materials or the simplification of maintenance processes.

Partnerships and Collaborative Ecosystems

Cooperation between aircraft manufacturers, materials suppliers and research players (universities, R&D centers) can facilitate the adoption of eco-design by sharing the costs of innovation and mitigating the associated risks.

Introduction of eco-design standards for the sector

The introduction of sector-specific standards would provide a common framework for the players involved and help to roll out these practices.

They have done it !

Thales

At Thales, eco-design has already been introduced in the field of mechanical engineering. The main challenge now is to extend and adapt it to the field of software.

For hardware: The main challenge is to reduce the weight of equipment, a priority particularly in aeronautics and space.

For software: The aim is to optimize server performance and reduce energy consumption.

Thales is investing significantly in eco-design, but remains partly limited by its reliance on off-the-shelf components.

Lebronze Alloys

Lebronze Alloys does not design its own products, but is actively involved in eco-design initiatives, sometimes exceeding its customers' specifications. As a site with R&D capabilities, the company focuses on :

- Material savings: Tests to reduce material consumption and develop new alloys.
- Substance substitution: Development of lead- and beryllium-free alloys as part of their commercial offering.

Life Cycle Assessment (LCA):

The company has taken steps to assess the environmental impact of its products:

- LCA calculation for a family of their products, offering the possibility of modifying parameters to get as close as possible to the customer's product, thus obtaining a more reliable LCA.
- Compliance with ISO standards, by adapting calculation parameters for different product families.
- Collaboration with other French players in an AFNOR committee to develop a standard for calculating the recycled content of metal products (not specific to the aeronautical sector).

Sustainable and local sourcing in aeronautics

Sustainable and local sourcing can reduce the environmental footprint of materials and components used in aerospace, while supporting regional economies. It can also contribute to greater supply chain resilience. This approach favors eco-responsible and renewable materials, and encourages stakeholders to work within local or regional ecosystems.

The subject covers both aircraft parts (composites, electronic equipment, etc.) and non-aviation parts (packaging, production equipment, etc.).

Responsible and involved actors

Responsible actors : purchasing and supply chain managers, strategic management of companies that design and produce aircraft parts, at the various stages of assembly.

Involved actors: suppliers and subcontractors, central purchasing agents, end customers (airlines)

The challenges of sustainable and local sourcing in the aeronautical sector

In a sector whose supply chains are now highly globalized, the implementation of alternative sources represents a challenge. The issue of sourcing is well identified by the players we interviewed (notably following carbon assessments which highlight raw material manufacturing as a major contributor), but little room for maneuver is currently identified.

What's more, some of the players do not have control over the suppliers they buy from (decisions being taken centrally, or by the principals), which limits the associated room for maneuver.

However, the potential for deployment in the aeronautical sector remains significant, following the example of the automotive sector (with territorial hubs bringing together suppliers and customers). However, the technical constraints associated with aeronautics are greater, and materials/components must be qualified for the sector. Certified suppliers of raw materials (especially metals) are generally international in scope.

Some players are currently looking at broader issues, such as non-avionizable materials, or standards for the incorporation of recycled materials.

The deployment of more sustainable and local sourcing in the aeronautical sector reflects a variety of issues:

Reducing carbon footprint

Aviation, a carbon-intensive sector, relies on a global supply chain that contributes significantly to its environmental footprint. Reducing this footprint means limiting transport distances in procurement, selecting suppliers committed to less polluting production processes (in line with eco-design and the introduction of innovative processes), and integrating renewable or recycled materials that meet the sector's demanding standards.

Long-term cost optimization

Although sustainable materials may entail higher initial costs, they offer long-term economic benefits. In the case of materials considered to be at risk, the use of local or circular solutions can reduce dependence on international market fluctuations, while mitigating the costs associated with international transport and supply chain disruptions.

Traceability and transparency of materials

In the aerospace industry, material traceability is essential to guarantee aircraft safety, regulatory compliance and operational reliability. Every component and material used must be identified and documented to ensure that it meets the strict performance and quality standards demanded by aeronautical certifications.

Supply chains are gradually evolving towards the integration of environmental and ethical criteria, anticipating future regulatory pressures and the growing expectations of end customers.

In a complex value chain like the aeronautics industry, involving numerous players and manufacturing and assembly stages, interactions with tier-N suppliers further down the chain can prove complex. This poses a major challenge in terms of information traceability, particularly concerning the origin of materials, manufacturing processes and environmental commitments.

Different challenges for different materials

The supply of aerospace-grade metals remains difficult in France and Europe, with extraction concentrated outside Europe and manufacturing limited to a few key players. For example, most European titanium comes from Russia, although alternatives such as Japan are developing. More locally, the use of recycled titanium (Ecotitanium) could contribute to more local sourcing.

Textiles and composites, on the other hand, can be produced locally, but only large manufacturers have the capacity to finance the necessary certifications.

Finally, non-aircraft parts offer greater flexibility, with alternative supplies already being explored.

Supply chain resilience

The health crisis of 2020 demonstrated just how fragile global supply chains can be (as in the case of semi-conductors). These issues are starting to be taken into account by players in their sourcing choices and are an opportunity to integrate sustainability and territoriality criteria into sourcing strategies

Current and future standards and regulations

There are no industry standards specific to procurement in the aerospace sector, but they can influence the way in which supply chains need to be managed.

In addition, environmental standards and regulations play a role in procurement, for example REACH - with possible exemptions for the sector, for example if there is no alternative.

European regulations such as the Due Diligence Directive, the CSRD (Corporate Sustainability Reporting Directive) and the CS3D (Corporate Sustainability Due Diligence Directive) impose increasing requirements in terms of sustainability and transparency throughout the value chain. These regulatory frameworks are forcing companies, starting with the largest (in the case of the aeronautics sector, mainly the principals), to ensure that they have control over their supplies and the associated ESG issues.

Main obstacles to more sustainable sourcing

Lack of flexibility on supply options

Some players in the aeronautics production chain have no room for maneuver when it comes to the specifications of purchased components. These decisions are often taken by the principals, who define technical specifications and supplier selection criteria. This organization limits the ability of subcontractors and suppliers to integrate and propose more sustainable practices in their activities, due to the lack of dialogue between the different players in the value chain.

Limited local availability of materials needed for aeronautics

One of the main obstacles to sustainable, local sourcing is the limited availability of certified aerospace materials on a regional, national or even European scale. This is particularly true of the majority of metals used in aerospace alloys, which are mined in third countries. What's more, since aeronautical supply chains are highly globalized, it can be difficult to find local suppliers capable of producing on an industrial scale.

Constraints related to industry standards and certifications

If more sustainable or local alternatives are identified, they must nevertheless meet the sector's safety and performance standards. Implementation times in the industrial chain are long: before a material or component can be used in an aircraft, it has to pass stringent tests and certifications.

Economic cost for small suppliers

In the aerospace industry, the high cost of compliance with industry requirements (certifications, traceability, quality standards) is a major obstacle for new entrants, especially smaller suppliers. The latter often have limited resources to comply with industry requirements.

Higher production costs

Sustainable and local materials are often more expensive than traditional alternatives (limited production volumes, innovative and more expensive manufacturing technologies, etc.). The sector is highly competitive, and this can hold back companies whose main purchasing criteria is competitive cost.

Key drivers for more sustainable sourcing

Development of standards for incorporating recycled materials

Such a standard would structure and promote the use of recycled materials (particularly metal) in production. It would encourage players in the supply chain to invest in recycling technologies and integrate more recycled materials, thus facilitating the transition to more sustainable supplies.

Image and environmental pressure

By integrating local, circular or low-carbon sourcing, industry players can reinforce their image as responsible companies committed to the ecological transition.

Relocation and short circuits

By promoting short supply chains and local sourcing, aerospace companies can help strengthen local and regional economies, and boost local industrial ecosystems. This level also contributes to improving the resilience of supply chains. This dynamic is all the more attractive in a post-COVID context, where disruptions to globalized chains have highlighted the need for a return to shorter, more reliable circuits. While certain critical components certified for the aeronautical industry remain difficult to relocate, this strategy is particularly applicable to non-avionizable elements such as packaging, tooling, certain consumables and so on.

Public policy support

Public policies, such as the France Relance plan, play a key role in encouraging more sustainable industrial practices or the industrial relocation of certain supply chains. Through tax incentives, innovation subsidies and public-private partnerships, they can help offset initial extra costs and facilitate the adoption of local, more sustainable sourcing.

Use of environmental labels and certifications

The adoption of labels or certifications guaranteeing suppliers' good environmental practices can encourage sustainable sourcing. These labels, such as those attesting to the use of recycled materials, the reduction of carbon emissions or the sustainable management of resources, offer a guarantee of compliance with environmental standards. They not only help to structure responsible sourcing initiatives, but also simplify the choice of partners by ensuring greater transparency about their practices.

Inclusion of environmental criteria in tenders and contracts

These criteria could relate to requirements for action or results (commitment to a GHG emissions reduction program, completion of LCAs, etc.). These criteria would need to be defined with the entire sector, in order to create a dynamic of shared responsibility throughout the supply chain.

Processes to reduce waste and impact

Innovative processes aimed at reducing waste and environmental impact in the aerospace industry focus on optimizing existing processes to minimize waste (e.g., reusing off-cuts from metal plates, composites) and improve energy efficiency, and using new technologies and practices throughout the production and assembly chain.

They are important to take into account right from the design phase - see the eco-design sheet, making sure that optimizing these processes does not come at the expense of impacts associated with other stages (maintenance, end-of-life).

Responsible and involved actors

Responsible actors: designers, players in the aircraft manufacturing chain, research institutes

Involved actors: other players in the aircraft manufacturing chain, maintenance, recycling and waste reclamation.

The challenges of processes to reduce waste and impact in the aeronautics sector

Reducing the costs associated with manufacturing processes is a priority for many players in the aerospace industry, particularly in the context of rising energy and raw material prices. This includes steps to reduce manufacturing waste (e.g. during cutting stages) and cut energy consumption in industrial processes.

In the longer term, the sector is exploring innovative processes such as additive manufacturing, which can limit material waste and optimize the use of resources. Already in place, these efforts are part of a global drive to reduce the energy footprint of manufacturing and maintenance processes, while guaranteeing equipment performance.

An environmental issue

The environmental issue is at the heart of the aeronautical sector's concerns, not only for reasons of image, but also in response to growing pressure to reduce its ecological footprint. While the focus is often on the aircraft use phase, the upstream part of the value chain - including production, assembly and associated logistics - also represents a key lever for limiting environmental impacts.

Among innovative processes, 3D printing for certain metal parts is attracting a great deal of interest, with many players seeking to position themselves in this market. This process has the advantage of reducing material loss rates, by optimizing their use. However, it is not suited to all situations: its relevance depends on the specific properties of the metals used, and there are still technological challenges, such as the non-recyclability of certain metal powders, whose quality can be altered during the manufacturing process.

Numerous innovations are underway to meet these challenges, with research and development work exploring viable solutions that can be economically integrated into existing production chains. These efforts are essential if the sector is to remain competitive, while complying with increasingly stringent environmental regulations and improving overall aircraft performance.

Safety and regulatory compliance

Innovations in the aeronautics industry have to comply with very strict safety standards, already discussed in previous sections. Each new process or material is rigorously tested and certified before being integrated into the production chain, to ensure that it does not affect aircraft safety once in use.

Current and future standards and regulations

To date, no specific or particularly restrictive regulations have been identified concerning environmental approaches specific to the aeronautical sector, apart from the general frameworks applicable to all industrial sectors.

Main obstacles to the deployment of low-impact manufacturing processes

High investment costs

Innovative processes require substantial initial investment. The cost of infrastructure development, research and the certifications required make the adoption of these technologies costly, especially for smaller companies in the supply chain. Aerospace players must balance these costs against the expected long-term economic gains, which can act as a brake on innovation.

Certification and regulatory issues

Aeronautics is a highly regulated sector, where every innovation must pass through a long and complex certification process to guarantee aircraft safety. New materials and processes have to meet stringent requirements in terms of strength, safety and durability. This considerably lengthens the time it takes to bring these technologies to market, creating a major barrier to their rapid adoption.

What's more, any process change, like the introduction of new materials, requires full re-certification to ensure compatibility with regulatory requirements. This process can be particularly costly and time-consuming.

Compatibility with existing specifications and materials

Some processes are strictly defined in specifications, which limit the scope for players to explore or adopt alternatives. For example, innovations such as the use of recycled materials or additive manufacturing processes must not only be compatible with existing systems, but also meet the specifications imposed by clients.

What's more, the reuse of certain materials can pose problems of structural integrity. It is imperative that these recycled or innovative materials meet the same quality standards as traditional materials, a requirement which often hinders their widespread adoption.

Technical limits of new processes

Some innovative technologies remain limited due to insufficient levels of technological maturity (TRL). For example, 3D printing is constrained by the size of the parts that can be produced and the types of materials that can be processed

Key drivers for deploying less impactful manufacturing processes

Anticipating regulations

In a context of increasingly stringent environmental regulations, it is crucial to anticipate restrictions on the use of hazardous substances.

Innovation and economic competitiveness

The development and implementation of less impactful manufacturing processes not only enables us to meet growing expectations in terms of sustainability, but also to position ourselves as a key player in a sector increasingly focused on the ecological transition. Lower energy bills

With energy costs on the rise, manufacturers are looking to optimize the energy consumption of their manufacturing processes.

They have done it!

FIGEAC AÉRO

FIGEAC AÉRO implements initiatives to optimize its production processes and reduce its environmental impact. The company uses advanced software to optimize the layout of parts cut from plates and forgings, thus minimizing material waste. This approach reduces waste while improving process efficiency.

