TRiREME

DIGITAL & GREEN SKILLS TOWARDS FUTURE OF THE MOBILITY ECOSYSTEM

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DESK RESEARCH OF TRENDS IN AUTOMOTIVE-MOBILITY SECTOR

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LIST OF ABBREVIATIONS

5G	...	5th generation mobile network
ACEA	...	European Automobile Manufacturers' Association
AFIR	...	Alternative Fuels Infrastructure Regulation
AI	...	Artificial Intelligence
BEV	...	Battery Electric Vehicle
CAM	...	Connected and Automated Mobility
CO2	...	Carbon-dioxide
CRM	...	Critical Raw Materials
CRMA	...	Critical Raw Materials Act
CSRD	...	Corporate Sustainability Reporting Directive
ESG	...	Environmental, Social and Governance
ESPR	...	Eco-design for Sustainable Products Regulation
ETRMA	...	European Tyre & Rubber Manufacturers Association
EU	...	European Union
EUDR	...	EU Deforestation Regulation
EURO	...	7 European emission standard 7 (2030 to 2031)
EV	...	Electric Vehicle
GHG	...	Greenhouse gas
IoT	...	Internet of Things
JRC	...	Join Research Centre
MaaS	...	Maintenance as a Service
MaaS	...	Mobility as a Service
PwC	...	PricewaterhouseCoopers brand
R&D	...	Research and Development
SME	...	Small and Medium Enterprises
TaaS	...	Tire as a Service
UNECE	...	United Nations Economic Commission for Europe
WP2	...	Work package 2
WP3	...	Work package 3
WP5	...	Work package 5
WP6	...	Work package 6

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INTRODUCTION

The present study is a desk research part of **Work Package (WP2) "Continuous Skills Intelligence Gathering"**, **Task 2.1 "Continuous Periodic Expert Desk Research"** and represents the first **Deliverable (D2.1) on "Sectoral Skills Intelligence: Reactive Response**".

As a first iteration, the **study gives an overview of the state-of-the-art of the automotive-mobility ecosystem, providing a quantitative and qualitative evaluation of its main sectoral trends for 2030-2050 and beyond. It does so by analysing their relevance, urgency and implications on skills and jobs forecasting, to support the digital and green transition towards the future of the automotive-mobility sector in the European Union.**

The study first provides a background on the automotive-mobility ecosystem in the EU, by focusing on challenges and future perspectives of the automotive-mobility industry, and giving insights and data on electrification, digitalisation, automation, sustainability, circular economy, tyres, and rubber components in the automotive-mobility sector, and global economy context.

The study also contextualises the most recent EU level policies affecting the automotive mobility ecosystem by specifying the key regulations and most recent developments, including climate neutrality, decarbonisation and circularity, raw materials and EU production capacity, infrastructure, and the social dimension.

The core of the study investigates the sectoral trends for 2030-2050 to address their relevance, urgency and implications on skills and jobs forecasting. Content wise, we address the following topics:

1. Digitalisation and Industry 5.0, and their impacts on mobility.
2. Green Sustainability and Circular Economy, with a special focus on batteries, tyres, and alternative fuels.
3. Resilience of value chains, and their potential in optimisation and localisation.
4. New business models, with a focus on Mobility as a Service, Tire as a Service, and Maintenance as a Service.

Additionally, **Annex 1** provides a data framework proposal for training provision and methods for the automotive-mobility ecosystem.

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1 BACKGROUND ON THE AUTOMOTIVE-MOBILITY ECOSYSTEM

The automotive industry is one of the most important sectors of the EU economy. As presented in Figure 1, motor vehicles and transport equipment are in the top five of manufacturing activities, with a 13% share of the European value of sold production in 2022. This is the reason why the mobility sector is crucial and fundamental in the wider European ecosystem.

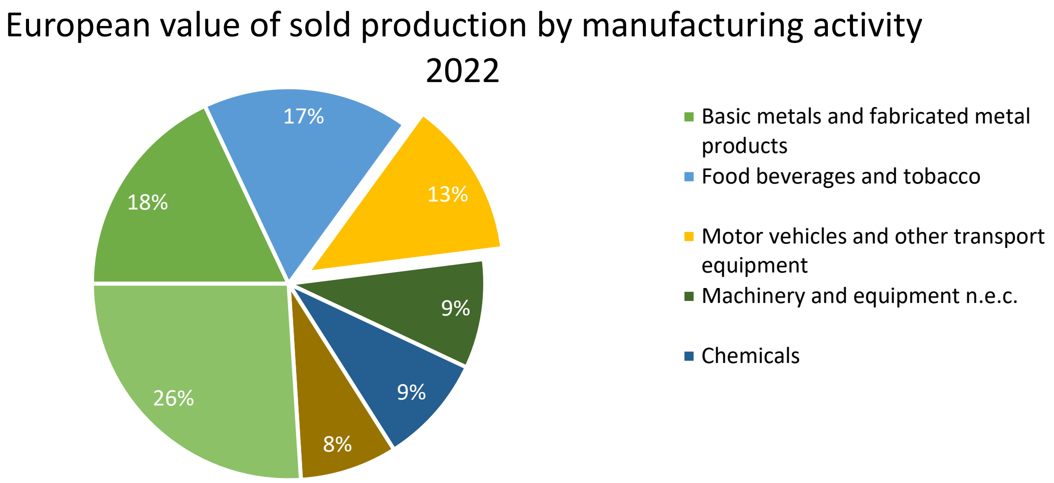

Figure 1: Source: Eurostat[1]

The automotive industry currently employs almost 13 million Europeans directly and indirectly. Manufacturing jobs account for around 24% of the total, 18% of which are directly involved. On the other hand, among the 76% of indirect jobs, 39% are related to transportation, both for freight and passenger land modes and 31% are related to the sales, retail and maintenance of vehicles, parts and accessories[2]. In this context, electrification alone puts 600,000 internal combustion engine-related jobs at risk. In contrast, hundreds of thousands of new jobs are created in the battery, electronics and software segments of the automotive supply chain.

[1] *Industrial production statistics, Data extracted in July 2023*, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Industrial_production_statistics#Industrial_production_by_sector

[2] *Automotive sector: direct and indirect employment in the EU - ACEA - European Automobile Manufacturers' Association, 7 October 2023*, https://www.acea.auto/figure/automotive-sector-direct-and-indirect-employment-in-the-eu/

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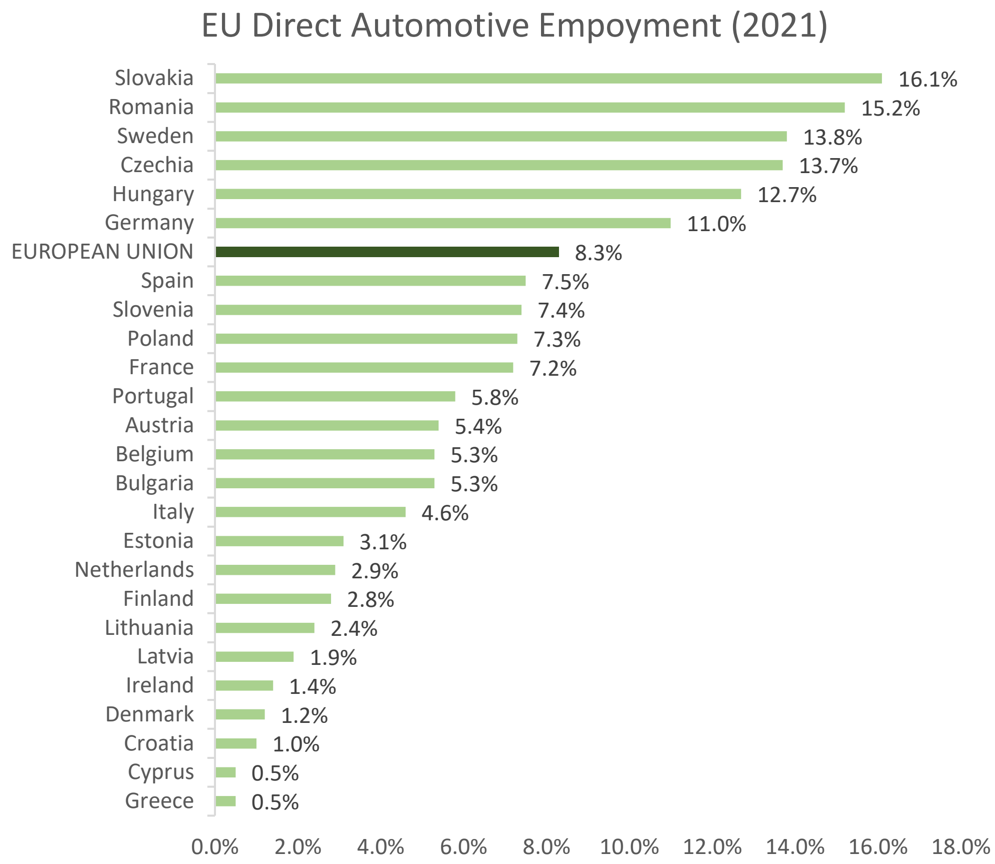

Figure 2: Source: ACEA[3]

The EU auto industry accounts for more than 10% of manufacturing jobs in six Member States.

European automotive companies actively prepare for the green and digital transitions, including the most ambitious CO2 reduction targets for vehicles and new circular strategies throughout the entire value chain, while scaling up electrification and automation of the mobility fleets.

Vehicles are shifting towards increasingly software defined technology, and new circularity and carbon neutrality requirements will translate into new materials, circular design and lifetime maximisation solutions. Furthermore, the European automotive industry is facing intense global competition for critical resources, funding, investments, and customers, which is compounded by rising costs of doing business and a radical change in the geopolitical landscape.

[3] *The Automobile Industry: Pocket Guide 2023/2024, ACEA September 20 23, https://www.acea.auto/files/ACEA-Pocket-Guide-2023-2024.pdf*

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To cope with these disrupting changes, the sector will require fundamental changes to components and technologies used along the vehicle and with it, significant investments by automotive suppliers in terms of production plants and equipment, research and development, reskilling and recruitment of the workforce. The automotive industry will need to ensure a just transition for workers whose jobs depend on declining technologies and is making significant efforts to ensure the necessary skills transition, with special training programs for employees working on internal combustion engines to work on new drivetrains, including hydrogen, battery-electric powertrains, and other technologies.

1.1 Electrification

Over the last years, the European auto industry achieved a substantial reduction in CO2 emissions and developed cutting-edge powertrain technologies. Investments of over €250 billion have been made in electrification and producing a diverse range of electric cars and vans.

The production of battery electric vehicles (BEVs) in the EU has been rapidly expanding. The European Green Deal and the “Fit for 55” package have set ambitious targets for reducing greenhouse gas emissions, incentivising manufacturers to accelerate BEV production. Major automotive companies are investing heavily in EV technology, establishing new manufacturing facilities, and forming strategic partnerships to secure battery supplies and enhance their production capacities (Figure 4 Cars account for around 4/5 of EU made vehicles).

EU market share of battery-electric cars has surged by six-fold in the last four (4) years[4].

[4] *The Automobile Industry: Pocket Guide 2023/2024, ACEA September 2023,* https://www.acea.auto/files/ACEA-Pocket-Guide-2023-2024.pdf

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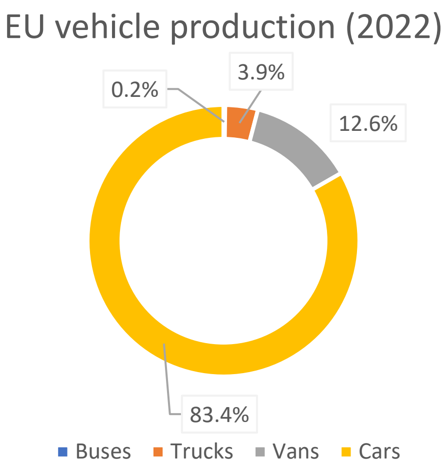
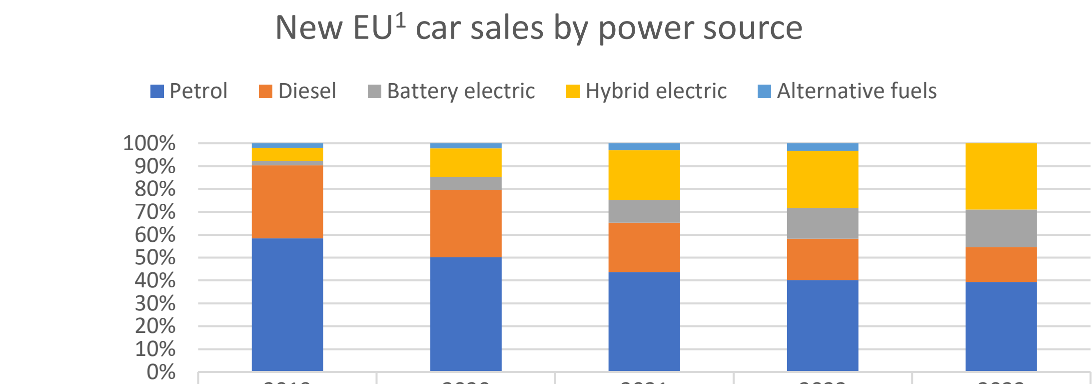


Figure 3: Source: ACEA[5]



	2019	2020	2021	2022	2023
Alternative fuels	2.0%	2.1%	2.8%	3.0%	
Hybrid electric	5.7%	11.9%	19.8%	22.6%	25.8%
Battery electric	1.9%	5.4%	9.1%	12.1%	14.6%
Diesel	31.6%	27.9%	19.6%	16.4%	13.6%
Petrol	57.8%	47.5%	39.9%	36.4%	35.0%

Figure 4: Source: ACEA[7]

Yet the vehicle production itself is but a piece of the puzzle. There must be an appropriate charging infrastructure at the national and European levels that can address the increasing demand. According to ACEA's recent numbers, there were 632,423 public charging points available across the EU at the end of 2023 and around 3 million battery-electric vehicles (BEVs) on the road.

[5] *The Automobile Industry: Pocket Guide 2023/2024, ACEA September 2023,* https://www.acea.auto/files/ACEA-Pocket-Guide-2023-2024.pdf

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The European Commission calls for 3.5 million charging points by 2030 to support the level of vehicle electrification necessary to reach the proposed 55% CO2 reduction for cars. Reaching this target would require the installation of nearly 2.9 million public charging points in the next seven years. That's almost 410,000 per year compared to the 153,000 public charging points installed in 2023.

Over the past seven years, sales of BEVs have outpaced the growth of the charging point network by more than threefold. Between 2017 and 2023, electric car sales increased over 18 times, while the number of public chargers in the EU grew merely sixfold during the same period. While some countries are powering ahead when it comes to infrastructure rollout, the majority are lagging. Indeed, just three EU countries covering over 20% of the EU's surface area – the Netherlands, France, and Germany – are home to almost two-thirds (61%) of all EU charging points. The other third (39%) of all chargers is distributed throughout 24 member states, covering almost 80% of the region's surface area.

1.2 Digitalisation and automation

Today, more than 50 million vehicles are connected, generating vast amounts of data that can enable new products and services, make mobility smarter and crucially keep it affordable. The forecasted trends shown in Figure 5 highlight the car sales of light vehicles in Europe between 2017 and 2030. A clear shift towards high levels of automation is visible.

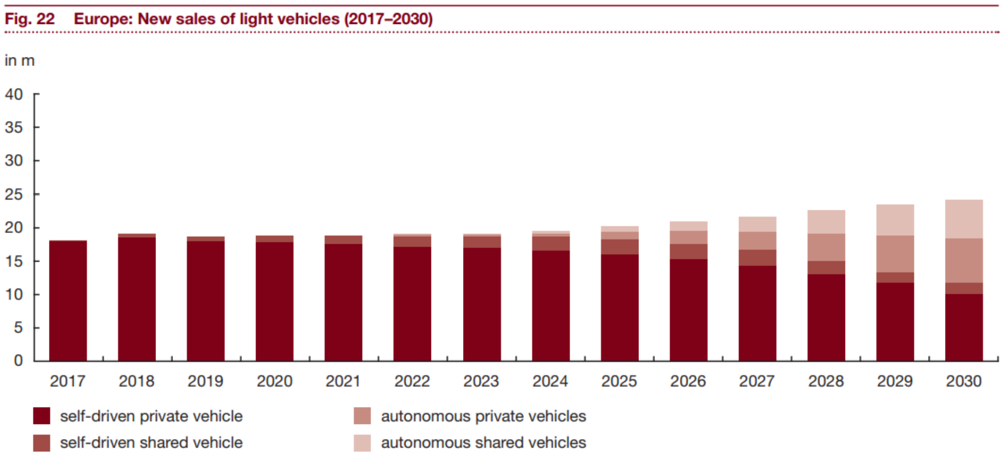

Figure 5: Source: PwC[6]

[6] *Felix Kuhnert, Christoph Stürmer and Alex Koster: Five trends transforming the Automotive Industry, PwC,* *https://www.pwc.com/gx/en/industries/automotive/assets/pwc-five-trends-transforming-the-automotive-industry.pdf*

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With autonomous vehicles, data is a crucial element to consider. The integration of data analytics enables manufacturers to optimise production processes, forecast demand, and enhance supply chain management, leading to cost savings and improved product quality. Automation, through robotics and AI-driven systems, streamlines assembly lines, reduces human error and accelerates manufacturing speeds. Additionally, data from connected vehicles provides real-time insights into performance and maintenance needs, enhancing customer satisfaction and reducing downtime. In autonomous vehicles, data and automation are crucial for navigation, decision-making, and ensuring passenger safety.

1.3 Sustainability and circular economy

Transport accounts for a quarter of the EU's total greenhouse gas (GHG) emissions, with approximately three-quarters of these emissions coming specifically from road transport. Further, manufacturing activities related to the production of vehicles represent 10% of global industrial emissions.

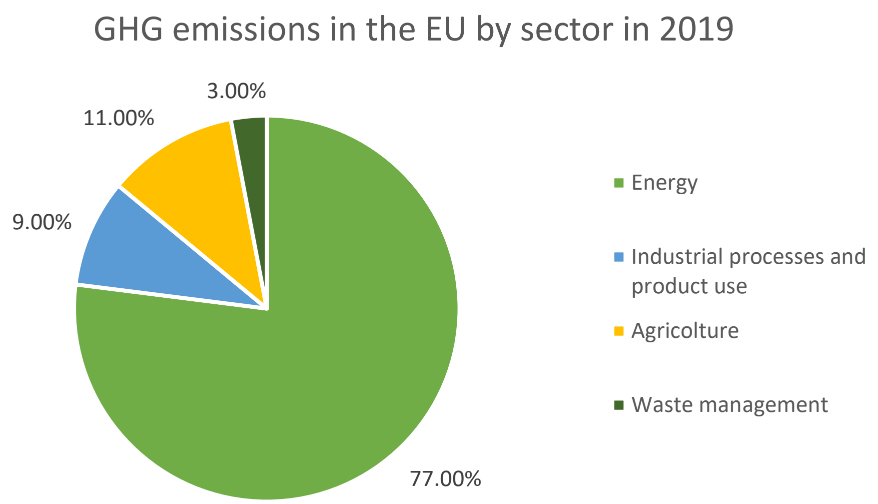

Figure 6: Source: European Parliament[7]

[7] *Greenhouse gas emissions by country and sector (infographic), 28-03-2023, European Parliament,* *https://www.europarl.europa.eu/topics/en/article/20180301STO98928/greenhouse-gas-emissions-by-country-and-sector-infographic#:~:text=Energy%20is%20responsible%20for%2077.01,management%20of%20waste%20with%203.32%25*

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Energy is responsible for 77% of greenhouse gas emissions in 2019, of which transport accounts for about a third.

Technologies such as battery electric vehicles and the transition from fossil fuels to hydrogen and other renewable fuels will enable significant emission savings in the use-phase. Here, automotive suppliers invest more than €20 billion a year in (the upgrade of) production facilities, production equipment, and research & development related to e-mobility alone.

As use-phase emissions continue to fall due to fleet turnover with zero and low-emission vehicles, the attention will increasingly shift towards the entire value chain involved in vehicle production. While emissions associated with material production, component assembly and logistics represent only 10% of the life-cycle emissions for traditional internal combustion engines, the scenario changes dramatically for battery electric vehicles, where the production phase can account for as much as 70% of life-cycle emissions due to a large reduction in use phase emissions and the energy intensity of battery production. The transition to EV alone, therefore is not sufficient to meet CO2 reduction targets.

ESG policy frameworks can foster a market for sustainable products by supplying customers with information that helps them make informed decisions. Over the past five years, the EU has implemented unified standards and classification systems, such as the Corporate Sustainability Reporting Directive, the EU Taxonomy Regulation, and the Green Claims Directive (see Chapter 2). Nonetheless, these measures have imposed a considerable bureaucratic burden on companies.

1.4 Tyres and rubber components in the automotive sector

The European Tyre and Rubber industry counts around 4,400 companies in the EU employing directly about 370,000 people. ETRMA tyre corporate companies represent globally 73% of world sales and 7 out of 10 world leaders are its members. These manufacturers have a strong presence in the EU and candidate countries with 93 tyre-producing plants.

The European tyre and rubber industry provides traction for Europe’s economy and society. Without tyres and rubber goods, Europeans cannot move, our economy – from agriculture to communications – grinds to a halt, and our defence and healthcare systems are unable to function. It is a sector that is energy, labour and capital intensive.

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Because of its specificities, the industry needs to find workers who combine mechanical, chemical, electronic engineering and digital skills to support the transition and continuous digitalisation of the sector. Finally, this strategic industry remains dependent upon third countries for natural rubber, one of its most important raw materials.

Coupled with this key role in the automotive sector, tyre companies continually invest in the digitalisation and green transition of the sector through 17 R&D tyre centres spread across Europe. Research and innovation departments are crucial to tackling current challenges and benefit future perspectives, such as data analysis and artificial intelligence. This is particularly evident in the industry's commitment to producing high-performance tyres in Europe, both in terms of driving safety, experience but also sustainability.