Recovering production waste in the aeronautics industry

The aeronautics production chain generates waste during the manufacturing, machining and assembly stages. It should be noted that this waste is treated separately from end-of-life waste (aircraft, replaced parts), which is dealt with in a dedicated section.

Players in the industry are required to ensure that the waste they generate is properly managed. Europe provides a European framework for waste management, and more specifically a hierarchy of treatment methods. Waste prevention and reuse are to be favored, followed by recycling (for a similar or other application) and energy recovery. **Waste prevention, reuse and recycling are the pillars of a circular economy.**

The materials and types of waste generated by the sector are diverse, and require a variety of treatment methods.

Responsible and involved actors

Responsible actors : players in the aircraft manufacturing chain

Involved actors : recycling companies, other players in the aircraft manufacturing chain

The challenges of recycling production waste in the aeronautical sector

Industrial players in the sector are required by law to manage the waste they generate, both production waste (machining offcuts, swarf, etc.) and waste associated with their activities (used packaging, consumables, etc.). The majority of players today seem to use external service providers, and are unaware of the precise fate of their waste. Some of the players interviewed are currently working to gain a better understanding of current practices (nature and volume of waste, fate of waste). The long-term aim is to identify more relevant, value-added recovery routes, in particular with a view to moving towards closed-loop recycling (reuse of materials for aeronautical applications).

The challenges vary from one material to another:

In the case of metals, certain initiatives are already in place, particularly for titanium alloys, due to the supply issues associated with this metal, and the use of alloys for very specific equipment (such as landing gear). Recovering waste for aeronautical use requires recycling waste by type of alloy, and therefore the logistical organization to enable this separation, as soon as the waste is generated. A number of players working on metal equipment are not currently in a position to ensure this sorting (economic cost, logistics). This represents scope for progress over the coming years.

There are a large number of initiatives aimed at recycling composites waste. These recycled materials would be destined for sectors other than aeronautics, which requires (at least for external structural parts, such as the fuselage) high mechanical strength properties (not compatible with short fibers, which are obtained by recycling scrap).

The assembly of electronic components can generate waste, which today seems to be directed towards the EPR channel for electrical and electronic equipment (EEE).

The interviews did not allow us to talk to any players generating plastic, polymer or textile production waste.

Moving from a "waste" to a "resource potential" vision

Because of the quality requirements imposed on raw materials, waste from the aeronautics industry can represent high value-added resources. This is particularly true of alloys (aluminum, titanium, nickel), which are generally specific to the sector. Setting up recycling lines for the aerospace industry helps to preserve the added value of these metals and alloys, and makes the sector more resilient in the face of the supply challenges it may face.

Knowledge of waste deposits and traceability

To ensure optimum management, it is essential to know the nature of the waste stream and to trace the waste flows generated at the various stages of the value chain.

Reducing the environmental footprint

Recycling reduces the use of virgin materials and the impact of their extraction. It also reduces the need for landfill and incineration.

However, certain processes can be highly energy-intensive, or require the use of solvents, etc. It is therefore crucial to assess the real environmental benefits of recycling. It is therefore crucial to assess the real environmental benefits of recycling and to continue developing more efficient technologies adapted to the characteristics of the waste.

In some cases, obtaining high value-added recycled materials (e.g. for use in the aeronautics industry) may prove irrelevant, especially when the processes involve complex waste.

Setting up territorial dynamics

The recovery of production waste can benefit from regional dynamics, enabling collaborative approaches to be structured on a local scale. Some players are integrating this perspective by working with regional partners to pool resources and optimize waste management. This approach facilitates collection, sorting and recycling by pooling the volumes needed to make the processes economically viable.

Current and future standards and regulations

There are no regulations or standards governing the management of production waste in the aeronautical industry.

However, national and European regulations have been evolving in this direction for several years: previously focused on the management of pollution generated by waste, they are now oriented towards the use of the potential resources represented by waste (including production waste, which is of better quality than end-of-life waste). In the case of metals, the Critical Raw Material Act (CRM Act) passed in 2024 sets a target of 25% supply of critical metals from recycling by 2030. .

Main obstacles to better recovery of production waste

Complexity of certain materials

The materials used in aeronautics, such as carbon fiber composites, are complex and high-performance, but difficult to recycle. These composites do not separate easily, and recycling them often results in a loss of quality. Setting up efficient processes to recover these materials while preserving their properties remains a major challenge.

Complex implementation of new logistics chains

The diversity of materials and production residues makes waste management complicated. Each type of material requires not only precise sorting, but also specific treatment adapted to its properties. Moreover, sorting may be impossible if several alloys are used on the same machine, leading to contamination of the materials. Without proper sorting, waste materials cannot be recovered effectively, and the result is usually a process of "downcycling", where materials are recycled for lower-value applications, with a significant loss of their properties and added value. This requires advanced technologies that are not always available or economically viable for all types of waste, especially those with high added value such as composites or complex alloys.

High costs

As long as dedicated channels are not fully developed, the investments required to sort, process and recover materials will remain substantial. What's more, the costs of these recovered materials can be higher than those of new raw materials, which is an economic drag for the players involved.

Strict regulations and safety requirements

Safety standards in the aeronautics industry are among the most stringent in the world, and represent a major obstacle to high value-added recovery of recycled materials. Recycled materials must meet the same performance standards as new materials, which limits their integration into critical applications. Each component made from recycled materials must be certified, and these certification processes are long, costly and technically complex. This requirement hinders the possibility of transforming waste materials into high-quality products, thus reducing their potential for valorization in aeronautical production chains.

Key drivers for better recovery of production waste

Lower raw materials costs

One of the main levers is cost reduction through in-house reuse of materials. The in-house reuse of composites, alloys and other production materials enables companies to reduce their need for new raw materials, which in turn cuts supply costs. This optimization of resources is crucial to improving the competitiveness of players in the sector.

Development of new recycling technologies

Innovative technologies are being developed to process complex aeronautical materials. For example, chemical recycling and carbon fiber recovery make it possible to recycle materials which, until now, were considered non-recyclable. These innovations open up new opportunities for reusing waste that was previously difficult to process.

Massification and industrial partnerships

The massification of volumes is one of the levers for improving the recovery of production waste. To achieve this, we need to encourage collaboration between major industrial players and startups in their geographical vicinity, whether or not they belong to the aeronautical sector. For example, territorial partnerships could be established with other local companies or industrial sectors generating similar types of waste, enabling efforts to be pooled and critical volumes to be reached to make recycling channels profitable.

They have done it!

Lebronze Alloys

Lebronze Alloys adopts a proactive circular economy strategy, exploring the recovery of its customers' production offcuts for reintegration into its own processes.

FIGEAC AERO :

- Noble metals, such as titanium and aluminum, are collected and recycled, although challenges remain, particularly with regard to alloy segregation and traceability.
- Solid offcuts (plates and forgings) and swarf are recovered and recycled thanks to industrial partnerships with players such as Constellium and Airbus.
- Initiatives are underway to strengthen selective collection and improve waste recovery, in collaboration with partners such as Ecotitanium and IMET.
- With regard to titanium, several contracts have been signed for the recovery of chips, notably with Airbus and Safran.

Maintenance in the aeronautics industry

Maintenance, Repair and Overhaul (MRO) encompasses all operations aimed at ensuring the airworthiness, safety and performance of aircraft throughout their lifecycle. It is downstream of the aeronautical industry's value chain, and helps to extend the service life of aircraft and the systems and sub-systems they comprise.

These operations are carried out by specialized players.

Aircraft maintenance can also include refurbishing activities, although these are distinct from MRO activities. Refurbishing refers to restoring or improving the aesthetics and functionality of equipment or parts, without necessarily including safety-critical repairs.

Responsible and involved actors

Responsible actors : airlines, approved maintenance organizations.

Involved actors : aircraft manufacturers, parts and equipment suppliers, regulatory authorities

The challenges of maintaining aeronautical equipment

Airlines such as Air France-KLM are continually investing in advanced infrastructure and technology to optimize their maintenance operations. However, challenges remain, particularly in terms of human resources management and spare parts supply, exacerbated by recent events such as the Covid-19 pandemic.

The high economic value of the equipment contained in aircraft encourages maintenance operations, and contributes to extending their lifespan. For example, an aircraft engine can have a lifespan of 20 to 30 years: when a component is damaged, it is replaced, thus extending the engine's service life.

In addition, certain players are interested in refurbishing activities, for example to refurbish aircraft interiors that an airline would like to renew. These activities seem to be emerging, and could evolve in the future. In particular, they could eventually lead to new business models such as the economy of functionality (e.g., interior leasing).

Guaranteeing flight safety

Safety is the prime concern of aeronautical maintenance. Maintenance operations aim to identify, correct and prevent faults or malfunctions that could compromise flight safety. Several types of checks are carried out: based on flight hours, based on duration, and based on equipment condition (conditional maintenance). Each aircraft must meet strict airworthiness criteria, imposed by national and international regulators, making maintenance essential to avoid incidents or accidents.

Responding to increasing regulation

Maintenance accounts for a significant proportion of airline operating costs, estimated at between 10 and 15% of the total cost per flight hour. As a result, players are seeking to optimize these costs without compromising the quality of maintenance operations. In this context, the maintenance market is particularly competitive, with strong pressure to offer services that are both efficient and economically viable.

Digitization and predictive maintenance, which make it possible to anticipate the need for intervention before a malfunction occurs, contribute to this optimization. Data analysis and intelligent sensors help rationalize maintenance costs while improving equipment availability. However, these technological advances require significant investment, intensifying competition between players to position themselves as leaders in this field.

Territorial issues

Aeronautical maintenance faces territorial challenges, due to the very nature of its operations. Maintenance activities are often carried out where aircraft are parked, making it difficult to adopt a localized or centralized approach. This geographical dispersion complicates the organization of resources, particularly in terms of personnel and spare parts supplies. These logistical constraints can limit the possibility of developing local value chains for maintenance activities, as they have to adapt to the immediate and specific needs of intervention sites.

Refurbishing: limited feasibility

Refurbishing is not applicable to all parts used in the aeronautical industry. It's easier to refurbish parts that don't have to meet stringent airworthiness requirements, such as interior fittings (seats, panels, carpets). On the other hand, for parts subject to stringent technical and safety constraints, their reconditioning requires complex and costly processes, in line with the strict regulations already mentioned. This limits the possibility of generalizing refurbishing to all aircraft components.

Current and future standards and regulations

Aircraft maintenance is governed by strict standards set by bodies such as the European Aviation Safety Agency (EASA) and the Federal Aviation Administration (FAA) in the USA. For example, EASA Part 145 (for maintenance workshops) and Part M (for airworthiness management) define the requirements for maintenance organizations and aircraft airworthiness management. These standards cover aspects such as personnel certification, maintenance procedures, quality management and documentation requirements. Regulatory changes are regularly introduced to keep pace with technological advances and new safety requirements.

Main obstacles to more maintenance

There are no major obstacles specific to maintenance activities, which are already well established and widely deployed in the aeronautical sector. The challenges lie more in the development of new economic approaches, such as the functionality economy, refurbishing, or innovative equipment management models.

Implementing these new models is complex, particularly at territorial level, as highlighted by the example of TARMAC's practices. This territorial dimension represents a major challenge in terms of organization and coordination of local players.

Key levers

Adoption of predictive maintenance

Predictive maintenance, made possible by data analysis and intelligent sensors, is a major lever for optimizing maintenance. By analyzing the condition of aircraft components in real time, predictive maintenance makes it possible to plan interventions before breakdowns occur. This not only reduces aircraft downtime, but also cuts costs by avoiding more costly unscheduled repairs. Major airlines and maintenance centers are increasingly investing in predictive maintenance systems to increase the efficiency and safety of operations.

Digitization and process automation

The digitization of maintenance processes, through digital operations management systems (Maintenance Repair and Overhaul - MRO), improves the traceability and efficiency of interventions. Digital platforms facilitate spare parts inventory management, maintenance tracking and real-time access to aircraft data. In addition, drones for visual inspections and repair-assist robots help to reduce operating time and costs, while guaranteeing a high level of precision and safety.

Industrial partnerships and collaboration with startups

Collaborations between major companies, technology startups and research organizations are helping to develop new solutions for aeronautical maintenance. These partnerships give industry players access to innovative technologies such as artificial intelligence and augmented reality for training and repair. In addition, public support programs such as grants and funding for innovation encourage maintenance companies to explore new technological solutions and invest in advanced equipment.

They have done it !

ISP System

ISP System takes an innovative and sustainable approach, offering an on-demand spare parts production service. Unlike traditional mass-production models, this system enables parts to be manufactured only when needed, thus reducing overproduction and unnecessary stocks. At the same time, this approach helps to prolong the life of equipment, limiting premature replacement.

End-of-life aircraft

Aircraft end-of-life management encompasses the processes of decommissioning, dismantling, recycling and recovery of aircraft equipment, components and materials at the end of their life cycle.

Some parts are recovered for reuse on other aircraft, due to their economic value.

The recycling of other components (electronic equipment, metal structure, etc.) contributes, as with production waste, to a circular economy.

Responsible and involved actors

Responsible actors : brokers, companies specializing in aircraft dismantling

Involved actors : airlines, aircraft manufacturers, recycling companies

The challenges of end-of-life aircraft

Aircraft end-of-life remains a complex and insufficiently regulated issue worldwide. At present, there are no international standards strictly governing the dismantling and recovery of end-of-life aircraft. Owners often sell their aircraft to brokers, who concentrate on recovering reusable parts, leaving the fate of the remaining structures uncertain, feeding the image of “aircraft graveyards”.

In Europe, a number of noteworthy initiatives have been launched to improve aircraft recycling. For example, Airbus has launched the PAMELA project (Process for Advanced Management of End-of-Life Aircraft), demonstrating that it is possible to recycle or reuse up to 85% of an aircraft's weight.