To ensure this, a highly skilled workforce, regulatory and financial incentives, secured global supply chain are necessary to upscale and rescale the tyre and rubber component manufacturers and, therefore, the automotive industry.

1.5 Global economy context

The automotive supply industry continues to be one of Europe's most competitive manufacturing industries but now faces fierce competition from other regions. Small and medium-sized suppliers, in particular, struggle to secure financing for these essential investments in the digital and green transition and face significant administrative burdens. While the European Union continues to be a stronghold of innovation, first production too often occurs in regions where energy costs are lower, financial conditions better and access to public funding is easier to obtain. Therefore, Europe requires consolidated efforts to reinforce its competitiveness, such as the reduction of energy costs, streamlined regulations, a strong single market, and an open trade policy, as well as a focus on skills.

The automotive industry heavily relies on critical raw materials sourced from Asia, particularly to produce electric vehicles (EVs) and advanced automotive technologies. Key materials such as lithium, cobalt, and rare earth elements are predominantly mined and processed in countries like China, Indonesia, and the Philippines. These raw materials are essential for manufacturing batteries, electric motors, and various electronic components. This dependency on Asian suppliers presents significant challenges, including supply chain vulnerabilities, geopolitical risks, and market volatility.

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Supply Risk Raw material	Supply risk	Li-ion battery	Fuel cells	Electrolyser	Traction motors	Heat pump	Data transmission network	Data storage and servers	Additive manufacturing	Robotic
Gallium	4.8						x	x		x
Magnesium	4.1			x				x	x	x
REE (magnets)	4.0		x	x	x	x	x	x		x
Boron	3.8		x	x	x	x	x	x		x
PGM	2.7		x	x			x	x		x
Lithium	1.9	x					x	x		x
Bismuth	1.9						x	x		x
Germanium	1.8						x	x		x
Natural graphite	1.8	x	x	x			x	x		
Cobalt	1.7	x	x	x			x	x	x	x
Titanium metal	1.6							x	x	x
Silicon metal	1.4		x	x	x	x	x	x	x	x
Tungsten	1.2			x				x	x	x
Manganese	1.2	x	x	x		x	x	x	x	x
Nickel	0.5	x	x	x		x	x	x	x	x
Copper	0.1	x	x	x	x	x	x	x	x	x
HREE (rest)	5.3		x	x			x	x	x	x
Niobium	4.4			x			x		x	x
LREE (rest)	3.5		x	x			x	x		x
Phosphorus	3.3	x						x		x
Strontium	2.6		x	x			x	x		
Scandium	2.4			x					x	x

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Vanadium	2.3	x	x			x		x	x
Antimony	1.8					x	x		x
Beryllium	1.8						x		x
Arsenic	1.6					x	x		x
Feldspar	1.5	x							
Hafnium	1.5							x	x
Baryte	1.3	x	x			x	x		x
Tantalum	1.3		x			x	x		x
Aluminium	1.2	x	x	x	x	x	x	x	x
Helium	1.2								x
Fluorspar	1.1	x			x	x	x		x
Phosphate rock	1.0					x	x		

Table 1: Raw material overview

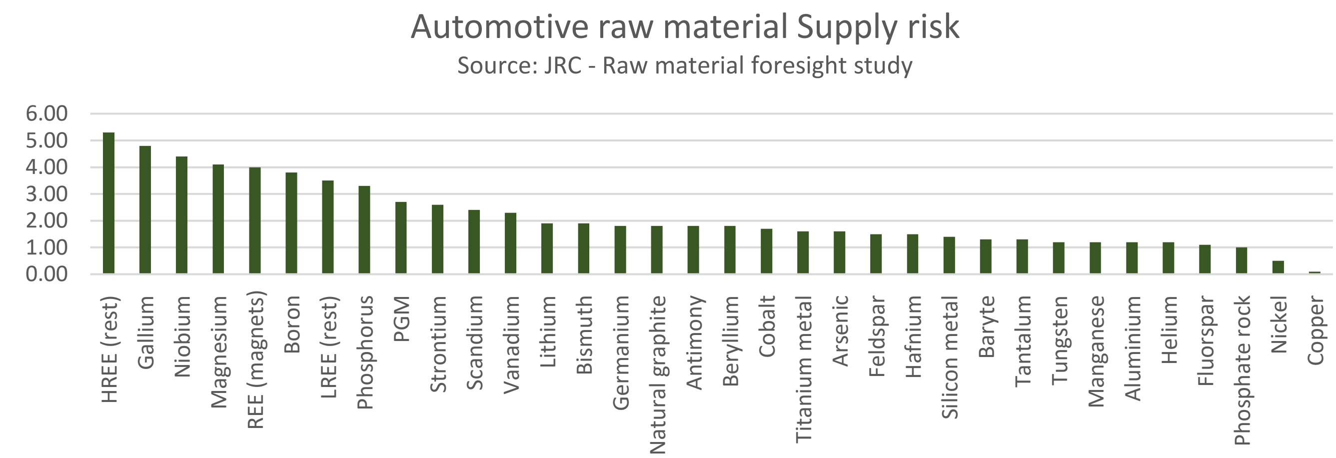

Figure 7: Source: JRC - Raw material foresight study[8]

While the need to diversify raw material sourcing is evident, the semiconductor shortage underscores the challenges of quickly adapting to demand fluctuations. Climate change and

[8] *Bobba, S., Carrara, S., Huisman, J., Mathieux, F., Pavel, C.: Critical Raw Materials for Strategic Technologies and Sectors in the EU A Foresight Study, European Commission, Joint Research Centre, 2020,* https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

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a more unstable geopolitical landscape indicate that automotive suppliers must brace for increased unpredictability. However, these suppliers depend on highly specialised processed materials and intermediate goods. The global automotive supply chain has evolved over decades of economic integration, propelled by free trade agreements, economic policies, and international cooperation. Thus, diversifying sourcing is a complex and gradual process that suppliers cannot undertake alone. Nonetheless, suppliers should audit their supply chains, identify risks, and implement strategies to mitigate them.

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2 MAIN EU LEVEL POLICIES AFFECTING THE ECOSYSTEM

As evidenced above, the EU is currently at the forefront of legislative efforts to transform the automotive mobility ecosystem. The growing focus on climate change and its environmental, social, and economic challenges has brought the ecosystem under scrutiny by the EU, with the objectives of reducing carbon emissions, achieving climate neutrality, enhancing safety and fostering innovation. This, of course, implies substantial changes in employment and skills required for the sector's current and future workforce.

Such policies are designed to address environmental concerns while promoting technological advancements as well as social and economic growth within the automotive sector. Therefore, the automotive mobility ecosystem is heavily influenced by a range of policies aimed at promoting sustainability, innovation, and competitiveness. These policies are impacting vehicle manufacturing, emissions, safety, digitalisation, and infrastructure development.

The present chapter will highlight the main policies affecting the ecosystem with the aim of investigating the state of the art of the sector when it comes to its level of awareness, preparedness and scalability of such legislative framework. This will ultimately better frame the current challenges and opportunities when it comes to the implementation of such requirements set by the EU.

2.1 Key regulations and most recent developments

The main legislative steps set by the EU underlined in this study aim at tackling the key interconnected aspects of climate neutrality, decarbonisation and circularity, raw materials, EU production capacity, infrastructure and social dimension.

The European plan to develop a greener transport sector was officially concretised at the end of 2019 with the elaboration of the **Green Deal**[9], a plan studded with very ambitious goals and aimed at achieving climate neutrality by 2050, with a significant focus on reducing greenhouse gas emissions from transportation. This includes stringent CO2 emission standards for vehicles and promoting the adoption of electric vehicles (EVs) and alternative

[9] *European Green Deal*. (n.d.). https://www.consilium.europa.eu/en/policies/green-deal/

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fuels. The paragraphs below provide an overview of the relevant key legislations and the most recent developments as of 2024.

2.1.1 Climate neutrality, decarbonisation and circularity

Corporate Sustainability Reporting Directive (CSRD)

This directive will require large and listed companies (except listed micro-enterprises), including those in the automotive sector, to report on sustainability matters such as environmental, social, and governance (ESG) factors, using mandatory EU sustainability reporting standards.

CO2 Emission Performance Standards For Cars And Vans

Concerning cars and light commercial vehicles, the main legislative steps taken at the European level are part of the "Fit for 55" package[10]. In the latest proposal for a revision of Regulation 2019/631 (EU) "setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles", the emissions of new passenger cars registered in the EU would have to be 55% lower, and the emissions of new vans would have to be 50% lower[11] by 2030.

CO2 Emission Standards For Heavy-Duty Vehicles

Heavy-duty vehicles (HDVs) are responsible for more than 25% of greenhouse gas (GHG) emissions from road transport in the EU and account for over 6% of the total EU GHG emissions. In April 2024, a revised regulation on CO2 emission standards for heavy-duty vehicles was adopted[12], with stricter CO2 emissions targets for trucks and buses, which will have to be reduced by 45% for the period 2030-2034, 65% for 2035-2039 and 90% as of 2040. By 2030, new urban buses will need to reduce their emissions by 90% and become zero-emission vehicles by 2035. Emissions reduction targets are also set for trailers (7.5%) and semi-trailers (10%), starting from 2030[13].

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[10] *Fit for 55*. (n.d.). https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55/

[11] European Parliament, *Revision of CO2 emission performance standards for cars and vans, as part of the European Green Deal*, https://www.europarl.europa.eu/legislative-train/package-fit-for-55/file-co2-emission-standards-for-cars-and-vans-post-euro6vi-emission-standards,

[12] https://data.consilium.europa.eu/doc/document/PE-29-2024-INIT/en/pdf

[13] European parliament, *MEPs adopt stricter CO2 emissions targets for trucks and buses*, https://www.europarl.europa.eu/news/en/press-room/20240408IPR20305/meps-adopt-stricter-co2-emissions-targets-for-trucks-and-buses

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EURO 7 Regulation

The Euro 7 regulation establishes rules for the exhaust emissions of road vehicles, but also for other types of emissions such as brake particle emissions, battery durability as well as other specific limits for electric vehicles. It is also the first time the European Union sets a framework to limit tyre abrasion, which will become the fourth tyre characteristic to be regulated after rolling resistance, wet grip and external rolling noise. The regulation will ensure alignment with the efforts of the UNECE World Forum for Harmonization of Vehicle Regulations to develop international rules regarding test methods and limits for several components in the automotive industry. This alignment will be strategic to keep the European industry competitive at the global level and make Euro 7 an opportunity for the automotive industry to upscale and innovate its own production and for the European Union to protect the single market from unfair competition and less sustainable practices.

End-Of-Life Vehicle Regulation

This regulation is set to advance a circular economy and support decarbonisation efforts by covering the entire vehicle cycle from design and production to end-of-life treatment[14]. Key aspects include enhancing the circular design of vehicles for easier material reuse and recycling, ensuring that at least 25% of plastic used to build a vehicle comes from recycling, improving the recovery of high-quality raw materials like critical raw materials (CRMs), but also making producers financially responsible for the proper treatment of end-of-life vehicles and prevent vehicles from going "missing" through better inspections, and extending to cover more vehicle categories, including motorcycles, lorries, and buses.

Eco-design for Sustainable Products Regulation (ESPR)

The Eco-design for Sustainable Products Regulation (ESPR), which entered into force on 18 July 2024, is the cornerstone of the Commission's approach to more environmentally sustainable and circular products. The ESPR aims to significantly improve the circularity, energy performance and other environmental sustainability aspects of products placed on the EU market. Tyres are set to be one of the first products to be regulated under the new

[14] *Proposal for a Regulation on circularity requirements for vehicle design and on management of end-of-life vehicles,* *https://environment.ec.europa.eu/publications/proposal-regulation-circularity-requirements-vehicle-design-and-management-end-life-vehicles_en*

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ESPR, reinforcing the industry's long-standing commitment to make its products more sustainable and contribute to the European Union's circular economy goals.

EU Deforestation Regulation

The EU Deforestation Regulation (EUDR) aims to minimise Europe's role in global deforestation and ensure that commodities under its scope, such as natural rubber, are produced in line with relevant local legislation and do not lead to deforestation. Natural rubber is a critical component of tyres and general rubber goods used in the automotive sector, and starting next year, its sourcing will become increasingly challenging.

European Battery Regulation

Regulation (EU) 2023/1542 mandates sustainability, safety, and labelling requirements for batteries, particularly for electric vehicles. Updates focus on improving battery recycling rates and ensuring transparency in raw material sourcing.

2.1.2 Raw materials and EU production capacity

As part of the **Green Deal Industrial Plan**, legislative initiatives like the **Net-Zero Industry Act** (approved by the Council in May 2024), the **Critical Raw Materials Act** (CRMA, entered into force on May 23, 2024), and reforms to the electricity market are aimed at enhancing the competitiveness and innovation in green technologies of EU industries. The CRMA aims at achieving greater European independence from imports of critical raw materials (such as arsenic, manganese, helium, copper, nickel, etc.[15]) and to diversify their supply chain towards sustainability and circularity; whereas the Net-Zero Industry Act aims to significantly bolster the EU's manufacturing capacity for net-zero technologies to meet climate and energy targets by 2030 and achieve climate neutrality by 2050.

2.1.3 Infrastructure

Alternative Fuels Infrastructure Regulation (AFIR)

This regulation supports the deployment of infrastructure for alternative fuels, such as electric recharging points and hydrogen refuelling stations, to promote zero-emission mobility. Key objectives include also mandating easy-to-use, contactless payment methods

[15] *European Commission, Critical Raw Materials,* https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en,

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and ensuring transparent pricing for consumers; creating consistent standards across the EU to ensure seamless use of alternative fuels infrastructure; facilitating cross-border travel and reducing barriers for EV adoption; providing guidelines and financial incentives to accelerate infrastructure deployment and support member states in achieving these targets.

2.1.4 Social Dimension

The twin transition, as well as the regulatory proposals to make Europe the first climate-neutral continent, are largely impacting the labour markets in the automotive-mobility ecosystem, though with varying intensity depending on the sector and geographical location. As a result, some parts of the ecosystem are facing significant labour relocation and an urgent need for re-skilling and up-skilling the workforce. Indeed, the impacts of the green transition on business, employment and skills needs vary largely according to sector, occupation, region and country, implying job changes within sectors and industrial ecosystems.

The green transition brings opportunities and challenges for workers and businesses at the same time. The green transition requires businesses to change profoundly, which implies the need to adapt the competences and skills of workers to new production processes, new materials, and finding new ways to provide services. A process of structural change is in place, which needs to be feasible in view of companies' and workers' real capacity to implement and finance the necessary adaptation to the green transition.

Against this background, the role of improved employment policies and better performing education and training systems will also be crucial to provide the skills needed in companies to implement the necessary adaptation to the twin transition.

When looking specifically into the European proposals released in order to tackle the employment and skills dimension of the twin transition in the economy, one can mention the **Council Recommendation on ensuring a fair transition towards climate neutrality**, unanimously adopted in June 2022, which provides concrete guidance to Member States on how to address the employment and social dimension of the transition and mainstream fair transition aspects across all policies. With this Recommendation, Member States are encouraged to take measures and actions adapted to their own circumstances around four policy areas:

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- Measures to support quality employment and facilitate job-to-job transitions. This includes, for instance, offering tailored job search assistance and promoting job creation, and facilitating access to finance and markets for micro, small- and medium-sized businesses, in particular those contributing to climate and environmental objectives. The measures should include specific support for workers affected by the transition beyond re-skilling and up-skilling.
- Measures to support equal access to quality education and training. This concerns, for example, developing up-to-date intelligence on skills needs in the labour market, providing high-quality and inclusive education and training in skills and competencies relevant to the green transition, and increasing adult participation in lifelong learning.
- Measures to support fair tax-benefit and social protection systems. Member States are invited to assess and, where necessary, adapt these systems, for instance, by further shifting the tax burden away from labour towards other sources contributing to climate and environmental objectives.
- Furthermore, the European Commission also encourages Member States to put in place measures to support affordable access to essential services and housing.

This mobility ecosystem pathway entered the co-implementation phase in February 2024, and all mobility stakeholders are now asked to promote ambitious and concrete actions to move towards the green and digital transition of the mobility ecosystem.

Solutions to tackle the impact of the green and digital transition on employment and skills

Recognising the scale and pace of the transition underway in the automotive and wider mobility ecosystem, several solutions shall be taken into consideration:

- **Mapping the employment impact of the green transition**: with a clear and granular mapping at the company, sectoral, regional and national levels.
- **Reinforcing social dialogue** – the key role of social partners at all levels in making the twin transition a reality. Social dialogue is a fundamental pillar of the European social model and is today a crucial component in dealing with the twin transition. At the national level, recognised sectoral social partners play a critical role in shaping the world of work in the frame of collective bargaining. Collective agreements remain an important tool to deal with the rapid transformation that the world of work is

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undergoing due to multiple structural factors, including the twin transition, the shortage of skills, etc. These agreements provide a framework for addressing labour market challenges and adapting employment conditions to the evolving needs of the world of work. Likewise, the social partners should be consulted in a timely manner about the development and deployment of employment and skills policies at the national and EU levels. In the transformation underway, all policies and legislative proposals are interconnected. Consequently, "greening policies" and "industrial policies", for example, exert a substantial impact on labour markets and their principal actors: companies and workers. In light of this, policymakers should also consult social partners in the formulation and implementation of such policies. Ensuring the involvement of social partners is essential to comprehensively address the implications of the different policy initiatives in the world of work. In the field of education and training, social partners at all levels have a critical role to play in anticipating and managing skills needs and organising up- and re-skilling. In the same way, they have a critical role to play in the anticipation of future skills needs, as well as supporting the green transition, by developing education and training curricula that are aligned with the labour market's changing skills needs.

- **Investing in up-skilling and re-skilling of the workforce**. Re-skilling and up-skilling policies must be put at the core of a renewed European industrial strategy. Decision-makers throughout Europe must firmly support the re-skilling and up-skilling of the automotive-mobility industries' workforce, particularly in the sectors which are experiencing significant technological transformations, such as the automotive sector.
- **Putting in place effective job-to-job transition measures with an active involvement of social partners at all levels**. Effective job-to-job transition measures should be put in place, in particular within those sectors of the automotive-mobility ecosystem that undergo a profound structural transformation due to rapid technological change and the need for new skills adapted to a greener economy. Against this background, national policymakers should urgently design and deploy effective job-to-job transition measures, especially targeted to those workers most affected by the twin transitions. These types of measures should enable those workers to change jobs and even sectors, without becoming unemployed. The active involvement of public

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employment services, together with the social partners, is crucial when designing these types of job-to-job transition measures.

- **Supporting SMEs**. SMEs, which are the vast majority of companies in the automotive-mobility ecosystem, face specific issues when it comes to putting in place training schemes due to limited financial resources, lack of personnel, lack of training facilities, or a non-existent dedicated Human Resources department. Targeted support must be deployed in a simple and user-friendly manner for companies, in particular SMEs, to deploy the right skilling schemes adapted to the needs of the labour market, including specific measures for workers that cannot be retrained within these companies.
- **Ensuring a stable and coherent regulatory environment for the sector**. The automotive-mobility industries and their workforce operate today in a highly complex, competitive, globalised economy and in a world of growing socio-political and economic uncertainties. The current fragmentation of the EU regulatory framework for the sector creates a context of uncertainty that undermines investment and weakens market demand. The European Commission should make proposals to streamline and better articulate regulations, ensuring that EU law-making delivers for everyone, including companies, workers and trade unions. The Commission should also conduct extensive impact assessments and competitiveness checks before proposing new regulations, including closely monitoring investment and innovation capacity. The environmental and social dimensions should be integrated, as possible, into all policies, ensuring that the transition is sustainable and fair.
- **Supporting the exchange of best practices at all levels**. There are many good examples of initiatives at the national level that have proven to be successful in order to tackle the impact of the twin transition on employment and skills in the automotive-mobility ecosystem. EU policymakers should facilitate a structured exchange of best practices and leverage these successful examples.

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2.2 Main implications: level of preparedness, scalability, opportunities and challenges

The above legislative framework focuses on the commitments to move the industry into fossil-free solutions, focusing on battery-electric and hydrogen-powered vehicles, along with new technologies, new infrastructure and circular business models.

Meeting climate targets is fundamental, with undeniable environmental and economic benefits[16],[17]: the shift towards low-emission and zero-emission vehicles contributes to improved air quality and reduced carbon footprint, aligning with global climate goals, while the development of new technologies and infrastructure stimulates economic activity, creating jobs and attracting investments in the green mobility sector[18;19].