In addition, specialist companies such as TARMAC Aerosave (owned by Airbus, Safran Aircraft Engines and Suez) have developed recycling processes that comply with strict environmental regulations, enabling parts to be recovered and reconditioned for the aftermarket. This demonstrates the growing involvement of prime contractors in this area.

Economic recovery of recycled parts

The aircraft is first drained of its fluids and prepared for dismantling. During the process, between 1,000 and 1,500 parts are removed from the aircraft's structure, including landing gear, electronics, and brakes. The engine alone contains approximately 3,000 components. These parts are sorted, inventoried, packaged, and labeled. Depending on their condition, they can be refurbished, recertified, and sent to customers on demand or sold on the used parts market.

Only about 10% of the aircraft's total weight is recovered and resold. However, this not only offsets the costs of the end-of-life operation but also reduces the demand for new parts, promoting a circular approach within the industry. However, the use of reclaimed parts is not systematically authorized. Decisions regarding their reintegration depend on the regulations of aviation authorities and the internal policies of airlines and manufacturers. So, while significant progress has been made in aircraft recycling, further efforts are needed to harmonize practices and regulations worldwide.

Different challenges for different materials

Aluminium accounts for around 80% of the weight of a conventional aircraft. It is relatively easy to recycle, thanks to well-established processes. Once recovered, it is melted down and reused to manufacture other industrial products. Today, the main challenge is to encourage recycling for aviation, which means being able to distinguish between alloys when sorting.

Titanium is one of these alloys. They require specific treatments to preserve their quality.

Electrical cables, generally made of copper, are dismantled and reused as raw materials in foundries.

Composite materials pose a major challenge, already discussed in the section on recycling production waste. In addition, the high mechanical stresses to which these materials have been subjected during aircraft operation degrade the properties of the fibers, as the materials are difficult to separate due to their bonded structure. At present, carbon fibers can be partially recycled by thermochemical or mechanical processes, but their quality is often inferior to that of virgin fibers. Recycled fibers are often used in less demanding applications, such as automotive or consumer products, rather than in aeronautics.

Foams and textiles (seat upholstery materials) are generally incinerated for energy recovery or landfilled.

It should be noted that these recovery practices are not yet widespread.

Compliance with regional environmental standards and regulations

In Europe, waste treatment requirements also apply to end-of-life aircraft, imposing obligations on the dismantling, depollution and safe storage of hazardous components, as well as on end-of-life waste management.

Current and future standards and regulations

At present, there are no specific regulations worldwide concerning the management of end-of-life aircraft. However, the industry must guarantee the safe management of spare parts.

Main obstacles to better recycling of end-of-life aircraft

Complex materials and technologies

Modern aircraft incorporate advanced materials such as carbon-fiber composites and complex metal alloys. Although effective for in-flight performance, these materials are difficult to disassemble and recycle without losing their mechanical properties.

High cost of infrastructure and dismantling technologies

The aircraft dismantling and recycling process requires investment in specialized infrastructure and state-of-the-art equipment to handle complex materials and hazardous components. Dismantling companies must invest in facilities capable of handling toxic fluids and composite materials, while complying with safety and environmental regulations. These high costs are holding back some players' commitment to large-scale recycling, especially for older aircraft which are not as easily recyclable as newer models.

Key drivers for better recovery of end-of-life aircraft

Innovation in recycling technologies

Advances in recycling technologies are opening up new opportunities for processing complex end-of-life aircraft materials. Innovations such as chemical recycling for composites, depolymerization processes and advanced separation methods make it possible to recover carbon fibers and other valuable materials without compromising their properties. These technologies help to improve aircraft recyclability rates and reduce the costs associated with processing advanced materials.

Ecodesign for end-of-life and recycling of future aircraft

Integrating eco-design principles right from the design phase simplifies dismantling and recycling at the end of life. By using more easily recyclable materials and developing modular systems, aircraft manufacturers can reduce the complexity of dismantling. This also facilitates the sorting and processing of materials, making end-of-life management more cost-effective. This proactive approach helps to prepare the industry for the future challenges of the circular economy.

Developing markets for recycled materials

Expanding commercial outlets for recycled materials from aircraft can increase the profitability of end-of-life operations. Recovered parts, such as aluminum alloys or carbon fibers, can be used in sectors such as automotive, construction or even fashion for decorative pieces. By diversifying the possible uses of recycled materials, dismantling companies can maximize the value of recovered materials, thus stimulating the development of the circular economy.

Establishing harmonized global regulations

Unlike land vehicles, there are no specific international regulations for aircraft end-of-life. Each country can therefore apply its own rules, creating uneven practices and complicating the establishment of an efficient recycling chain on a global scale. Harmonized standards would encourage investment in international recycling solutions, and companies would have a general framework to complement local regulations. It should be noted, however, that imposing overly stringent environmental constraints in Europe could lead to unfair competition, as end-of-life aircraft could be sent to countries with less stringent requirements.

Setting up industrial partnerships

Please refer to the "Massification and Industrial Partnerships" lever in the "Recovering production waste" section.

They have done it !

TARMAC

Recycling end-of-life aircraft: TARMAC manages to recycle 92% of materials from end-of-life aircraft at its facilities. The remaining 8%, mainly composed of plastics and composites, represents a major challenge.

Limits to circularity in the aeronautics sector: A tiny proportion of recycled materials is returned to the aeronautics sector, which is a key challenge for increasing circularity.

Anticipating new challenges: As aircraft to be dismantled become increasingly composed of carbon fibers, TARMAC is actively working on solutions to process and recycle these materials.

Innovative initiatives: TARMAC has launched a Call for Expressions of Interest (AMI) in collaboration with **Aerospace Valley** and **Airbus**, aimed at encouraging innovative projects linked to the recovery of end-of-life aircraft. The aim is to improve the recovery rate of materials or propose more circular solutions (around ten projects have been selected, covering themes such as metals, plastics, composites and textiles).

Future Perspectives and Emerging Trends

Automotive and Aeronautic Sectors

Emerging Innovations and Trends in the Aeronautic Sector

Extraction of materials

Raw materials are the foundation of all industrial value chains. The extraction and refining of raw materials, particularly ores and metals, is dominated by certain countries outside Europe and their supply is synonymous with dependence, which represents a risk of inflation and disruption for high-tech sectors such as aeronautics. Mining and refining are also synonymous with severe environmental impacts with the discharge of heavy metals, water contamination, excessive water and energy consumption.

The European Union, through the Critical Raw Materials Act, has identified 34 critical metals and 17 rare earths for which there are no substitutes, and the risks of supply disruption are high, which can generate serious economic and industrial impacts. The criticality of raw materials is also specific to each country and sector, and it is therefore important for the aeronautics sector to know its strategic materials and its level of dependence on its entire value chain to control their supply and carbon footprint.

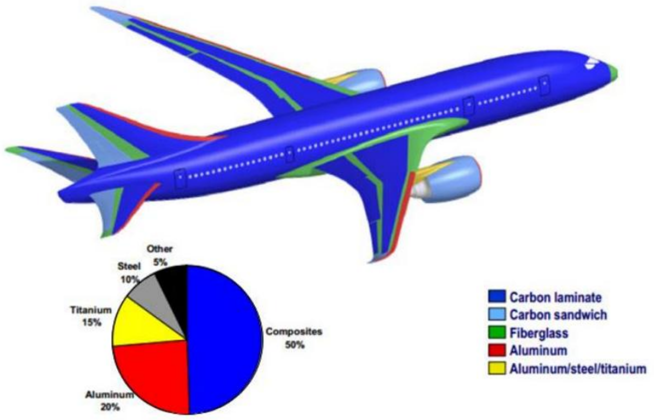


Figure 2 - *Mapping of the main aircraft materials – source Aimere 2014 Project*

Safety and traceability regulations allow the aviation industry to have a good understanding of its dependence on aircraft parts, including aluminium, titanium, nickel, iron, tungsten and cobalt alloys and carbon fibres composite materials.

An area for improvement was raised during discussions with the aeronautical supply chain in terms of knowledge and traceability of the products used during surface treatments on aircraft parts to increase their performance. These treatments modify the surface composition of the parts and these modifications are not always well known at the end of the chain as well as the origin of the products used to make them.

There is currently a lot of talk about the dependence of aeronautics on the subject of aircraft materials, but there is a grey area on materials used to produce aircraft parts; such as the materials constituting the machines and production systems essential to the aviation sector. It would be interesting for the aeronautics sector to be able to map the flows of materials, and in particular metals such as steel, which represent the majority of the production and maintenance system of aircraft, going back to the extraction of materials.

This analysis would:

- Assess supply risks, according to their scarcity but also their dependence on fossil fuels (example of "low-carbon" steel),
- Identify the non-substitutable materials on which the production system depends,
- And to consider the production system to complete the calculation of the carbon footprint of the aviation sector.

The key drivers:

Knowledge of Material and Energy Exposure

- Assess the criticality of metal supplies,
- Map the material and energy flows (by type) that pass through the production system in the form of a Sankey diagram,
- List the associated risks: supply disruption, impact on profitability, legislative, technological, environmental, climatic, social, geopolitical risks, etc.
- Assess n-1 supplier risks: financial strength, reliability, supply failure risks, ESG (Environmental, Social and Governance) strategy,
- Assess supplier risks n-2 to n-6: knowledge and transparency of the value chain, response to the "extended responsibility" requirements of Large Groups.

Manage and control risks

- Strategy to diversify suppliers: producers of raw materials (miners, smelters, refiners) to secondary materials (recyclers), including suppliers of raw materials and alternative technologies,
- Identify the ecosystem of metals, of each chain (mining, refining players, recyclers), new entrants, new substitute technologies,
- Strategy of partnerships, cooperation, investments,
- Resource optimization strategy: support research and innovation in the efficient use of resources and the development of substitutes, strengthen recycling and low-tech and "Ethics by design" approaches,
- Identification of the different levers of action available to the public authorities (European Raw Materials Alliance, EU Raw Materials Diplomacy and European Critical Raw Materials Act),
- Identify and structure the emergence of bio-based, low-carbon and resilient materials sectors,

- Changing purchasing practices towards responsible and fossil-free purchasing (example of the purchasing policies implemented by Volvo 2022 through the SteelZero initiative),
- Integration of the two items "critical materials" (availability) and "fossil fuel-free materials" in the eco-design reference framework during the R&D phase of a product,
- Relocation of all stages of the production cycle that can be relocated (production of ingots and forgings).

Adapt the "Purchasing" strategy

- Rethink supplier contractualization: long-term contracts, off-take contracts, upstream equity investments, commitments to its direct suppliers and rethink the relationship,
- Develop dialogue between the Purchasing function and the other departments of the company (industrial department, inventory management, executive committee),
- Make sales and direct supply forecasts more reliable.

Anticipate the medium and long-term future with data

- Carry out forecasts prior to any strategic decision, it is necessary to enlighten the decisions of the present in the light of potential futures (sustainable, desirable, endured, unmanageable, fluctuating),
- Develop crisis plans: What are the critical thresholds (quantity, price, deadlines) in terms of supplies? At what level will the impacts on production, turnover and profitability be severe? What actions and levers should be deployed in the short term in the face of such a situation?
- Have a predictive model to detect trends in price increases and decreases based on international events.

Production

What is the level of dependence of production and assembly sites on fossil fuels in the aeronautics sector? How can a life cycle analysis of an aircraft be carried out throughout its supply chain, considering the production system? How can we continue to produce in a world limited in resources? This study aims to deepen these questions of sustainability and vulnerability of the production system and to propose short- and long-term levers for action.

Aerospace assembly lines have complex supply chains, made up of a wide range of companies, from large operators and system integrators to small and medium-sized high-tech companies that are often closely linked to other industries. Small and medium-sized enterprises, representing 80% of the companies in the aviation manufacturing chain, are a strategic part of the sector by performing many complex and innovative tasks and providing, among other things, high-tech materials processing and engineering services.

To estimate the carbon footprint of their production equipment, many aeronautical companies rely on only two pieces of data: the amount of their investments in euros and the energy used to produce or assemble a part. They very often justify this lack of analysis by the long lifespan of the production facilities, which can go beyond 30 years, which they believe would lead to a more impactful phase of use of the machine than that of its manufacture. This analysis remains fairly accurate for thermal machines burning fossil fuels (gas furnaces, cars, etc.) for which we must find substitutes quickly, but is generally not true for electrical machines (robots, machining machines, etc.) with an energy consumed during the manufacture of a machine three times greater than during its use.

Factories in the aeronautics sector must also transform themselves in order to improve their energy efficiency, while guaranteeing their competitiveness and robustness against future risks and fluctuations. Companies positioned in foundry, forging, surface treatment and painting operations are the most energy-consuming in the sector. Energy and industrial processes will have to switch to low-carbon alternatives, which are initially more expensive.

In a finite world, the challenge for the aeronautics sector is also to ensure the sustainability of supplies, particularly for primary resources with the criteria of availability and low-carbon extraction technologies.

The industry has already launched recycling initiatives, but the challenge for the aerospace industry now is to sort and recycle its materials for reuse in aeronautics and to make it economically viable. The sector of sorting and recycling aeronautical waste to be reused again in aeronautics is far from being a structured and sustainable sector. Waste is produced at each stage of the aircraft's life cycle (manufacturing scraps and swarf, scrap, test waste, maintenance waste, aircraft waste) and is a heterogeneous source and complex material or substance that must be sorted and recycled to obtain the same original properties.