Such transformation hinges on several enabling conditions which need to be implemented in order to ensure a smooth transition. In this regard, several factors come into play, such as:

- **Political will and governance[20]**: EU and national Governments' commitments are crucial. The extent to which the EU and Member States prioritise and commit to enforcing automotive regulations significantly impacts their effectiveness. Strong political support and alignment between EU directives and national policies enhance enforcement.
- **Technological Readiness[21;22]**: The adoption of EVs, alternative fuels, and advanced safety systems depends on the maturity and cost-effectiveness of these technologies. Continuous innovation and economies of scale are essential for wider adoption.
- **Infrastructure Development**: The success of policies like AFIR[23] relies on the rapid and widespread deployment of EV charging and alternative fuel infrastructure. This requires

[16] *Sedgwick. (2024b, April 19). European Union automotive industry will go zero emissions by 2035 | Sedgwick. Sedgwick.* https://www.sedgwick.com/blog/european-union-automotive-industry-will-go-zero-emissions-by-2035/?loc=eu

[17] *Industry, Innovation, and Infrastructure | Close the Gap Foundation. (n.d.). Close the Gap Foundation.* https://www.closethegapfoundation.org/glossary/industry-innovation-and-infrastructure

[18] *GGI Insights. (2024, April 9). Industry, Innovation, and Infrastructure: Building a Prosperous Future. Industry, Innovation, and Infrastructure: Building a Prosperous Future.* https://www.graygroupintl.com/blog/industry-innovation-and-infrastructure

[19] *Skills for green jobs*. (n.d.). https://www.cedefop.europa.eu/files/3057_en.pdf

[20] *Team, I. (2021, October 19). What regulations affect the automotive sector? Investopedia*. https://www.investopedia.com/ask/answers/042015/how-much-impact-does-government-regulation-have-automotive-sector.asp

[21] *Dosso, Mafini. (2020). Technological readiness in Europe. 10.4324/9780429057984-12.*

[22] *Jagani, S.; Marsillac, E.; Hong, P. The Electric Vehicle Supply Chain Ecosystem: Changing Roles of Automotive Suppliers. Sustainability 2024, 16, 1570.* https://doi.org/10.3390/su16041570

[23] *Press corner. (n.d.-b). European Commission - European Commission.* https://ec.europa.eu/commission/presscorner/detail/en/IP_23_1867

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substantial investment and coordinated efforts between the public and private sectors. A dense network of charging and refuelling stations is a key enabling condition[24]. However, transitioning to sustainable mobility requires substantial investments in R&D, manufacturing, and infrastructure This can be a financial strain, especially for smaller companies and economies[25].

- **Market Dynamics[26]**: The automotive market's response, including consumer acceptance of new technologies and willingness to adopt low-emission vehicles, influences enforcement effectiveness and legislative efforts' scalability. Incentives for EV adoption and penalties for non-compliance with emission standards are crucial levers. Market incentives and consumer preferences play a significant role. Concerns about range, cost, and infrastructure availability need to be addressed[27;28].
- **Harmonisation and Flexibility**: The EU's ability to harmonise regulations across Member States while allowing for flexibility in implementation is critical. Meeting stringent emission and safety standards can be challenging for automakers, requiring significant changes in vehicle design and production processes[29;30]. Uniform standards ensure a level playing field, while flexibility accommodates varying national contexts and market conditions. Effective monitoring and penalties[31], along with a robust compliance mechanism, including regular monitoring, reporting requirements, and penalties for non-compliance, ensure adherence to legislative frameworks.

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[24] *ACEA, Auto sector CEOs to EU leaders: Europe needs robust Industry deal to make the Green Deal happen,* *https://www.acea.auto/press-release/auto-sector-ceos-to-eu-leaders-europe-needs-robust-industry-deal-to-make-the-green-deal-happen/*

[25] *Krishnan, M., Samandari, H., Woetzel, L., Smit, S., Pacthod, D., Pinner, D., Nauclér, T., Tai, H., Farr, A., Wu, W., & Imperato, D. (2022, January 25). Six characteristics define the net-zero transition. McKinsey & Company.* *https://www.mckinsey.com/capabilities/sustainability/our-insights/six-characteristics-define-the-net-zero-transition*

[26] *Our Automotive & Assembly Insights. (2023, July 10). McKinsey & Company.* *https://www.mckinsey.com/industries/automotive-and-assembly/our-insights*

[27] *Potter, Kaledio & Favour, Olaoye. (2024). Studying the Current Market Trends, Consumer Demand, and Government Incentives Driving the Adoption of Electric Vehicles. Vehicle Engineering*

[28] *Buhmann, K. M., & Criado, J. R. (2023). Consumers' preferences for electric vehicles: The role of status and reputation. Transportation Research. Part D, Transport and Environment, 114, 103530.* *https://doi.org/10.1016/j.trd.2022.103530*

[29] *Team, E. S. (2024, January 6). The World of Automotive Compliance: Safety and Regulations - ESS Global Training Solutions. ESS Global Training Solutions.* *https://esoftskills.com/the-world-of-automotive-compliance-safety-and-regulations/*

[30] *Evolution of the automotive sector – regulation & compliance — Financier Worldwide. (n.d.). Financier Worldwide.* *https://www.financierworldwide.com/evolution-of-the-automotive-sector-regulation-compliance*

[31] *Mobility and Transport 2022. (n.d.). European Commission.* *https://commission.europa.eu/law/application-eu-law/implementing-eu-law/infringement-procedure/2022-annual-report-monitoring-application-eu-law/mobility-and-transport-2022_en*

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- **EU competitiveness**[32]: EU policies drive innovation in vehicle technology, fostering a competitive edge for European automakers in the global market. Advances in EVs, autonomous driving, and smart mobility solutions present significant growth opportunities. However, there is a need to build a holistic industrial strategy to make the EU competitive and build a stronger business case for the auto industry's green and digital transition.

The European automotive industry[33] stands at a critical juncture, balancing the immense opportunities presented by green mobility, technological innovation, and new business models against the significant challenges of high costs, regulatory compliance, shifting consumer preferences, supply chain issues, and the need for robust infrastructure. The perception of companies regarding the implementation of EU policies is mixed, reflecting a balance of optimism and concern[34;35;36]. There is a positive perception as many companies view EU policies as a catalyst for innovation and market transformation. They recognise the long-term benefits of sustainable practices and the potential for leadership in green mobility. However, companies are at the same time worried about the financial burden and operational disruptions caused by regulatory compliance. Smaller firms may struggle with the pace of change and the resources required. This, of course, requires strategic adaptation to align with EU policies. This includes investments in EV technology, partnerships for infrastructure development, and efforts to meet emission targets.

[32] *Automotive industry transformation and industrial policy in the EU and Germany: A critical perspective. (n.d.-b).* *https://www.econstor.eu/bitstream/10419/271001/1/1840242728.pdf*
[33] *The Future of the EU automotive sector. (n.d.).* *https://www.europarl.europa.eu/RegData/etudes/STUD/2021/695457/IPOL_STU(2021)695457_EN.pdf*
[34] *Megyeri, Eszter & Pelle, Anita & Tabajdi, Gabriella. (2023). The realities of EU industrial policies analysed through automotive value chain dynamics. Society and Economy. 45. 10.1556/204.2023.00005*
[35] *European Auto Industry Is at a Crossroads. (n.d.). Retrieved June 6, 2024, from https://mkt-bcg-com-public-pdfs.s3.amazonaws.com/prod/european-auto-industry-is-under-pressure.pdf*
[36] *How auto manufacturers can design for sustainability. (n.d.). DXC Technology.* *https://dxc.com/us/en/insights/perspectives/paper/how-auto-manufacturers-can-design-for-sustainability*

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3 SECTORAL TRENDS FOR 2030-2050: RELEVANCE, URGENCY AND IMPLICATIONS ON SKILLS AND JOBS FORECASTING

This section describes sectoral trends for 2030-2050 in terms of relevance, urgency, and implications on skills and job forecasting.

3.1 Digitalisation

Major progress in digital technologies such as artificial intelligence (AI), the Internet of Things (IoT), cloud and edge computing and 5G networks are leading the digital transformation of the mobility sector. In the following subsections, we look at the impacts digitalisation has on mobility, challenges, and benefits[37].

3.1.1 How is digitalisation impacting mobility?

- **Autonomous vehicles are on the rise**, allowing new transport solutions like robotic taxis, connected lorries or driverless delivery systems.
- **New mobility services enabled by digital platforms** are changing how we move, from shared mobility, such as ride hailing and bike sharing, to Mobility as a Service, which gives access to multiple transport modes on a single application. Freight transport relies more on greater synchronisation across modes.
- **The data generated and exchanged by vehicles is exploding**. Autonomous vehicles could produce around four (4) terabytes of data per day. Vehicles are increasingly connected to their physical and digital environment.
- **New habits and behaviours caused by digitalisation**, such as the rapid development of e-commerce and working remotely, are transforming mobility patterns.

3.1.2 Challenges

- **Addressing technological challenges**: Connected and automated mobility and smart transport systems require huge investments to develop and deploy new technologies and infrastructures. We will need a cloud-edge computing continuum to process vast

[37] *Digitalisation: driving the transition towards smart and sustainable mobility, Retrieved June 19, 2024, from* *https://digital-strategy.ec.europa.eu/en/policies/digitalisation-mobility*

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amounts of data in real time, 5G connectivity to ensure rapid and reliable data transfer, AI to analyse complex information, chips for smart vehicles, and new kinds of automotive operating systems. The EU remains highly dependent on other regions for some technologies like AI, cloud, or semiconductors.

- **Uniting in diversity**: the European mobility ecosystem is composed of a multitude of actors with different specialisations and sizes. This diversity is a strength but can also lead to fragmentation. To seize the benefits of digitalisation, mobility and transport, stakeholders will need to build partnerships, pool investments, and agree on common standards, infrastructures, platforms, and governance frameworks. This will also help to reach critical mass and avoid dependence on large dominant actors.
- **Ensuring security and privacy**: the digitalisation and automation of transport raise challenges in terms of personal data protection, cybersecurity, and user acceptance. Cyber-attacks could affect the functioning of services, cause damage to systems, data thefts and even injuries.
- **Managing social impacts**: the social acceptance of self-driving mobility will be key for its deployment. This transition will require new skills and could lead to the disappearance of certain types of jobs. It should thus be well managed. Certain new forms of mobility create types of work characterised by more flexible conditions, which need to respect EU labour law and ensure social protection.

3.1.3 Benefits

- **Connected and Automated Mobility (CAM)** can make roads, railways and waterways safer. Optimising the use of vehicles and infrastructures can enhance efficiency, reduce congestion and help to lower gas emissions. CAM can also create business opportunities and increase competitiveness. It will make transport more accessible to the elderly and people with disabilities, transforming travel in the years to come.
- **Mobility as a Service** can help to decarbonise transportation by allowing seamless multimodal travel and facilitating access to greener alternatives. Leveraging the way different transport modes improve and enhance each other would allow more efficient use of resources and save time and costs for passengers and transporters.

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- **Tyre as a service (TaaS)** describes the concept of providing tyres and the associated services under a subscription model with strong consideration of all direct and indirect safety, environmental, economic and usability impacts for the customers and society. The optimisation of TaaS requires an in-depth understanding of all the dimensions and their interdependencies for each application case. Tyres as a Service can help drivers and fleet operators increase road safety, save fuel, decrease CO2 emissions, reduce congestion and increase vehicle uptime.
- **Pooling and exchanging mobility data** can improve the synchronisation between different transport modes and infrastructures. Accessing large pools of data would fuel the development of AI-driven applications. Better access to mobility data will help public authorities monitor transport activities and their impacts, and plan transport infrastructure and services. Access to mobility data can create new sources of value: car sensor data, for instance, can be highly valuable to insurance, navigation, or road maintenance companies, while tyre sensors and algorithms collect and translate vehicle data into alerts and advice for repair, maintenance, diagnostic and prognostic services and the wholesale or retail of spare parts.
- **Supporting the transition to zero-emission mobility**. AI can improve the energy efficiency of electric or hydrogen vehicles and optimise the deployment of charging infrastructures. Bi-directional electric vehicle charging could provide flexibility to the grid, making it possible to optimise energy usage and production while better integrating renewable energies. Such sector coupling requires digital enablers and real-time data sharing.

3.1.4 Supporting contemporary mobility systems

Contemporary mobility systems are supported by physical, digital (information) and regulatory (rules) foundations[38].

[38] *The Geography of Transport Systems, SIXTH EDITION, Jean-Paul Rodrigue (2024), New York: Routledge, 402 pages. ISBN 9781032380407, DOI: 10.4324/9781003343196, Retrieved June 19, 2024, from* https://transportgeography.org/contents/chapter2/information-technologies-and-mobility/digitalization-mobility/

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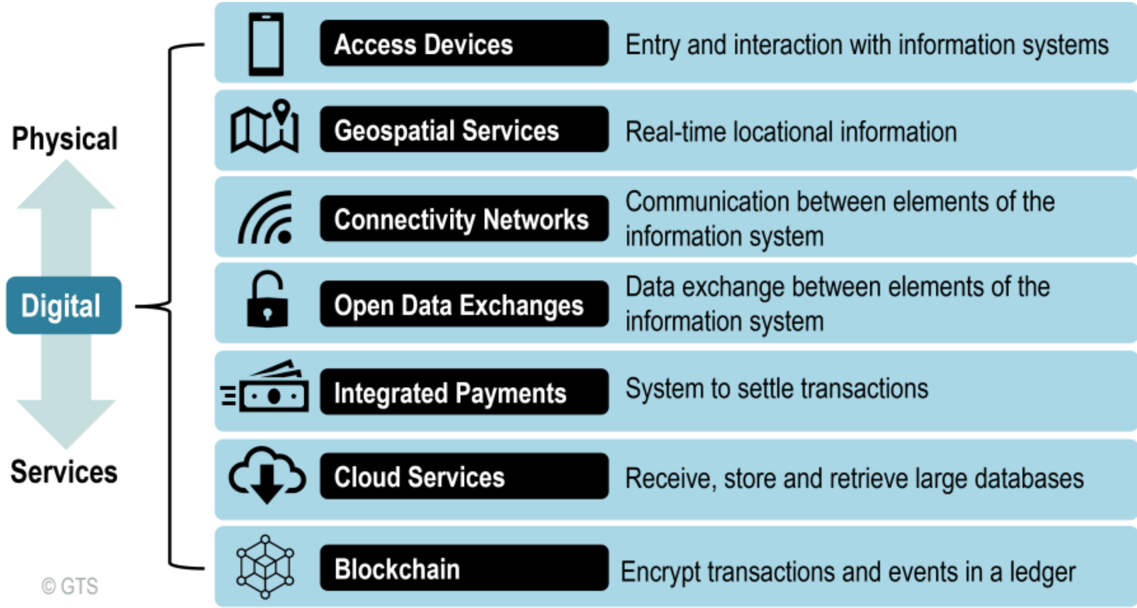

Figure 8: Digital foundations of mobility systems[39]

While physical (e.g., infrastructures) and regulatory (governance, policies) issues are well understood, the digital dimension has considerably evolved in recent years with the introduction of new information technologies. Among the most significant are:

- **Access devices**. A whole array of computing devices, such as computers and smartphones, can access telecommunication networks and retrieve, process, and send information.
- **Geospatial services**. Computing devices able to provide real-time locational information that can be used for a variety of purposes, including vehicle tracking and navigation. They can also include other sensors that can be used to supply visual information (optical character recognition or environment processing) or attribute information (temperature, pressure, humidity).
- **Connectivity networks**. A range of telecommunication systems enabling components of the information system to communicate, which include wired and wireless networks.

[39] *Designing a Seamless Integrated Mobility System (SIMSystem) A Manifesto for Transforming Passenger and Goods Mobility, World Economic Forum, January 2018, Retrieved June 19, 2024, from https://www3.weforum.org/docs/Designing_SIMSystem_Manifesto_Transforming_Passenger_Goods_Mobility.pdf*

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- **Open data exchanges**. A set of standards allowing information exchange and storage that all devices can handle.
- **Integrated payments**. A system that allows actors, such as financial institutions, to settle transactions, such as contracts, purchases, tolls, or fares.
- **Cloud services**. A distributed network of servers that is able to offer massive storage, retrieval, and processing of data.
- **Digital ledgers**. An encrypted digital ledger system, such as a blockchain, is able to accurately record events and transactions.

3.1.5 Industry 5.0

Industry 5.0, the Fifth Industrial Revolution, builds upon the advancements and automation set by Industry 4.0. It can be described as the ultimate result of the automation brought about by Industry 4.0, with a slight twist—the emphasis on human-machine collaboration (HMC), bringing human workers to the centre stage of manufacturing operations, innovations, and decision-making[40].

This paradigm shift in the role of human managers and operators is the core characteristic of Industry 5.0. In Industry 4.0, humans' main roles are to monitor and supervise the automated systems. In Industry 5.0, on the other hand, humans' role is to actively collaborate with machines and systems. Industry 5.0 recognises humans' unique cognitive abilities that machines cannot (yet) replicate, and leverages these abilities to enhance innovation, creativity, adaptability, and problem-solving in day-to-day processes.

European industry is a key driver in the economic and societal transitions that we are currently undergoing. In order to remain the engine of prosperity, the industry must lead the digital and green transitions.

This approach provides a vision of industry that aims beyond efficiency and productivity as the sole goals and reinforces the role and the contribution of industry to society[41].

[40] *Lewis Dixon, Unveiling The Differences Between Industry 4.0 And Industry 5.0, January 4, 2024, Retrieved June 19, 2024, from https://news.lineview.com/unveiling-the-differences-between-industry-4.0-and-industry-5.0*

[41] *Industry 5.0, Retrieved June 19, 2024, from https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/industry-50_en*

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It places the wellbeing of the worker at the centre of the production process and uses new technologies to provide prosperity beyond jobs and growth while respecting the production limits of the planet.

It complements the existing "Industry 4.0" approach by specifically putting research and innovation at the service of the transition to a sustainable, human-centric and resilient European industry.

Key Technological Enablers of Industry 4.0

- **Internet of Things (IoT)**

The essence of Industry 4.0's technology is where embedded sensors and actuators are interconnected with each other, collecting and transmitting data in real-time. This is the Internet of Things (IoT), which enables a seamless flow of real-time information, providing unprecedented insights into each step in the process and facilitating more informed decision-making.

- **Artificial Intelligence (AI)**

AI, or Artificial Intelligence, is the brain of Industry 4.0. AI can analyse data collected in real-time by IoT sensors, identify patterns, and provide machines with the ability to automate decision-making and the execution of their processes. AI facilitates predictive maintenance and smarter quality control software to reduce downtime, optimise production, improve product quality, and enhance overall efficiency.

- **Big Data and Analytics**

IoT sensors, actuators, and machines generate a sheer volume of data. Powerful computing tools capable of sifting through this massive amount of information to extract meaningful insights are critical, or else all this data will become useless.

Big data and analytics play a critical role in facilitating better decision-making, strategic planning, and continuous process optimisation.

- **Cyber-Physical Systems (CPS)**

A key characteristic of Industry 4.0 is the seamless integration of physical components (sensors, machines, actuators) with computational systems (software, AI systems).

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This network of interconnected and synchronised systems enables real-time monitoring, control, and feedback to facilitate continuous improvement.

Why Industry 5.0?

Industries can play an active role in providing solutions to challenges for society including the preservation of resources, climate change and social stability. The Industry of the Future approach brings benefits for industry, for workers and for society. It empowers workers, as well as addresses the evolving skills and training needs of employees. It increases the competitiveness of the industry and helps attract the best talents. It is good for our planet as it favours circular production models and supports technologies that make the use of natural resources more efficient. Revising existing value chains and energy consumption practices can also make industries more resilient against external shocks, such as the Covid-19 crisis.

How to make it happen?

This approach to industry contributes to three of the Commission's priorities[42]:

- "An economy that works for people",
- "European Green Deal" and
- "Europe fit for the digital age".

Elements related to the future of the industry are already part of major Commission policy initiatives:

- **Adopting a human-centric approach** for digital technologies, including artificial intelligence[43].
- **Up-skilling and re-skilling European workers**, particularly digital skills[44][45].
- Modern, **resource-efficient** and **sustainable industries** and transition to a circular economy[46].

[42] *The European Commission's priorities, Retrieved June 19, 2024,* https://commission.europa.eu/strategy-and-policy/priorities-2019-2024_en
[43] *Proposal for AI regulation, Retrieved June 19, 2024, from* https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1623335154975&uri=CELEX%3A52021PC0206
[44] *Skills Agenda , Retrieved June 19, 2024, from* https://ec.europa.eu/social/main.jsp?catId=1223
[45] *Digital Education Action plan, Retrieved June 19, 2024, from* https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12453-Digital-Education-Action-Plan_en
[46] *Green Deal, Retrieved June 19, 2024, from* https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

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- **A globally competitive** and world-leading industry, speeding up investment in research and innovation[47].

[47] *Industrial Strategy, Retrieved June 19, 2024, from https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en*

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3.2 Green, Sustainability and Circular Economy

In line with the overlying European Green Deal targets and evolving customer demands and expectations, suppliers are increasingly investing in circularity strategies, developing a new approach to product design and manufacturing. Circularity maximises the efficiency of resources and energy use by extending the useful life of the products and reducing or eliminating waste during production and end-of-life, while recycling products and materials. Circular economy is also becoming vital in terms of addressing the increasingly high energy costs associated with production processes, material import dependencies as well as product carbon footprint reduction of materials[48].

3.2.1 Strategies for environmental impact reduction

When evaluating a product from a life cycle perspective, a comprehensive view of its environmental costs and benefits emerges. This holistic analysis encompasses various stages, including raw material production, parts fabrication, item transport distribution, energy conservation during the "use phase", product lifetime extension, and post-consumer /end of life management. It also considers recycling retrieval, reuse, or waste-to-energy recovery, offering a full-bodied and conclusive picture of the product's environmental impact[49]. This is known as a Cradle to grave life cycle assessment.