Production waste is precisely located and its composition is known because the products are identified and held by the producer, which can facilitate collection, but their sorting still needs to be optimized. It is estimated that for 1kg of titanium or aluminium in flight, 10kg is needed at the extraction stage. These different ratios highlight the important deposits available but whose recycling potential is not used by the aeronautics sector for its own needs, in particular due to the lack of sorting of scraps and swarf at the end of machining within the sector and to the pollution of waste, for example by aqueous lubrication during machining. There is also the problem of the properties of recycled materials, do the properties remain the same after recycling and can they be recycled for aeronautical production?

Waste from the end of life of products is less numerous than production scraps or swarf and more difficult to collect. This waste is not located, which can complicate collection logistics and make it more expensive. Disassembly and sorting phases are necessary because this type of waste is often multi-material. In addition, for end-of-life products, it can be complicated to identify the materials (no marking). Finally, for end-of-life products, time has elapsed since the production phase, so it is necessary to plan for the long-term management of the deposits.

The issue of recycling is also important for aeronautical composites (prepreg, carbon fibre, glass fibre) whose recycling is particularly difficult, and the waste ends up mostly in landfill or incineration with energy production. This theme is very well covered today by the literature and many recycling projects have been launched, but always with the difficulties of knowing the full energy balance of such projects and recycling materials for the aeronautics sector.

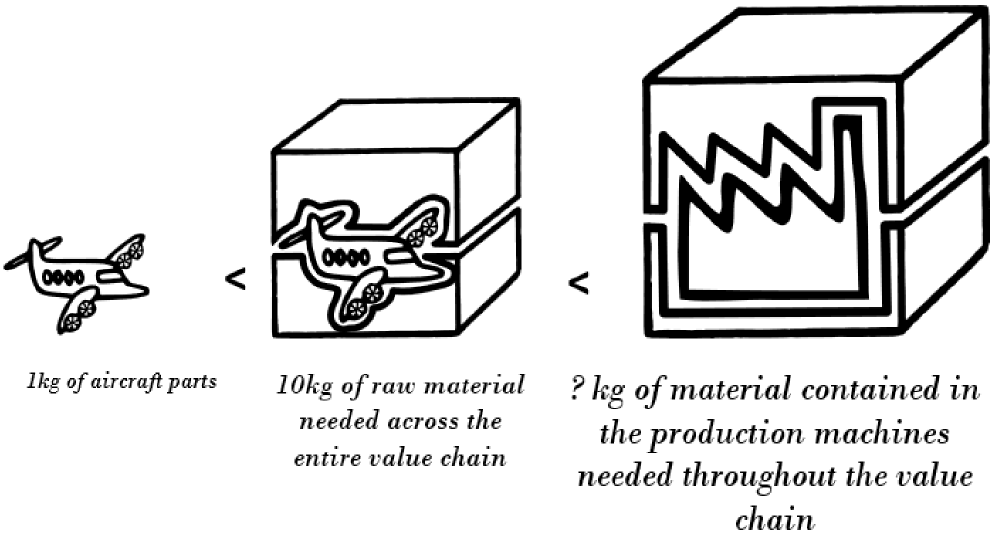


Figure 3 - *Illustration of the raw material requirements in relation to 1kg of aircraft parts. Today, the weight of material contained in production machines needed to produce 1kg of aircraft part is unknown*

The key drivers:

Knowledge of the material and energy exposure of production sites

- Mapping of material and energy flows throughout the aeronautical supply chain, including production sites, maintenance and surface treatment facilities, to determine the dependence of the aeronautical production system on fossil fuels and to know precisely its vulnerabilities. The obstacles to the achievement of this work axis are mainly found in the collection of data from suppliers, the standardization of relevant data to be collected between suppliers and the sharing of data between all actors in the sector. What forum should be implemented to overcome issues of intellectual property and confidentiality between customers and suppliers within a value chain?
- Implementation of the digital continuity (Airbus DDMS program, Boost Aerospace's AirSupply®),
- Digitalization of industrial processes through the introduction of new tools (modernization of ERP, MES).

Energy efficiency, carbon-free energy, energy/material sobriety

- Energy audits,
- Investments to increase energy efficiency,
- Substitution of fossil energy sources,
- Purchase of renewable electricity in short circuits and energy independence of local companies),

- The availability of low-carbon energy at competitive prices,
- Build and supply industrial sites according to the resources around (examples: orientation of the site according to sunshine and wind to reduce energy consumption, installation of a power plant for a company located next to a river, that produces the equivalent of what the company consumes,
- Example of paint, used by Freyssinet Aero of SOLAR PAINT, on the roofs of its production site to reduce the temperature of the production workshops (and therefore reduce the air conditioning in summer),
- Sharing infrastructures between companies (logistics, storage, means of production, transport, laboratories and common test centres), pooling of machines and tools,
- New production processes for parts that generate less scrap and swarf (forming, molding, etc.),
- Energy recovery from waste for production machines: part of the material is used as fuel as an energy source (possible for composite waste but not for inert materials),
- Investments in photovoltaic panels, complete self-consumption on certain sites, example of a company that has reduced its electricity bill by -40% while fully recharging its company's electric cars,
- Waste heat recovery.

Water efficiency

- Reducing water consumption in industry and improving the quality of the water discharged (sobriety, efficiency, reuse of non-conventional water, innovation and technology transfer in the water sector),
- Build and supply industrial sites according to the resources around them (e.g. use of rainwater and grey water recovery),
- Reduce land artificialisation and improve soil permeability on industrial sites,

Waste management

- Move towards the economy of the functionality of the means of production and industrial infrastructures,
- Extension of the life of industrial resources (repairability, simplification, reuse),
- The need for eco-design on the means of production and components of the industrial system is raising. Eco-design is still only in its early stages in the design of machines and production facilities (use of bio-sourced materials for the manufacture of production machines?) as well as in the surface treatments applied to aeronautical parts that use dangerous and polluting additives (flame retardant, paint).
- Considering machining scraps no longer as waste but as a source of low-carbon resources and communicating widely on this point in connection with the future constraint on the low-carbon primary resource (example for aluminium).

Logistics

Logistics, particularly the transport of goods, is essential to the functioning of the aeronautics sector and more generally in industrial activities. It can be considered as the blood that allows the system to function the various organs that make it up.

In a low-carbon future, the transport of goods will be a major limiting factor, unlike the current criteria where the low logistics cost and the abundance and ease of transport make it non-dimensional. The capacity to be transported will be reduced, more expensive, less accessible and subject to the constraint of competition of use.

The key drivers:

The main areas of work are:

- Collecting data at each stage of logistics (including distance travelled),
- Reuse of logistics packaging via deposits,
- Lighter packaging,
- Packaging recycling,
- Relocation of the various actors to the territory,
- Optimize the occupancy rate of vehicles and avoid empty return trips,
- Sharing means of transport between companies,
- Use of rail, river and airport networks that cover the national territory for customer delivery (with other means of transport for the last kilometres).

Operations

Direct emissions from aircraft in the operations phase account for 98% of emissions generated by the aeronautical industry, i.e. Scope 1 for airlines, or Scope 3 for aircraft manufacturers, according to the Green House Gas Protocol classification. This analysis is comparable to the automotive sector, where the vehicle uses phase accounts for 80% of the total carbon footprint of a combustion-powered vehicle, and only 15% for an electric vehicle using electricity produced in France.

The key drivers:

Eco-design

80% of an aircraft's environmental impact is determined at the design stage. The eco-design approach must be:

- Multi-criteria: consideration of all potential environmental impacts.
- Multi-stage: considering all stages of the product life cycle, from extraction of raw materials to end-of-life, including manufacturing, surface treatments, distribution, use and maintenance.
- Multi-actor: raising awareness of eco-design among the entire product development team, so that all its principles are applied.

When it comes to eco-design, beware of impact transfers: for example, bio based polymers and natural fibers generally have less impact on climate change and fossil fuel depletion, but more on water consumption, land use and soil pollution.

When it comes to lightening materials, today's challenge lies in the design and manufacture of recyclable and/or biodegradable composite materials. For example, there is currently no substitute for phenolic resin, which is under REACH scrutiny, is of fossil origin and whose manufacturing process emits a lot of CO2. The same applies to NAFTA (a raw material for fibers and resins), whose price trends are difficult to anticipate.

At the manufacturer's level

- Optimization of aircraft design, and in particular engine design, to reduce fuel consumption (improved aircraft aerodynamics, improved engine energy efficiency, lighter aircraft, etc.). However, many production rejects are generated as a result of very fine tolerances dictated by quality standards that are difficult to modify. One of the possible levers would be to lower the level of requirements to reduce the number of rejects, or to consider substitute materials. So far, however, these proposals have come up against obstacles in the way of taking responsibility for validating new specifications or new materials.
- We also need to develop innovative assembly processes for aluminum and steel, and hybrid composite and metal structures.
- Examples of achievements:
- JEC World 2023: everything you always wanted to know about Daher and advanced composites - Daher
- R&D - Daher
- Development of low-energy basalt fiber with interesting mechanical properties

At Airlines level

Reducing the environmental impact of cabin interiors, which are changed 5 to 6 times and for which we have no visibility on the quantities of waste generated and on recycling,

- Increased use of sustainable fuels, lighter cabins, reduced cabin waste, optimization of ground and in-flight operations through increased use of digitalization, and carbon offsetting of flights.

At airports level

- Introduction of Airport Carbon Accreditation,
- Reducing APU Auxiliary Power Unit emissions,
- The conversion of vehicle fleets and runway equipment to electric power, the replacement of all lighting (both in terminals and on runways) with LEDs, the development of photovoltaics for the production and self-consumption of electricity (and where this is not possible or sufficient, the purchase of green energy from suppliers),

- The evolution of terminal architecture to reduce emissions linked to heating and air conditioning,
- Reforestation of green spaces to promote local biodiversity).

The renewal of fleets with more powerful, lighter, more efficient aircraft, using alternative fuels to kerosene (electric, hydrogen, SAF, biofuels, Efuels or hybrid aircraft) is a strong lever for decarbonization action, but one that will generate production increases, notably with Airbus' commitment to produce a hydrogen-powered aircraft by 2035. If we draw a parallel with the automotive sector, the electrification of cars has increased emissions linked to vehicle production, and we now need to identify and activate the levers that will enable us to offset this increase in production emissions as far as possible. In the aeronautics sector, as in the automotive sector, the increase in production to renew fleets, coupled with the growing carbon footprint of new-generation aircraft production and the increase in waste emitted to renew aircraft, means that we need to rapidly activate levers to reduce the carbon footprint of production sites.

Maintenance

During aircraft maintenance, environmental impacts are generated by energy consumption, the production of maintenance materials (e.g. cleaning products) and spare parts, and the waste and wastewater generated. The production of spare parts and maintenance products has impacts comparable to those occurring during the aircraft production phase. On the other hand, waste production is similar in the case of aircraft dismantling, including for example the disposal and recycling of parts that are no longer usable and the draining of fluids.

In the MRO (Maintenance, Repair, and Operating) sector, which is subject to time pressure, safety and reliability, decarbonization is generally not yet a priority. MRO organizations comply with waste management regulations, but additional measures to increase sustainability are not yet widespread.

Dismantling

Managing end-of-life aircraft to reduce their environmental impact and reuse critical materials is a major challenge for the aeronautics industry, with Airbus forecasting that more than 20,000 commercial aircraft will be retired from the fleet over the next 20 years.

In order to develop a circular model, an industry for dismantling end-of-life aircraft has been developing in Europe over the last ten years. Tarmac Aerosave (shareholders: Airbus 33.6%, Safran 32.8%, Suez 33.6%) is a leading player in aircraft dismantling, with two sites in France and one in Spain. Currently, 92% of the total weight of the aircraft is recycled. The remainder is recycled for energy or sent to landfill. Aircraft currently being dismantled have a high metal content (77% aluminum, 12% steel), and few composite materials (only 3%). To date, TARMAC Aerosave has recycled over 350 aircraft since its creation.

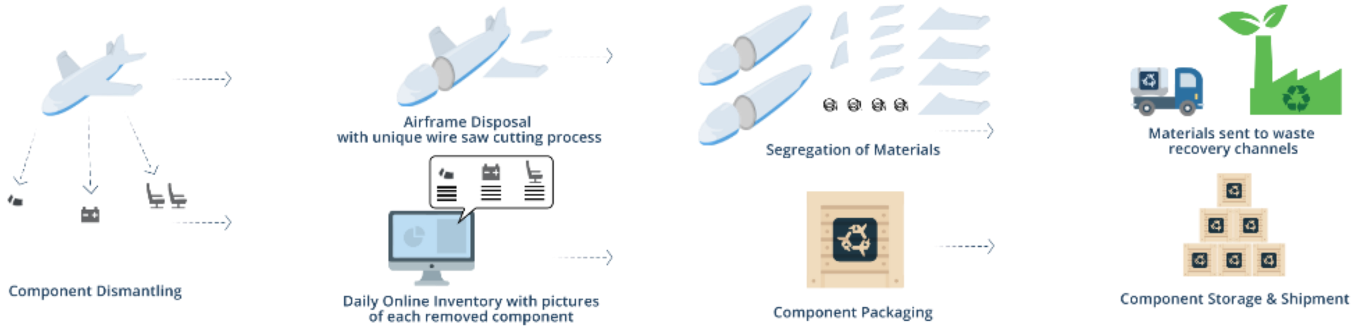


Figure 4 - *The main stages in dismantling and upgrading aircraft components - Source Tarmac Aerosave*

The majority of composites used in the aeronautics sector are carbon-fiber composites, the proportion of which grew strongly between 1970 and 2010, accelerating with the latest generations of aircraft such as the Airbus A350 and Boeing 787. Carbon fiber composite waste flows and associated inventories generated by the aeronautical sector are set to grow rapidly as new generations of aircraft reach the end of their useful lives. It is estimated that by 2050 a total of almost half a million tonnes of carbon fiber composite waste will have been generated, most of it in North America and Europe with around 162 kt and 145 kt respectively. A waste deposit of around 10,000 t/year has been estimated up to 2035. From that date onwards, the waste will increase rapidly, reaching an estimated 30,000 t/year in 2050, following the first dismantling of the Airbus A350 and Boeing 787.

The key drivers:

The main lever for action is recycling, for which it is vital to achieve a compromise between material and energy recovery. One of the first hurdles to overcome is an economic one, since in most cases, raw material remains cheaper than recycled material.

Recycling from aeronautics to aeronautics

For the aeronautics industry, there is a major need for high-quality recycling of materials such as aluminium and titanium. Today, however, it is difficult to find a way of recycling materials from the aeronautical sector for re-injection into the aeronautical sector. In this case, it is important to maintain aeronautical quality. This is only possible if volume and scale are created with several recyclers, making sorting processes, such as the separation of parts from different alloys, profitable for them. Otherwise, the materials lose their aeronautical quality and are instead used in other sectors or for tooling. Some recyclers, for example, prefer to take only deposits from large production sites and a single alloy to achieve economic viability.

Sorting plays an important role in recycling. Today, a number of sorting processes are in place, some automated, others still manual. Investments are often necessary, such as the purchase and installation of spinners at the feet of machine tools, to make the swarf reusable. In discussions with the aeronautical supply chain, one area for improvement was the lack of understanding of waste processing by recyclers.

Some are already sorting, but think that recyclers mix the chips together afterwards, doubting the usefulness of their sorting. Better communication and vision of waste treatment processes would be important so that all players can develop effective solutions together. It is necessary to develop flexible and competitive scrap sorting processes, avoiding the risk of pollution by other metals when the machine operates different parts of different alloys. It is also important to find solutions for testing sorting quality and traceability, and to demonstrate the profitability of sorting processes.

As far as thermoplastics are concerned, the use of recycled thermoplastics drastically reduces environmental impact (by almost 75% in this study).

- Recycled materials are nowadays almost systematically enhanced with a few percent of virgin material.
- Recycled material is used without additives for less demanding applications

But there is a need for more ambitious collection resources.

There is also a need to recycle rubber, a material for which a large quantity of scrap is generated during manufacture and currently sent to incineration. The main obstacle to recovery or recycling is the addition of various additives during the manufacturing process to change the material's properties.

Recycled carbon fibres are not reused in aeronautics, as they do not have the same mechanical characteristics after recycling.

Examples:

Titanium recycling:

- Production of recycled aerospace-grade superalloys by Aubert&Duval and Ecotitanium, financed to the tune of €17m => Production of aerospace-grade titanium by recycling (aubertduval.com)
- Imet Alloys creates a titanium recycling plant in Corrèze | Les Echos

Composites recycling:

- Daher has manufactured rudder pedals in reclaimed thermoplastics from production offcuts => JEC World 2023: everything you always wanted to know about Daher and advanced composites – Daher
- Recycling aircraft waste: new processes from startup Fairmat (gifas.fr)
- Towards an environmentally-friendly process for recycling composites (gifas.fr)
- Carbon reuse in tooling structures

Others:

- Nexans uses recycled aluminium for its cables (gifas.com)
- The AiMeRe project
- Automotive sector for aluminium ALUNITED: Supplier of aluminium components for electric vehicles - ALUnited

Recycling from aeronautics to other sectors

Examples:

- Recycling of tire rubber for applications in construction and industry. Tire: 80% of material recycled and 20% of material recycled for energy. Recycling must consume as little energy as possible.
- Panels made from recycled plastic and mineral fibers, produced in one-shot (low energy demand) to make caravans or cockpit/cabin partitions as well, but with the added constraint of fire.
- Veso concept is working with ATR on linen partitions (to be found on the Internet), with the problem of reproducible properties. MANIFICA - Design of durable and structural products (veso-concept.com)
- Châlons - Industry - Lebronze Alloys focuses on metal recycling (lhebdoduvendredi.com)
- Hopper, the French start-up that produces eco-responsible racing blades - Ecolosport
- For instance, Airbus has created an alternative reuse project to employ recycled carbon waste from aircraft EoL to produce bicycles.
- https://www.entreprises.gouv.fr/fr/actualites/france-2030/france-2030-5-premiers-laureats-de-l-appel-projets-metaux-critiques
- Extracthive https://www.polymeris.fr/actu/extracthive-est-le-laureat-de-l-aap-rrr-de-l-ademe-sur-la-thematique-du-recyclage-des-composites.html
- Environnement Recycling https://www.environnement-recycling.com/projet-devipeee/

Emerging Innovations and Trends in the Automotive Sector

The automotive industry is undergoing an accelerated transformation, driven by the need for innovation, sustainability, and adaptation to evolving consumer and regulatory demands. Emerging technologies are reshaping the future of mobility, offering solutions that enhance efficiency, reduce costs, and address critical challenges. Below, we explore the **key innovations or Key drivers for** this transformation, highlighting their **benefits**, the **needs** they fulfil, and the **problems they solve**:

Solid-State Battery Technology and Redox Flow Batteries

Solid-state batteries, represent a significant technological leap from traditional lithium-ion batteries, using solid electrolytes that provide higher energy density, reduced fire risk, and faster charging times, offer higher energy density, reduced fire risk, and faster charging times compared to traditional lithium-ion batteries. This technology enhances EV range while reducing weight and improving safety 【IEA, 2023. It also resolves safety issues linked to thermal runaway and battery degradation, ensuring longer lifespan and reduced environmental impact 【Nature Energy, 2023】

Challenges:

High production costs and manufacturing complexities

Companies like Toyota and QuantumScape are investing in R&D to overcome these challenges, aiming for commercialization within the next few years【BloombergNEF, 2023】

Applications Beyond EVs:

Potential uses include portable electronic devices and renewable energy storage systems【Science Advances, 2023】.

Advanced Materials and Nanotechnology

Innovations like graphene and carbon nanotubes are revolutionizing automotive manufacturing, making vehicles lighter, stronger, and more energy-efficient and enhance safety by increasing impact resistance 【Applied Energy, 2023】

3D Printing

The combination of nanotechnology and 3D printing enables the production of customized, complex, and optimized components, reducing costs and production times. This approach allows for the creation of parts that are otherwise impossible to manufacture using traditional methods【Deloitte, 2023】

Biomaterials

The use of biomaterials, such as bamboo and hemp fibres, is being explored as sustainable alternatives to plastics and metals. These materials reduce carbon footprint and promote circular economy practices【Nature Sustainability, 2023】.

Integration of Solar Energy into Vehicles

The integration of solar panels into vehicles is an emerging technology that enables additional energy generation during driving or when parked, increasing EV range. Companies like Lightyear and Sono Motors are developing vehicles leveraging this technology to reduce reliance on charging infrastructure【Solar Energy Journal, 2022】.

Efficiency and Energy Storage

The effectiveness of solar panels depends on factors such as design and sunlight exposure. Combined with high-density batteries, this technology provides a complementary energy system that enhances vehicle self-sufficiency【IEA, 2023】

Needs Addressed

It resolves charging infrastructure shortages and offers an additional energy source, particularly useful in regions with high solar exposure, such as Portugal and Spain.

Artificial Intelligence and Machine Learning

AI and machine learning play pivotal roles in the development of autonomous vehicles and predictive maintenance systems. Technologies such as sensors, cameras, radar, and LIDAR work together to create safer vehicles capable of real-time decision-making and adaptive behaviour【IEEE Transactions on Intelligent Vehicles, 2023】.

Predictive Maintenance

AI enables continuous analysis of vehicle data, predicting failures and recommending maintenance before major issues occur. This enhances reliability, reduces costs, and extends vehicle lifespan【McKinsey, 2023】.

Needs Addressed

AI improves vehicle safety and efficiency, reduces downtime, and supports more effective fleet management.

Advanced Recycling and Upcycling

Advanced recycling and upcycling practices are transforming the automotive sector by enabling the reuse of materials from end-of-life vehicles. This approach supports a circular economy, reduces resource extraction, and minimizes waste, converting scraps into high-value products【European Commission, 2023】.

Needs Addressed

It addresses the need for sustainable practices, reducing environmental impact, and creating new business opportunities from recycled and upcycled materials.

Legislation

European regulations encourage manufacturers to meet specific recycling targets, fostering innovation in sustainable and efficient processes【European Parliament, 2023】.

Green Hydrogen for Heavy-Duty Transport

Green hydrogen emerges as an ideal solution for heavy-duty and long-distance transportation, where electric batteries face limitations. Hydrogen-powered vehicles offer extended ranges and fast refuelling times, making them particularly useful for logistics【IEA, 2023】.

Infrastructure and Battery Comparison

Building hydrogen refuelling infrastructure remains a challenge, but continuous investment in green technology and refuelling stations is improving feasibility【Science, 2023】.

Needs Addressed

This technology addresses EV limitations for heavy transport, providing a sustainable alternative with reduced environmental impact and operational flexibility.

Blockchain for Component Traceability

Description and Benefits

Blockchain technology provides comprehensive traceability of automotive components, ensuring quality and compliance with environmental standards. This immutable ledger increases consumer trust and supply chain efficiency【Deloitte, 2023】.

Needs Addressed

It guarantees transparency, reduces fraud, and ensures only certified parts are used, enhancing vehicle durability and quality.

Advanced Recycling and Upcycling

Recycling and upcycling practices are fostering a circular economy in the automotive sector, reducing resource extraction and waste【European Commission, 2023】

Energy Harvesting Technologies

Description and Benefits

Emerging methods like piezoelectric systems convert mechanical vibrations into usable energy, increasing vehicle efficiency【Journal of Energy Conversion, 2023】It can be applied to tires, road surfaces, and interior components to generate energy during motion【Journal of Energy Conversion, 2023

Needs Addressed

It offers innovative internal energy generation solutions, reducing reliance on external energy sources and increasing vehicle efficiency.

Autonomous Vehicles as a Service (AaaS)

Description and Benefits	Business Models and Social Impact
Autonomous Vehicles as a Service (AaaS) offer practical solutions for urban mobility, eliminating the need for vehicle ownership and reducing congestion. This approach promotes more efficient resource use and improves accessibility to transportation【PwC, 2023】	Subscription-based or pay-per-use models democratize mobility while creating new employment opportunities in AI technology and fleet maintenance.

Gamification to Promote Sustainability

Description and Benefits	Needs Addressed
Gamification leverages game design techniques to encourage sustainable driving practices, rewarding drivers for eco-friendly behaviours. This approach creates a more engaging driving experience, motivating positive behaviour changes【Accenture, 2023】.	It promotes sustainable driving habits in an effective and enjoyable way, reducing environmental impact.

Biomimicry in Automotive Engineering

Inspired by nature, biomimicry is driving innovations in vehicle design and efficiency, from aerodynamic shapes to lightweight, high-strength materials. Biomimicry applies nature's principles to develop more efficient vehicles. Examples include the Mercedes-Benz Bionic Car, inspired by the boxfish for optimal aerodynamics, and the Lotus Elise, utilizing a mollusc-inspired structure for strength and reduced weight【Biomimetics Journal, 2023】.

Augmented and Virtual Reality (AR/VR)

Description and Benefits	Needs Addressed
AR and VR are gaining prominence in worker training and automotive project visualization. These technologies simulate assembly and driving scenarios in safe environments, enabling operator training without real-world risks【PwC Report, 2023】.	They provide safe and effective training, reduce training time and operational errors, and enhance customer experiences by allowing interactive vehicle customization and virtual test drives.

Drone Technology for Inspections and Logistics

Description and Benefits	Needs Addressed
Drones are increasingly integrated into industrial operations for inspection and logistics. In the automotive sector, they can inspect assembly lines, detect defects or maintenance needs, and rapidly transport spare parts within factories【McKinsey Report, 2023】.	They significantly reduce time and costs associated with manual inspections and logistics, improving precision and operational efficiency.

Advanced Sensor Technology

Advanced sensors, including those for temperature, pressure, humidity, and wear monitoring, are crucial for predictive maintenance and real-time vehicle performance monitoring. These sensors help identify potential issues before they become critical【IEEE Sensors Journal, 2023】

Intelligent Energy Management Systems

Description and Benefits	Needs Addressed
AI-driven energy management systems predict and optimize energy consumption in EVs and hybrids. These systems learn user driving patterns and adjust energy performance in real-time, enhancing efficiency and battery life【Nature Communications, 2023】.	They address limited EV range by managing energy usage intelligently, improving both driver experience and operational efficiency.

Microalgae for Biofuels

Description and Benefits	Needs Addressed
Using microalgae for biofuel production is a promising innovation offering a sustainable alternative to fossil fuels. Microalgae grow rapidly, have high energy density, and can be cultivated in non-arable areas, such as wastewater【Journal of Renewable Energy, 2023】.	This technology provides a renewable, carbon-neutral fuel source that reduces dependence on fossil fuels while promoting sustainability.

Thermal Energy Storage Systems

Description and Benefits	Needs Addressed
Thermal energy storage systems utilize materials that capture and store heat, releasing it when necessary. These systems improve the efficiency of heating and cooling systems in vehicles, reducing battery dependence【Applied Thermal Engineering Journal, 2023】.	They optimize temperature control energy consumption, particularly in extreme climates, contributing to more efficient and comfortable driving.

Dispersed Passive Hydrodynamic Cavitation Technology

Description and Benefits	Strategic Advantages
This patented technology transforms conventional fossil fuels into low-emission alternatives by mixing them with water through hydrodynamic cavitation. It enables cleaner and more efficient combustion, reducing CO_2 emissions by up to 90%【Infinitive Petroleum, 2023】.	Immediate implementation without modifications to existing engines. Cost-effective for transitioning existing fleets. Ideal for heavy and long-distance vehicles, particularly in regions where electrification is challenging.