[48] *CLEPA: R&I vision on circularity,* https://clepa.eu/wp-content/uploads/2023/09/Vision-on-Circularity_CLEPA.pdf
[49] *ACCESS: Circularity, Automotive Plastics,* https://www.automotiveplastics.com/roadmap-for-future-mobility/the-access-framework/circularity/

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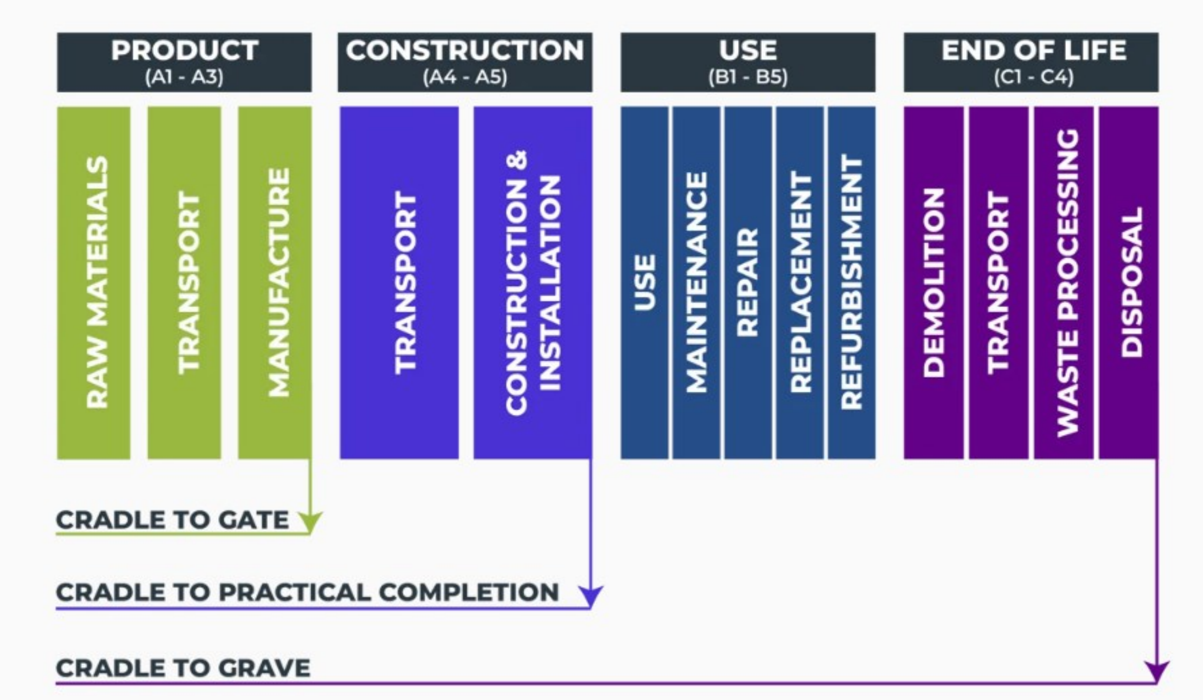

Figure 9: Cradle to Grave Life Cycle Assessment[50]

Circular Economy is a system to reduce – and eventually, eliminate – waste and manage raw materials' scarcity through the continual use of resources. This can be achieved through strategies such as long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and open and close loop recycling. Other practices, specifically used by the automotive industry, include tyre regrooving and retreading[51].

90% of biodiversity loss is attributed to resource extraction and processing, and up to 80% of a product's environmental impact is determined at the design phase. Thus, thoughtful design and strategic resource management are critical in mitigating environmental impacts and promoting sustainability, from the supply of materials to the end of life of a product[52].

3.2.2 Integration of waste from manufacturers as raw material in industrial production

The Council of Supply Chain Management Professionals (CSCMP) defines Supply Chain Management (SCM) as the planning and management of all activities involved in sourcing and

[50] *What are the Life Cycle Assessment Stages? Tunley Environmental, 12 Sept. 2023,* https://www.tunley-environmental.com/en/insights/life-cycle-assessment-stages
[51] *European Plastics Converters,* https://www.plasticsconverters.eu/
[52] *Circular Economy,* https://environment.ec.europa.eu/topics/circular-economy_en

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procurement, conversion, and all logistics management activities. Importantly, SCM also involves coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. Essentially, SCM integrates supply and demand management within and across companies. The supply chain encompasses the processes required to acquire materials, add value to them according to the needs of customers and consumers, and ensure the products are delivered to the desired location and time[53]. The green supply chain management is considered the sum of the following elements: green purchasing, green materials management/manufacturing; green marketing/distribution and reverse logistics. In order that the interested parties have knowledge of the existence of waste, this can be integrated into the value chain as raw material.

The commitment of several automotive industries in this regard is coupled with the increasing challenges with the global supply chain. This is the case with natural rubber, a critical raw material for tyres and other rubber components in vehicles, where the EU Deforestation Regulation accelerated pledges of tyre manufacturers to move towards deforestation-free supply chains. As this transformation had to happen in a very short time frame, both supply chains had to change, and products had to be reformulated to allow for different kinds of natural rubber.

The inclusion of recycled as well as renewable content in the manufacturing of new products is an opportunity to increase the sustainability of the European industry. In the EU – and its Member States – there is a clear trend towards the development of mandatory requirements, with a direct impact on the automotive industry – both from the point of view of the vehicles as a whole (End of Life Vehicle Regulation) and components (Eco-design for Sustainable Products Regulation).

Automotive manufacturers are increasingly adopting recycled plastics in their production processes, including for car interiors and components. This approach is crucial for reducing environmental impact by decreasing the need for virgin plastics and minimising waste. Ford has been a pioneering force in this movement, incorporating recycled plastics into various car parts such as seat fabrics, underbody shields, and engine components. For example, Ford

[53] *Davidson de Almeida Santos et al. 2020, Proposal for a Maturity Model in Sustainability in the Supply Chain in Special Issue Supply Chain Management for Sustainable Development, 12(22),9655,* https://doi.org/10.3390/su12229655

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utilises recycled plastic bottles to manufacture underbody shields for models like the Ford Escape. Volvo is also committed, aiming to incorporate recycled materials in 25% of plastics used in every new Volvo model. These recycled materials primarily originate from discarded fishing nets, maritime ropes, and PET fibres sourced from plastic bottles[54].

Automotive manufacturers are finding innovative ways to manage and repurpose waste. This includes using scrap metal, plastics, and other materials from the production process to create new car parts. This not only reduces waste but also cuts costs and resources needed for new materials[55]. For instance, BMW has implemented several recycling initiatives to integrate waste materials into their production. They use recycled materials in their cars, such as recycled aluminium and plastics, and have set ambitious targets for increasing the amount of recycled content in their vehicles. This helps in reducing the environmental footprint of their production processes.

In conclusion, the integration of green supply chain management practices is essential for the sustainable development of industries, particularly in the automotive sector. Automotive manufacturers are leading by example, adopting innovative methods to incorporate recycled materials into their production processes. These practices not only help in managing waste and cutting costs but also underscore the importance of collaboration across the supply chain. By working together, companies can create a more sustainable value chain, ultimately benefiting the environment and society. The shift towards green supply chain management is a crucial step in addressing the pressing issues of climate change and resource scarcity, ensuring a sustainable future for the automotive industry and beyond.

3.2.3 Changing the mindset towards a circular economy in the automotive sector

The EU aims to transition to a circular economy to reduce the pressure on natural resources as well as to create sustainable growth and jobs. For that, it is necessary to be climate neutral by 2050 and stop biodiversity loss. There is a need to transition to a regenerative growth

[54] *Volvo Cars aims for 25 per cent recycled plastics in every new car from 2025, Jun 18, 2018,* *https://www.media.volvocars.com/global/en-gb/media/pressreleases/230703/volvo-cars-aims-for-25-per-cent-recycled-plastics-in-every-new-car-from-2025*
[55] *5 barriers to using recycled materials to boost the circular economy, World Economic Forum, Dec 10, 2021,* *https://www.weforum.org/agenda/2021/12/5-barriers-to-using-recycled-materials-to-boost-the-circular-economy/*

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model, instead of the old one, so that natural resources can be protected while boosting sustainable growth.

The main principle of circularity emphasises not only recovering materials at the end of their life cycle but reusing them in new products, extending products' life cycles (e.g., retreading practice in the tyre industry), reducing the demand for finite raw materials. In Europe, only 11,8% are from circular material, having the objective to double that in the upcoming decade.

The automotive industry is increasingly adopting circular economy principles. This involves recycling and reusing materials to create a closed-loop system. For example, old car parts are being recycled to produce new ones, and automotive companies are working on developing vehicles with parts that are easier to recycle at the end of their lifecycle[56]. 50 of the 280 kilograms of plastics used in a Renault Espace come from recycled sources, including closed-loop EOL plastics[57]. This new approach opens the opportunity to develop the following areas:

- Collection and Dismantling,
- Lifecycle Assessment,
- Recovery and Sorting,
- Remanufacturing and refurbishing.

Knowing that Eco Desing is getting an important role in circularity, automotive manufacturers are focusing on designing vehicles with more recyclable and renewable quantities of parts or an open-loop approach (for alternative applications).

The tyre industry drives circularity ensuring that for every tyre sold, a tyre is collected and made available for recycling. The industry has retread and regroove truck and bus tyres, saving raw materials and energy. More can be done to enhance tyre circularity by creating a single market for secondary raw materials and providing financial incentives for innovative production and recycling processes. These tyre-derived secondary raw materials can be used in a number of applications, and their value could be better recognised through the development of end-of-life criteria.

[56] *5 barriers to using recycled materials to boost the circular economy, World Economic Forum, Dec 10, 2021,* *https://www.weforum.org/agenda/2021/12/5-barriers-to-using-recycled-materials-to-boost-the-circular-economy/*
[57] *Ellen MacArthur Foundation, Scaling Recycled Plastics across Industries, March 2017,* *https://www.ellenmacarthurfoundation.org/assets/downloads/ce100/Scaling-Recycled-Plastics-across-Industries.pdf*

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In the mobility sector, rubberised asphalt is a promising market for ELT-derived secondary raw materials. It refers to regular asphalt that has been modified with ELT-derived rubber powder. This comes with several advantages, such as high durability of pavement with lifetimes up to three times longer compared to traditional asphalt, increased drainage in wet weather, and better response in case of sudden braking.

General Motors has a goal to source 100% sustainable materials for their vehicles by 2030[58]. BMW has integrated recycled plastics into electric vehicles, such as the BMW i3, with interior components made from recycled materials. Mercedes-Benz has implemented recycled plastics in their production lines, including parts like wheel arch linings and underbody panels[59].

These practices are part of a broader industry shift towards a circular economy, where materials are kept in use for as long as possible, and the lifecycle of products is extended through recycling and reuse. The automotive industry is increasingly adopting these methods to lower environmental impacts, improve resource efficiency, and meet regulatory requirements for sustainability.

3.2.4 Process alteration in manufacturing for environmental sustainability

The advent of Industry 4.0 has revolutionised the manufacturing industry by incorporating interconnectivity, decentralised decision-making, resource optimisation, and automation. This transformation has been made possible through the integration of advanced digital technologies. While Industry 4.0 has significantly enhanced production efficiency and real-time transparency, the urgency of creating a holistic and sustainable environment has become increasingly apparent[60].

Sustainability began to be debated after the publication of the Brundtland Commission (World Commission on Environment and Development, 1987), which presented sustainable development as one that “meets the needs of the present without compromising the capacity

[58] *Volvo Cars aims for 25 per cent recycled plastics in every new car from 2025, Jun 18, 2018,* *https://www.media.volvocars.com/global/en-gb/media/pressreleases/230703/volvo-cars-aims-for-25-per-cent-recycled-plastics-in-every-new-car-from-2025*
[59] *ACCESS: Circularity, Automotive Plastics,* *https://www.automotiveplastics.com/roadmap-for-future-mobility/the-access-framework/circularity/*
[60] *Schuh, G., Kuhlmann, K., & Gartzen, T. (2015). "Industry 4.0 and the impact on sustainability in the manufacturing sector."*

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of future generations to meet their own needs"[61]. Sustainability has been defined in three major dimensions (environmental, social, and economic) and should overcome organisational boundaries, including transparency of supplier operations, risk management, and improve stakeholder engagement[62].