Solid Oxide Fuel Cells (SOFC) for Vehicles

Description and Benefits	Needs Addressed
SOFCs are being adapted for vehicle use, enabling electricity generation from natural gas or biofuels. These fuel cells offer a sustainable alternative to internal combustion engines, particularly for heavy-duty transport【Ceres Power, 2023】.	They provide a sustainable propulsion solution for heavy vehicles, addressing emission challenges associated with traditional engines.

4D Printing for Self-Adaptive Components

Description and Benefits	Needs Addressed
4D printing, an evolution of 3D printing, allows the creation of components that can adapt or transform post-production. This innovation offers applications such as adaptive tires and collision-responsive bumpers【MIT, 2023】.	It supports the development of intelligent, adaptive automotive components, improving safety and efficiency.

Self-Healing Coatings Inspired by Plants

Description and Benefits	Needs Addressed
Inspired by plant healing mechanisms, these coatings can autonomously repair minor scratches and damage, extending vehicle lifespan and reducing maintenance needs【University of Illinois, 2023】	They enhance durability and reduce wear-related maintenance, especially critical for autonomous vehicles requiring pristine external surfaces.

Switched Reluctance Motors (SRM)

Description and Benefits	Needs Addressed
SRMs, known for industrial applications, are being tailored for EV propulsion. They offer advantages such as lower costs, higher robustness, and improved efficiency compared to conventional motors【Switched Reluctance Drives, 2023】.	They provide a cost-effective, efficient propulsion solution for EVs, addressing the challenges of high costs and efficiency limitations in traditional motors.

Global Megatrends – Shaping the Automotive Industry in SUDOE Region

The automotive industry is undergoing a profound transformation driven by four key megatrends that are expected to reshape the landscape by 2040:

Polarization: The regionalization of production and supply chains is becoming increasingly prominent, as countries and regions seek to mitigate risks and strengthen local resilience.

Automation: Advances in artificial intelligence, robotics, and autonomous vehicles are redefining how vehicles are designed, manufactured, and utilized.

Connectivity: Software-defined vehicles and the integration of Internet of Things (IoT) technologies are enabling smarter, more connected mobility solutions.

Electrification: The widespread adoption of electric vehicles (EVs) and the integration of renewable energy systems are accelerating the transition to a zero-emission future.

To remain competitive and future-ready, the SUDOE region must align its strategies with these transformative trends. Strengthening local clusters and leveraging regional strengths are essential for addressing the challenges of increasingly polarized global supply chains.

The emphasis on electrification across Europe, including the EU's 2035 target for zero-emission vehicles, perfectly aligns with SUDOE's goals of fostering sustainability and innovation. By capitalizing on these trends, the region can position itself as a leader in the evolving automotive landscape, while contributing to broader environmental and economic objectives.

Electrification and Green Energy Transition

Description and Benefits	Challenges
Electrification remains the cornerstone of automotive transformation. By 2040, Europe is projected to achieve a 99% BEV market share. **Infrastructure Expansion**: Invest in widespread charging networks, especially in rural areas. **Example:** Fast-charging corridors that connect rural and urban areas can reduce regional disparities. Renewable Energy Integration: Solar and wind energy solutions integrated with EV charging infrastructure. France's leadership in hydrogen technology can serve as a model for	Dependence on critical materials (e.g., lithium, cobalt). Limited charging infrastructure in rural areas.

hydrogen adoption in Portugal and Spain.

Strategic Actions

Establish local recycling hubs for EV batteries to reduce reliance on imported materials.

Accelerate the deployment of rural EV charging infrastructure using mobile units and renewable energy sources.

Automation and AI Integration

Description and Benefits

Automation is reshaping the automotive landscape, with advancements in AI transforming R&D, production, and autonomous vehicle deployment.

Autonomous Vehicles: The rollout of Level 4 AVs is expected by 2040, but adoption will remain limited to urban areas initially.

AI in Manufacturing: Predictive maintenance, optimized production, and real-time supply chain management are becoming industry standards.

Challenges

Urban vs. Rural Divide: Urban areas may see faster adoption of AVs and shared mobility services. Rural areas require tailored approaches, such as autonomous shuttles for low-density regions.

Workforce Transformation: Automation will displace traditional jobs but create opportunities in AI, robotics, and software development.

Strategic Actions

Pilot autonomous mobility solutions in urban centres like Barcelona, Lisbon, and Paris.

Develop training programs focused on AI and robotics to prepare the workforce for automation-driven roles.

Connectivity and Software-Defined Vehicles

Description and Benefits

By 2040, vehicles will increasingly function as software platforms, enabling continuous updates and new functionalities.
Collaboration between tech startups and automotive clusters to develop cutting-edge connectivity solutions.

Integration of IoT and 5G for enhanced vehicle-to-everything (V2X) communication.

Challenges

High initial costs for adopting software-defined vehicle (SDV) architectures. Cybersecurity risks in connected vehicles.

Strategic Actions

Promote open-source collaboration between regional OEMs and software developers.

Implement cybersecurity frameworks tailored to connected vehicles.

Polarization and Regional Strategies

Description and Benefits

Global markets are increasingly polarized, with a shift towards regional production ("local-for-local") to reduce supply chain vulnerabilities.

Challenges

The region's geographic position can be leveraged as a logistics hub between Europe, Africa, and Latin America.

Strengthening local supply chains will reduce dependency on global disruptions.

Strategic Actions

Foster cross-border collaboration between Spain, France, and Portugal to create a unified market for sustainable mobility.

Develop localized production hubs for EV components and materials recycling.

Emerging Business Models

Description and Benefits

The automotive industry is transitioning from product-centric to service-oriented models. **Mobility as a Service (MaaS)**: Shared mobility solutions, such as robo-taxis and shuttles, are gaining traction.

Vehicles as Service Platforms: Monetization of connected vehicle features (e.g., in-car entertainment, personalized services).
Urban areas like Paris and Barcelona can pilot MaaS solutions.

Rural areas can adopt shared EV fleets to address mobility gaps.

Challenges

Strategic Actions

Launch regional MaaS pilot projects in collaboration with local governments and tech companies.

Explore new revenue streams, such as subscription-based connectivity services for vehicles.

Circular Economy and Material Innovation

Description and Benefits

Sustainability is critical for future growth, with a focus on reducing environmental impact across the value chain.

Challenges

High upfront costs for developing sustainable materials.

Development of bioplastics and advanced composites for lightweight vehicles. Establishment of recycling facilities for batteries and components.	Complexity of circular supply chain integration.

Strategic Actions

Partner with research institutions to explore sustainable material innovation.

Implement regulatory incentives for companies adopting circular economy practices.

Workforce and Social Inclusion

Description and Benefits	Challenges
The transition to electrification and automation requires proactive workforce management. Upskilling programs for green technologies and digital tools. Inclusion of rural communities in the green transition.	Social resistance to automation-driven job displacement. Gaps in digital literacy in rural areas.

Strategic Actions

Develop cross-border training initiatives in partnership with universities and industry. Promote green job creation in rural areas through renewable energy projects.

The SUDOE region's automotive sector is well-positioned to lead in sustainability, innovation, and connectivity by leveraging its regional strengths and aligning with global megatrends. Future perspectives and trends should be framed through a lens of inclusivity, resilience, and adaptability, ensuring balanced development across urban and rural areas.

ISME – Iberian Sustainable Mobility Ecosystem

The ISME is designed as a dynamic and interconnected ecosystem encompassing the entire automotive value chain, from research and development to production, usage, and end-of-life processes. It is built on five fundamental pillars:

- Circular Technological Innovation
- Transformation of the Value Chain
- Intelligent and Connected Infrastructure
- Adaptive Regulation
- Cross-Border Collaboration

Core Principles of the ISME

Comprehensive Sustainability: Embedding sustainability principles across all stages of the vehicle lifecycle and throughout the value chain processes.

Collaborative Innovation: Creating an open innovation environment that fosters collaboration among industry, academia, and startups.

Circularity: Prioritizing business models and processes that maximize resource reuse, recycling, and recovery.

Digitalization: Leveraging advanced digital technologies to optimize processes, improve efficiency, and enable new business models.

Resilience: Developing value chains and production systems capable of quickly adapting to changes and disruptions.

Inclusivity: Ensuring the transition to sustainable mobility benefits all social strata and geographical regions.

Global Competitiveness: Positioning the Iberian region as a global leader in innovative and sustainable mobility solutions.

Main Components of the ISME

Circular Technological Innovation

Advanced Battery Excellence Center:

- **Location:** Valladolid industrial cluster, Spain.
- **Focus:** Development of solid-state batteries, advanced recycling technologies, and intelligent battery management systems.

Objective: Increase battery energy density by 50% and reduce costs by 40% by 2030.

Sustainable Materials Laboratory:

- **Location:** National Institute of Engineering and Computer Systems (INESC TEC), Porto, Portugal.
- **Focus:** Development of bio-composites, nanomaterials, and advanced steels for lightweight, efficient vehicles.

Objective: Reduce the average weight of vehicles by 30% by 2035 while maintaining or improving safety.

Hydrogen Propulsion Hub:

- **Location:** Occitanie Aerospace Cluster, Toulouse, France.
- **Focus:** Development of advanced fuel cells, hydrogen storage systems, and refueling infrastructure.

Objective: Achieve hydrogen propulsion systems with over 60% efficiency and 50% cost reduction by 2030.

Piezoelectric Energy Generation Research Center:

- **Location:** Polytechnic University of Madrid, Spain.
- **Focus:** Technologies to harness vehicle motion for powering auxiliary systems.

Objective: Implement piezoelectric systems in 20% of new vehicles by 2030, reducing main battery energy consumption by 5%.

Redox Flow Battery Laboratory:

- **Location:** University of Coimbra, Portugal.
- **Focus:** Development of compact redox flow batteries for electric vehicles, offering enhanced safety and longer lifespans.

Objective: Create redox flow battery prototypes with energy density comparable to lithium-ion batteries by 2028.

Transformation of the Value Chain

Digital Traceability Platform:

- Implementation of blockchain to trace components and materials throughout the value chain.
- Development of "digital passports" for all new vehicles detailing composition, carbon footprint, and recycling potential.

Objective: Achieve 100% traceability for critical components by 2030.

Network of Smart and Carbon-Neutral Factories:

- Modernization of existing facilities with Industry 4.0 technologies.
- On-site renewable energy systems and carbon capture technologies.

Objective: Transition 80% of production facilities to carbon-neutral operations by 2035.

Green Logistics Consortium:

- Development of a fully electrified or hydrogen-powered transport and logistics network.
- Urban consolidation centres for zero-emission last-mile deliveries.

Objective: Reduce logistics-related emissions by 70% by 2030.

Intelligent and Connected Infrastructure

Pan-Iberian Charging Network:

- Deployment of ultra-fast charging stations (>350 kW) along key routes connecting Spain, France, and Portugal.
- Development of bidirectional charging systems (V2G) in urban areas.

Objective: Install 1 million public charging points by 2030.

Autonomous Mobility Corridors:

- Dedicated corridors for autonomous vehicles connecting major urban and industrial centers.
- 5G communication infrastructure along these routes, with considerations for seamless integration with future 6G technologies.

Objective: Establish 5,000 km of autonomous mobility corridors by 2035.

Smart Urban Traffic Control Centers:

- Implementation of AI-based traffic management systems in major cities.
- Integration of data from connected vehicles, public transport, and micro-mobility.

Objective: Reduce urban congestion by 40% and traffic-related emissions by 50% in major cities by 2035.

Adaptive Regulation

Iberian Regulatory Sandbox for Mobility:

- Creation of testing zones for new mobility technologies under flexible regulations.
- Establishment of a trilateral committee for rapid evaluation and approval of innovations.

Objective: Reduce the time to market for new mobility technologies by 40%.

Harmonized Incentive System:

- Unified incentives for sustainable vehicles and technologies across the three countries.
- Development of transferable sustainability credits among countries.

Objective: Increase low-emission vehicle adoption by 50% by 2030.

Mobility Data Governance Framework:

- Common protocols for the collection, storage, and use of connected vehicle data.
- Creation of a "Data Trust" to ensure user privacy and enable data-driven innovation.

Objective: Establish a secure and innovative mobility data ecosystem by 2028.

- Cross-Border Collaboration

Sustainable Mobility Innovation Fund:

- Joint €5 billion fund to invest in startups and innovation projects.
- Acceleration program for sustainable mobility startups.
- **Objective:** Finance 500 startups and innovative projects by 2030.

Talent Exchange Program:

- Mobility program for engineers, researchers, and students across the three countries.
- Development of a common "Sustainable Mobility Engineering" curriculum in select universities.

Objective: Facilitate the exchange of 10,000 professionals and students by 2030, including streamlined access for specialized talent from third countries like India.

Sustainable Mobility Cities Alliance:

- Network of cities across the three countries sharing best practices in urban mobility.
- Coordinated pilot projects in multiple cities.

Objective: Engage 50 cities in the alliance by 2025 and implement 100 joint pilot projects by 2030.

Expected Benefits

The successful implementation of the **Iberian Sustainable Mobility Ecosystem (ISME)** promises substantial benefits across economic, environmental, social, technological, and geopolitical dimensions, creating a virtuous cycle of innovation, sustainability, and growth.

Strategic Considerations for the Automotive Sector

To effectively navigate the challenges and opportunities of the rapidly evolving automotive sector, a clear and strategic approach is essential. The recommendations outlined in this document aim to provide actionable guidance tailored to key stakeholders, including governments, automotive manufacturers, suppliers, research institutions, and investors.

These recommendations are designed to foster collaboration, drive innovation, and support the transition towards a sustainable and competitive automotive ecosystem. By addressing critical areas such as regulatory harmonization, infrastructure development, workforce reskilling, and sustainable practices, these measures provide a comprehensive roadmap to enhance regional competitiveness while aligning with global sustainability goals.

The successful implementation of these recommendations will require a collective effort, leveraging the unique strengths and resources of each stakeholder group. Together, they can shape a future where the automotive sector thrives economically, minimizes its environmental impact, and meets the evolving needs of society.

For Governments

Regulatory Harmonization: Establish a harmonized regulatory framework among the three countries to create an effective single market for sustainable mobility, facilitating investment and innovation.

Infrastructure Investment: Accelerate investment in electric and hydrogen charging infrastructure, aiming to create Europe's densest and most efficient network by 2030.

Fiscal Incentives: Implement a coordinated package of fiscal incentives to stimulate the adoption of low-emission vehicles and sustainable production technologies. Provide Tax breaks for EV manufacturers and suppliers.

Training and Reskilling: Initiate a large-scale trilateral program for training and reskilling, emphasizing critical skills for the future of mobility. In parallel, implement strategies for workforce upskilling and reemployment, acknowledging that AI and automation are set to replace traditional roles in the automotive industry.

Raise awareness about the benefits of electric mobility and the importance of sustainability in vehicle choices, fostering the adoption of greener mobility solutions.

For Automotive Manufacturers

Accelerating Electrification: Speed up the transition to electric vehicles, with the goal of achieving 100% electrified new models by 2030.

Open Innovation: Embrace open innovation models by fostering close collaboration with startups, universities, and other industries to accelerate the development of critical technologies. Leverage cutting-edge advancements in AI and automation to enhance efficiency and productivity, while simultaneously reducing non-compliances and minimizing waste.

Digital Transformation: Implement comprehensive digital transformation strategies across the entire value chain, from design to after-sales services.

New Business Models: Explore and develop new business models based on mobility services and connected data, and acquiring new set of strategic resources to meet the evolving demands in the value chain. (Lamia Kamal-Chaoui, 2024)

Invest in digitalization technologies to optimize value chains while adopting circular economy practices that reduce waste and enhance efficiency.

For Suppliers

Technological Diversification: Invest in diversifying the technological portfolio, focusing on components for electric vehicles, autonomous driving systems, and connectivity solutions.

Sustainability in the Value Chain: Implement sustainability practices across the value chain, including the use of recycled materials and renewable energies.

Vertical Collaboration: Strengthen collaboration with OEMs and lower-tier suppliers to develop integrated and innovative solutions.

Encourage public policies that expand charging infrastructure, particularly in rural areas, and promote the integration of renewable energy into industrial processes.

For Research Institutions and Universities

Collaborative Research Programs: Establish cross-border collaborative research programs focused on critical areas such as advanced batteries, sustainable materials, and AI applied to mobility.

Adapted Curricula: Develop and implement curricula tailored to the sector's future needs, including skills in software engineering, advanced electronics, and sustainable design.

Technology Transfer: Strengthen technology transfer mechanisms to accelerate the commercialization of innovations.

For Investors

Specialized Funds: Create specialized investment funds for sustainable mobility technologies and startups in the sector.

ESG Criteria: Integrate robust Environmental, Social, and Governance (ESG) criteria into investment decisions within the automotive sector.

Public-Private Partnerships: Explore opportunities for public-private partnerships to finance large-scale infrastructure and innovation projects.

Next Steps

To initiate the implementation of ISME, the following immediate steps are recommended:

Trilateral Summit: Organize a high-level summit among leaders of Spain, France, and Portugal to formalize the commitment to ISME and establish a governance structure.

ISME Working Group: Form a trilateral working group comprising government, industry, and academia representatives to develop a detailed implementation plan.

Implementation Roadmap: Develop a comprehensive implementation roadmap with clear goals, deadlines, and responsibilities for each ISME component.

Financing Mechanism: Establish a joint financing mechanism to support ISME initiatives, combining public and private resources.

Monitoring System: Implement a robust monitoring and evaluation system to track the progress and impact of ISME initiatives.

Next scenarios were created using morphological analysis methodology, enriched by expert input through a meta-analysis process that included content analysis of prospective studies and research papers. These sources utilized various methodologies, including the Delphi method, among others, and were carefully selected for their relevance to the subject matter.

The primary uncertainties considered in the development of these scenarios include:

The pace of adoption of electric vehicles.

Advances in autonomous driving technologies.

Shifts in vehicle ownership and usage patterns.

Progress in implementing sustainable mobility infrastructure.

Evolution of the regulatory framework and public policies.

These scenarios aim to provide a structured perspective on the potential trajectories for the automotive industry, offering valuable insights to guide stakeholders in navigating an increasingly dynamic and uncertain landscape.

Scenario 1 – Sustainable Leadership

Forecasts	Implications
In this optimistic scenario, the region emerges as a global leader in sustainable mobility: ✓ 90% of new vehicles sold are electric by 2035. ✓ Level 4 and 5 autonomous vehicles account for 40% of urban traffic. ✓ A 70% reduction in CO_2 emissions from the sector compared to 2020 levels. ✓ The region holds 30% of the global market for sustainable mobility technologies	This scenario requires massive investments in R&D and infrastructure, as well as unprecedented collaboration between the public and private sectors.

Scenario 2 - Gradual Transition

Forecasts	Implications
A more moderate scenario, characterized by steady but slower progress: ✓ 70% of new vehicles are electrified (including hybrids) by 2035. ✓ Autonomous vehicles are limited to specific applications and controlled zones. ✓ 50% reduction in CO_2 emissions from the sector. ✓ The region maintains its competitive position but does not become a global leader.	This scenario suggests a more cautious approach, leading to less short-term disruption but also a lower potential for global leadership.

Scenario 3 - Disruption of Mobility Services

Forecasts	Implications
In this scenario, business model innovation outpaces technological advancements: ✓ Private vehicle ownership decreases by 40% in urban areas. ✓ Shared mobility services dominate the urban market. ✓ Traditional manufacturers pivot to become mobility service providers. ✓ Significant reduction in the total number of vehicles, with increased usage per vehicle.	This scenario requires a significant restructuring of the industry and the development of new competencies in services and data management.

Scenario 4 - Stagnation and Loss of Competitiveness

Forecasts	Implications
A pessimistic scenario in which the region fails to adapt to global changes: ✓ Slow adoption of electric vehicles, reaching only 40% of sales by 2035. ✓ Significant delays in the development of autonomous technologies. ✓ Loss of market share to Asian and American competitors. ✓ Failure to meet emissions reduction targets, resulting in penalties and loss of investments.	This scenario highlights the risks of inaction or insufficient action, underscoring the need for a proactive and coordinated strategy.

These scenarios are not predictions but rather tools designed to serve multiple purposes in strategic planning and decision-making. They are intended to test the robustness of proposed strategies under various future conditions, ensuring that plans remain resilient even as the landscape evolves. By exploring a range of potential futures, these scenarios help identify opportunities and risks that may not be immediately apparent through current analysis, offering a broader perspective on potential challenges and advantages.

Moreover, these scenarios aim to stimulate strategic thinking and encourage preparation for multiple possible futures. By considering diverse outcomes, stakeholders can better anticipate shifts in the market, technology, and regulatory environment, enabling more informed decision-making.

We strongly recommend that industry stakeholders integrate these scenarios into strategic planning exercises and long-term investment evaluations. Doing so will enhance the ability to adapt to uncertainties, align strategies with emerging trends, and capitalize on opportunities while mitigating potential risks.

Future and Hypothetical Case Studies as a Prospective Exercise

1. Case Study: Advanced Battery Cluster in Navarra, Spain

Key Initiatives	Likely outcomes
Establishment of a "gigafactory" in partnership with a global battery manufacturer	Creation of 5,000 direct jobs and 15,000 indirect jobs by 2030
Creation of an R&D center specializing in solid-state battery technologies	30% reduction in battery costs for local manufacturers
Development of a state-of-the-art battery recycling facility	45% increase in the energy density of batteries produced between 2025 and 2035
Training program in partnership with local universities	Establishment of Navarra as a European leader in battery technology

Lessons Learned for this Potential Future Scenario

The importance of public-private collaboration in funding and planning

The need to simultaneously address production, R&D, and recycling

The value of integrating training and skills development from the outset

2. Case Study: Autonomous Mobility Corridor Paris-Bordeaux

Key Initiatives	Likely outcomes
Implementation of 5G communication infrastructure along the entire corridor	60% reduction in traffic accidents along the corridor.
Development of safe transition zones for entering and exiting autonomous mode	30% increase in traffic flow efficiency.
Creation of a centralized AI-based traffic management system	25% reduction in CO_2 emissions related to transportation within the corridor.
Collaboration with multiple manufacturers to ensure interoperability	Positioning France as a leader in infrastructure for autonomous vehicles.

Lessons Learned for this Potential Future Scenario

The need for close collaboration between transportation authorities, telecom companies, and automakers.

The importance of addressing safety and regulatory issues from the outset.

The value of a phased approach, starting with Level 3 applications and progressing to more advanced levels

3. Case Studies: Transformation of the Automotive Value Chain in Portugal

Key Initiatives	Likely outcomes
Implementation of a blockchain platform for component traceability.	40% increase in the added value of Portuguese automotive production.
Conversion of 80% of factories to carbon-neutral operations.	70% reduction in the carbon footprint of the supply chain.
Development of an innovation hub for sustainable materials.	Creation of 20,000 new high-tech jobs.
National retraining program for workers in the sector	Establishment of Portugal as a benchmark in sustainable manufacturing

Lessons Learned for this Potential Future Scenario

The importance of a holistic approach encompassing technology, skills, and sustainability.

The value of collaboration between large companies and SMEs within the supply chain.

The need for alignment between industrial and environmental policies

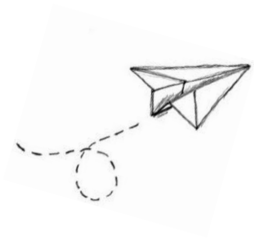
Conclusion

In a low-carbon future, industry faces two major challenges: one associated with corporate sustainability, and the other with the sustainability of its products and services. These two challenges also apply to the aeronautics sector, which is also a single-product industry with demanding specifications.

Current aeronautical roadmaps propose a number of ambitious actions to make aircraft use more sustainable, but few are yet highlighted to determine and eliminate the aeronautical production system's dependence on fossil fuels.

To succeed in producing aircraft in a world under biophysical constraints, the restructuring of the aeronautical industry seems unavoidable, with the implementation of collaborative systems based on trust between all players in the value chain, as well as with other mobility sectors such as road, rail and sea transport. The traditional "customer-supplier" relationship must evolve towards collective paradigms such as simultaneous engineering. It would also seem unavoidable to revise the corporate accounting framework with new criteria and a new hierarchy of priorities, considering, for example, that respect for planetary boundaries takes precedence over economic performance to enable environmental or biophysical issues to be considered at the right scale. It will be essential to take responsibility for innovations and new priorities as soon as possible.

Decarbonization in a world with limited natural resources is now a collective task, thanks to digital technology and the exchange of best practices across the extended enterprise, from source to end-of-life.



The global automotive sector is undergoing an historical paradigm shift, facing a changing environment driven by electrification, connectivity, and autonomous mobility, which are emerging as the primary forces shaping the industry's future. This demands not only a quick adaption, as well as a reinvention of the sector. By 2030, electric vehicles (EVs) are expected to account for over 50% of global new vehicle sales, underscoring the rapid pace of transformation.

In Europe, the transition is being led by the European Union's ambitious policies, including the European Green Deal and the goal of achieving carbon neutrality by 2050. While these initiatives present significant challenges, they also offer substantial opportunities for the automotive sector to innovate and thrive in a highly competitive and evolving market.

Spain, France, and Portugal are particularly well-positioned to become leaders in sustainable mobility. These countries benefit from robust industrial bases, strong political commitments to sustainability, and thriving ecosystems of innovation. Together, they can leverage their unique strengths to drive the adoption of new technologies and create a more resilient and sustainable automotive landscape.

This sectorial transformation should consider the following:

Systemic Innovation: Focus on developing not just advanced vehicles but integrated and sustainable mobility ecosystems.

Strategic Agility: Foster the ability to pivot quickly in response to technological, regulatory, and geopolitical disruptions.

Comprehensive Sustainability: Embed circular economy principles and environmental responsibility throughout the value chain.

Deep Digitalization: Embrace digital transformation not only in products but across all operational processes and business models.

Expansive Collaboration: Forge strategic partnerships beyond the traditional boundaries of the sector, including technology, energy, and urban planning.

Customer-Centric Approach: Transition from being product manufacturers to providers of personalized mobility solutions and value-added services.

Adaptive Resilience: Build supply chains and organizational structures capable of thriving in a volatile and uncertain world.

Social Responsibility: Actively lead a just transition to new forms of mobility, addressing social and labour impacts.

This white paper introduces the Iberian Sustainable Mobility Ecosystem (ISME) as a comprehensive and integrated solution to address the challenges and opportunities in the sector. The ISME framework encompasses technological innovation, value chain transformation, smart infrastructure development, adaptive regulatory frameworks, and cross-border collaboration, ensuring a holistic approach to sustainable mobility in the region.

The successful implementation of ISME is projected to have a significant economic impact, boosting the region's automotive sector competitiveness by 15-20% by 2030 and creating over 100,000 new highly skilled jobs across the Iberian Peninsula.

In terms of environmental sustainability, the proposed approach could lead to a 55% reduction in CO_2 emissions from the automotive sector by 2030 and a 90% reduction by 2050, aligning with the European Green Deal's objectives and contributing to a cleaner, greener future.

Moreover, ISME holds the potential to attract over €50 billion in green investments by 2030, positioning the Iberian Peninsula as a global hub for innovation in sustainable mobility. By fostering investment and collaboration, the region can become a leading example of how to combine economic growth with environmental stewardship.

Building on the outlined opportunities and challenges, it becomes evident that the Iberian Peninsula stands at a critical juncture in redefining its automotive ecosystem. The need for bold and integrated strategies, as exemplified by the proposed Iberian Sustainable Mobility Ecosystem (ISME), is more urgent than ever. This section delves deeper into the transformative potential of ISME and highlights the strategic imperatives that must be addressed to secure the region's position as a global leader in sustainable mobility.

An Inevitable Transformation: The automotive sector in Spain, France, and Portugal is undergoing an unprecedented transformation driven by environmental, technological, and social challenges. Adapting to this new reality is not merely desirable but essential for the sector's survival and long-term prosperity.

A Unique Opportunity: The region has a unique chance to position itself as a global leader in sustainable mobility by leveraging its complementary strengths in manufacturing, innovation, and energy policy. These advantages create a solid foundation for fostering growth and driving the green transition in the automotive ecosystem.

An Integrated Approach: The success of this transition hinges on adopting a holistic and collaborative approach, as outlined in the Iberian Sustainable Mobility Ecosystem (ISME). This framework integrates technological innovation, value chain transformation, smart infrastructure, adaptive regulation, and cross-border collaboration, ensuring a cohesive strategy for sustainable development.

Multidimensional Impact: The successful implementation of ISME promises to deliver significant benefits not only for the automotive sector but also for the economy, the environment, and society at large. From boosting competitiveness and creating jobs to reducing emissions and enhancing mobility, the potential positive outcomes are vast.

The Urgency of Action: Given the rapid pace of global change and intensifying international competition, there is an urgent need for coordinated and ambitious action to seize this opportunity. The time to act is now, ensuring the region's leadership in shaping a sustainable, innovative, and resilient automotive future.

Suggestions to accelerate Innovation in the Automotive Sector

Based on the analysis conducted, the following recommendations are proposed to drive innovation in the automotive sector:

Public Incentive Policies: Develop policies that encourage investment in R&D through financial support and tax benefits. Regardless of FDIs tend to flow into regions with strong infrastructure, established business ecosystems, and skilled labor pools, these characteristics naturally attract investors seeking efficiency, connectivity and access to a qualified workforce. (…) Policies at National and regional level, can make a difference by attracting FDI and enhance their impact on local SMEs in the automotive sector, especially in less developed regions (Lamia Kamal-Chaoui, 2024)

Promotion of Collaboration: Foster partnerships between companies, universities, and innovation centers to strengthen the automotive innovation ecosystem.

Training Programs: Create training and capacity-building programs to prepare professionals for the new technological demands of the sector.

Regulatory Simplification: Reducing the complexity of regulatory processes is essential to accelerate the introduction of new technologies. Aligning policies across regions can foster seamless collaboration and reduce compliance barriers, creating a more cohesive framework for innovation. Additionally, introducing targeted incentives can further support the adoption of sustainable and innovative technologies. For example, providing tax breaks or subsidies to companies that embrace circular economy practices or produce zero-emission vehicles can drive industry-wide progress toward environmental and economic sustainability. These measures will not only encourage technological advancements but also ensure alignment with broader climate and policy goals.

Case Study Analysis: Research case studies of leading companies in innovation and compare practices in the markets of Portugal, Spain, and France to identify gaps and opportunities for improvement.

Prioritize Regional Innovation Hubs: Investing in regional production and supply chain ecosystems is essential to creating local-for-local solutions that reduce dependency on global markets and mitigate supply chain disruptions. Additionally, developing specialized innovation clusters can further strengthen regional competitiveness. By connecting manufacturers, suppliers, and technology companies, these hubs foster cross-sectoral collaboration, drive technological advancements, and enhance the overall resilience of the automotive industry.

Strengthen Research and Development (R&D): Boosting investments in automotive R&D is critical to staying competitive in a rapidly evolving industry, particularly in areas such as electrification, automation, and software-defined vehicles. A focused approach to emerging technologies can further amplify these efforts. Key priorities include advancing autonomous vehicle systems like Level 4 automation, exploring alternative battery chemistries such as solid-state and sodium-ion batteries, and utilizing digital twins and AI tools to streamline design and manufacturing processes. These strategic investments will drive innovation, reduce costs, and position the industry at the forefront of global technological advancements.

Enhance Workforce Reskilling and Training: Develop New Skillsets Equip the workforce with expertise in software development, robotics, and green technologies.

Collaborate with Academia: Collaborating with universities and technical schools is vital for creating programs that equip students with the skills needed for emerging roles in the automotive industry. Additionally, offering on-the-job training for workers transitioning from roles impacted by automation ensures a smooth adaptation to new technologies and processes. These initiatives will foster a highly skilled workforce capable of driving innovation and sustaining competitiveness in a rapidly changing industry.

These recommendations aim to create a more conducive environment for innovation, enabling the automotive sector to quickly adapt to new global market demands and lead in sustainability and technology.

In conclusion, the findings of this white paper highlight the Iberian Peninsula's unique position to lead the transformation of the automotive sector, delivering economic, environmental, and social benefits while setting a benchmark for sustainable mobility worldwide. The transformation of the automotive sector in Spain, France, and Portugal represents both a monumental challenge and an unprecedented opportunity. The Iberian Sustainable Mobility Ecosystem (ISME) offers an ambitious yet achievable roadmap to navigate this complex transition and emerge as global leaders in sustainable mobility.

The success of this initiative will depend on close collaboration among all stakeholders, a sustained commitment to innovation and sustainability, and the ability to adapt quickly to a constantly changing environment.

By embracing this vision and acting decisively, Spain, France, and Portugal have the potential not only to transform their automotive sectors but to lead a mobility revolution with lasting positive impacts on the economy, the environment, and the quality of life of their citizens.

The future of sustainable mobility begins now, and the Iberian region is uniquely positioned to be at the forefront of this global transformation.

Appendices

Methodology and Approach

To ensure an in-depth and holistic understanding of the automotive innovation ecosystem in Europe, this study adopted a methodological approach based on extensive document analysis. Various documents, technical reports, scientific articles, and case studies were examined to provide insights into emerging trends, challenges, and opportunities within the automotive sector, with a particular focus on sustainability and the energy transition.

The selection of documents was carried out based on their relevance to automotive clusters in France, Spain, and Portugal, as well as their contribution to understanding the dynamics in rural areas. The analysis was structured to identify critical information and organize it into thematic categories that facilitate the formulation of strategic recommendations.

A systemic approach was adopted to analyze the automotive ecosystem as a complex and interconnected system. This approach enables the identification of interactions among value chain components, the mapping of constraints that limit performance, and the understanding of influence dynamics among critical variables, as well as identifying new opportunities and challenges for the transition to a production model and more sustainable consuming in the automotive industry.

Analysis Process Steps

1. **Data Collection and Document Analysis:** Comprehensive data collection from diverse sources, including market reports and academic publications.
2. **Data Cataloging and Processing:** Structuring data to ensure consistency and integrity.
3. **Content Analysis:** Identification of relevant patterns and trends.
4. **Cross-Analysis and Comparative Study:** Data comparison to capture a holistic view of the sector.
5. **Identification of Patterns and Critical Insights:** Defining priority areas for innovation.
6. **Final Report Preparation:** Synthesizing results with strategic recommendations.

VUCA and OODA Framework

The automotive sector is characterized by a high degree of Volatility, Uncertainty, Complexity, and Ambiguity (VUCA). To navigate this dynamic environment, the VUCA model was adopted as an analytical lens. It helps identify the main forces, shaping the sector and anticipating future changes.

Additionally, the OODA (Observe, Orient, Decide, Act) cycle was used to guide decision-making processes. This cycle allows for rapid and effective responses to environmental changes, adapting strategies as necessary.

These methods were adopted because the VUCA model is essential for understanding the complexity of the automotive sector, which is subject to constant technological changes, regulations, and consumer preferences; OODA cycle supports strategic decision-making in high-uncertainty environments, such as the automotive sector.

Identification of Constraints (Theory of Constraints - TOC)

To identify bottlenecks that limit the performance of automotive value chains, the Theory of Constraints (TOC) was employed. TOC is a methodology that seeks to identify and eliminate the constraints that prevent a system from achieving its goals.

We applied TOC by identifying the constraint through data analysis and tools such as flow diagrams and value maps, the process steps with the lowest throughput or highest cycle time were identified as the system's constraint. Then we followed the Constraint Exploration phase, an In-depth analysis to understand the root causes of the constraint. Subordination, adjusting the rest of the system to maximize the constraint's performance, avoiding other resources becoming bottlenecks. We then implemented actions to eliminate or increase the capacity of the constraint - Elevating the Constraint phase. Finally, all the previous process is repeated, in order to identify and address new constraints – Repetition Phase.

Applying TOC allowed the identification of key constraints that limit innovation and sustainability in the automotive sector, such as the lack of charging infrastructure for electric vehicles and challenges in sourcing sustainable materials.

TOC is connected with VUCA and OODA, as it complements the VUCA and OODA approaches by identifying specific actions to overcome constraints and seize opportunities in a VUCA environment. By eliminating constraints, organizations can respond more quickly and effectively to market changes, aligning with the OODA cycle.

Analysis Tools and Techniques Used

To analyze the automotive ecosystem, a combination of qualitative and quantitative tools and techniques was employed. The selection of these tools was guided by the need to understand the sector's complexity and identify major trends and challenges.

- Content Analysis: A methodology was employed to extract qualitative insights from a diverse range of documents, including market reports, academic articles, and industry publications. This approach facilitated the identification of key patterns, recurring themes, and core concepts, enabling a deeper understanding of emerging trends, sector actors' perceptions, and challenges in the automotive industry.

- SWOT Analysis: Applied to assess the strengths, weaknesses, opportunities, and threats of the automotive sector in each analyzed market, aiding in identifying key drivers and challenges.

- Decision Models and Strategic Recommendations: A combination of decision models and frameworks such as VUCA and OODA was used to develop strategic recommendations, enabling the evaluation of different strategic options, and selecting the most suitable ones for each context.
- Thematic Mapping: A tool used to categorize the extracted information and organize the data into relevant themes such as sustainability, technological innovation, and challenges in rural areas. This mapping facilitates the identification of gaps and opportunities for developing strategic recommendations.

- Qualitative Analysis Software: Specialized software was used to assist in document coding and qualitative data analysis, ensuring a systematic and replicable approach to information extraction

The content analysis served as the foundational step in gathering data, which was essential for conducting the SWOT analysis. This initial phase allowed for a comprehensive understanding of key themes, industry insights, and emerging trends, laying the groundwork for a robust SWOT assessment. The insights derived from the SWOT analysis, in turn, guided the application of decision models and informed the development of strategic recommendations tailored to the context of the automotive sector.

The VUCA model was instrumental in providing a contextual framework that highlighted the uncertainties and complexities inherent in the industry. By applying this model, it was possible to anticipate potential disruptions and strategically navigate the challenges posed by the dynamic nature of the market. Complementing this, the OODA (Observe, Orient, Decide, Act) cycle was utilized to enhance decision-making capabilities, enabling swift and effective responses to environmental changes and ensuring that strategies remained adaptable and responsive.

Through the integration of these methodologies, the analysis process achieved a cohesive approach that not only identified critical factors and opportunities but also empowered strategic decision-making in an ever-evolving sector.

Sources of Information Consulted

Market Reports

Academic Studies

Publications from Industry Organizations

Innovation Cluster Data

Government Reports

For more detailed information, please refer to the original documents mentioned

The work was carried out on three main stages:

• Targeted bibliographic analysis, to study existing literature, standards, regulations, and relevant studies. Documents previously identified as part of the SCAIRA project were also included in the analysis.

• Consult key players, with targeted interviews of a dozen strategic companies to gather practical information and feedback from the field.

• Analysis and reporting of the information gathered in the form of clear, concise, and illustrated deliverables.

Challenges

• Maximize the effectiveness of the bibliographic phase to meet specific expectations.

• Mobilize strategic players and gather high-quality information to feed into the study results.

Report organization

The report is structured into several sections, providing an in-depth look at the challenges of the circular value chain in the aeronautics industry. After an introductory context, it presents the key stages in the aeronautical value chain. A section dedicated to key messages provides an overview of the main findings. Subsequent chapters focus on a number of key themes: eco-design, sustainable and local sourcing, innovative processes to reduce waste and impact, recovery of production output and waste, maintenance and aircraft end-of-life. Each section explores the issues at stake, current and future standards, and the main obstacles and levers identified, illustrated by concrete examples ("They've done it!").

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SCAIRA

DOCUMENT INFORMATION

Title

"Territorial and Industrial Challenges in the Automotive and Aeronautic Sectors."

Start - end date

01/01/2024 - 01/01/2027 (36 months)

Programme

Interreg VI-B SUDOE

Project type

"Promoting social cohesion and territorial and demographic balance in the SUDOE region through innovation and the transformation of productive sectors".

ERDF funding

1.865.807,42 €

Coordinator

Aerospace Valley

Project overview

The SCAIRA project, co-funded by the Interreg SUDOE Programme, aims to develop a customized training programme to support the creation and acceleration of start-ups in rural areas of the SUDOE region. A consortium of twelve beneficiaries (local incubators, regional clusters, and industrials) and eighteen associated partners located in regions of France, Portugal, and Spain will support the initiative.

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