In terms of operations, Volvo Cars aims to have climate-neutral manufacturing operations by 2025. In January this year, the engine plant in Skövde, Sweden, became its first climate-neutral facility[63].

Lifecycle tools and other long-term design strategies could help reduce technical and logistical barriers to EoL vehicle disassembly and improve recycled material recovery rates for automotive plastics and polymer composites.

Global automakers use closed-loop recycling approaches to reduce material waste and manufacturing energy consumption by replacing virgin materials with recycled materials in the same production cycle. This approach is not widely implemented due to difficulties with insufficient scale, supply chain coordination and recycling quantity[64].

Companies invest in modern cooling systems or new machinery to save energy or water and to reduce CO2 emissions. They optimise their production process to minimise waste and recycle their scrap material. They implement eco design rules to support the sustainability of their products and constantly search for new ways to further improve their products.

BMW has been exploring innovative materials, including bioplastics and natural fibres such as hemp, kenaf, and flax. These materials not only help in reducing the vehicle's weight and overall carbon footprint but also contribute to sustainable production practices[65].

According to a study from the Global Economic Forum, the greatest areas to be analysed and improved so that we can achieve sustainable manufacturing are:

- Design products for longer, effective life,

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[61] *Standing, C.; Jackson, P. An approach to sustainability for information systems. J. Syst. Inf. Technol. 2007, 9, 167–176.*
[62] *Davidson de Almeida Santos et al. 2020, Proposal for a Maturity Model in Sustainability in the Supply Chain in Special Issue Supply Chain Management for Sustainable Development, 12(22),9655, https://doi.org/10.3390/su12229655*
[63] *Volvo Cars aims for 25 per cent recycled plastics in every new car from 2025, Jun 18, 2018, https://www.media.volvocars.com/global/en-gb/media/pressreleases/230703/volvo-cars-aims-for-25-per-cent-recycled-plastics-in-every-new-car-from-2025*
[64] *ACCESS: Circularity, Automotive Plastics, https://www.automotiveplastics.com/roadmap-for-future-mobility/the-access-framework/circularity/*
[65] *BMW Group: Sustainable thanks to innovative materials. 08.10.2021, https://www.bmwgroup.com/en/news/general/2021/innovative-materials.html*

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- Explore new business models – products as a service,
- Develop agreed-upon terminology to facilitate alignment,
- Adopt standards to facilitate industrial development and trade,
- Disseminate best practices around advanced manufacturing technology,
- Raise consumer and customer awareness,
- Increase business awareness of sustainable procurement,
- Promote certificates and clear labelling programs,
- Evolve education and training, and develop new tools to facilitate Re-X in design,
- Expand extended producer responsibility,
- Eliminate trade barriers,
- Launch new schemes for regulating products[66].

3.2.5 Batteries

Addressing the Environmental Impact of Lithium Exploration

The global shift towards renewable energy sources and the accelerating adoption of electric vehicles (EVs) have brought into sharp focus the indispensable role of lithium-ion batteries in contemporary energy storage solutions. Within the heart of these high-performance batteries lies lithium, an extraordinarily lightweight alkali metal. As a foundational component, lithium's significance cannot be overstated. Consequently, gaining a comprehensive understanding of the diverse methodologies used to extract lithium from natural sources becomes not merely a scientific pursuit but an imperative to support the transition towards cleaner and more sustainable energy systems[67].

[66] *World Economic Forum, White Paper - Making Manufacturing Sustainable Design, 2019*
[67] *Krishnan, R., Gopan, G. (2024). A comprehensive review of lithium extraction: From historical perspectives to emerging technologies, storage, and environmental considerations, Cleaner Engineering and Technology.* *https://doi.org/10.1016/j.clet.2024.100749*

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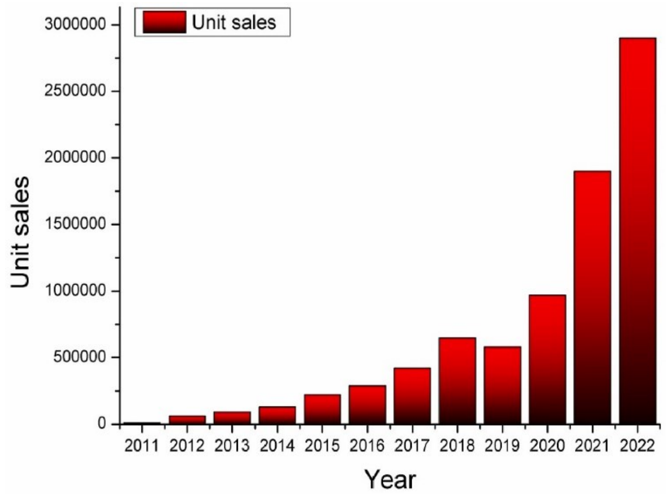

Figure 10: Worldwide hybrid electric vehicles sold from 2011 to 2022[68]

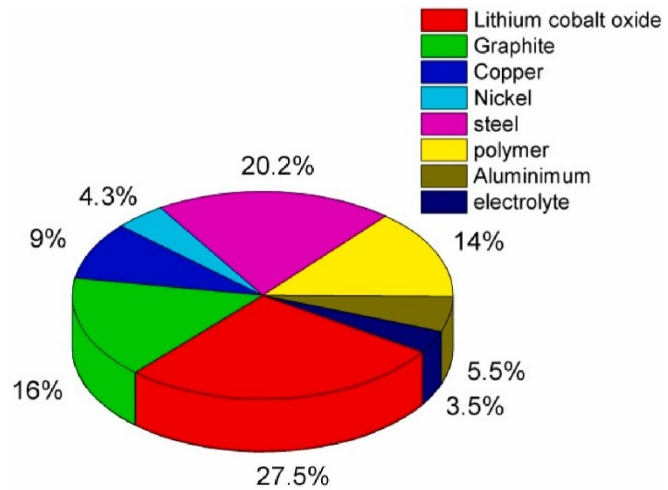

Figure 11: Constituents composition in Li batteries[69]

Lithium extraction, despite its vital role in renewable energy and electric vehicle industries, poses notable environmental challenges. One major concern is the substantial water consumption associated with lithium extraction, particularly in lithium brine production. The process relies on the pumping of brines to the surface, followed by evaporation in large ponds. This can lead to significant freshwater depletion in arid regions, exacerbating water

68 *Krishnan, R., Gopan, G. (2024). A comprehensive review of lithium extraction: From historical perspectives to emerging technologies, storage, and environmental considerations, Cleaner Engineering and Technology.* *https://doi.org/10.1016/j.clet.2024.100749*

69 *Krishnan, R., Gopan, G. (2024). A comprehensive review of lithium extraction: From historical perspectives to emerging technologies, storage, and environmental considerations, Cleaner Engineering and Technology.* *https://doi.org/10.1016/j.clet.2024.100749*

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scarcity issues. Another environmental concern is the use of chemicals, such as acids and solvents, in lithium extraction methods. These chemicals are used for leaching lithium from ores or separating it from brines. The disposal of these chemicals, if not managed properly, can result in soil and water contamination, posing risks to ecosystems and human health. Additionally, traditional lithium mining, especially open-pit mining and salar (salt flat) exploitation, can cause habitat disruption and destruction. These activities may displace wildlife, disrupt local ecosystems, and alter water flows, affecting both terrestrial and aquatic environments.

Recycling is one of the most sustainable solutions when a battery reaches its End-of-Life (EoL) and can no longer be re-used in an EV. Critical raw materials (CRM) that have the potential to be re-used in new battery units can be retrieved from EoL batteries and thus close a potentially significant gap between future supply and demand for these materials. There are currently three major recycling procedures for waste Li-ion batteries: pyrometallurgical, hydrometallurgical, and direct physical recycling[70].

3.2.6 Tyres

For the European tyre industry, the Circular Economy begins with design by developing tyres for both optimal performance and longevity.

[70] *Hill, N., Raugei, M. et al. 2023, Research for TRAN Committee – Environmental challenges through the life cycle of battery electric vehicles, European Parliament, Policy Department for Structural and Cohesion Policies, Brussels. Research for TRAN Committee: Environmental challenges through the life cycle of battery electric vehicles,* [*www.europarl.europa.eu/RegData/etudes/STUD/2023/733112/IPOL_STU(2023)733112_EN.pdf*](www.europarl.europa.eu/RegData/etudes/STUD/2023/733112/IPOL_STU(2023)733112_EN.pdf)

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Figure 12: European tyre industry Circular Economy (from ETRMA website)

European tyre manufacturers have taken significant steps to ensure their production processes employ raw materials sustainably reducing waste and, where technically possible, replacing materials that may challenge the recycling of the end-of-life tyre.

During tyre use, new vehicle technology assists drivers in ensuring optimal tyre maintenance by alerting dysfunctionalities, such as low tyre pressure and sub-optimal load. This has a recognised measurable positive effect in extending a tyre's lifespan – thereby, improving resource efficiency – and allowing the consumer to enjoy the full benefit of improved tyre technologies.

Furthermore, several steps have been taken to design tyres in ways that facilitate repair and remanufacturing, increasing tyre lifetime and reducing environmental impact. Truck tyres, for example, are designed to be retreated up to three times. Retreading is the process of replacing the worn-out tyre tread with a new tread, thereby reducing waste, limiting the use of resources and reducing CO2 emissions. It is a safe, low-cost and environmentally friendly solution. The practice of retreading is a perfect example of the circular economy and resource efficiency in practice. Retreading reduces approximately 160 kg of waste for each tyre

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retreated twice and saves 104 kg of raw materials, all whilst achieving CO2 savings. Today, European retreading activities employ 30.000 people, mostly by SMEs across the value chain.

At the end-of-life, tyres are collected, and their treatment (through material recycling and energy recovery) is organised, through the ELT Management Companies across EU countries, the vast majority of these operating under extended producers' responsibility (EPR).

Closed loop recycling is limited in the tyre industry because of the limitations linked to rubber vulcanisation. Nonetheless, in the tyre industry, companies are focusing on the use of recycled and renewable materials such as biomass-derived butadiene rubber, biomass-derived styrene-butadiene rubber, rice husk ash silica, plant-derived oil, and bio-derived polyester fibre. As for the recycled materials research and development are ongoing both on tyre chemical and mechanical recycling and tyre devulcanisation.

Furthermore, secondary raw materials from end-of-life tyres (ELTs) are important resources for industries such as construction, automotive, cement, etc. The success of the tyre circular economy strongly depends on the ability of tyre recyclers to access these markets, and it is based on a robust confidence in the ability of these materials to substitute new ones in all their performances.

Consolidated data on End-of-Life Tyres (ELTs) management for 2020 and 2021, covering 32 countries (EU28, Norway, Serbia, Switzerland and Turkey) show that, in Europe, every used tyre is collected and sustainably recovered thanks to a well-developed end-of-life tyre chain.

In 2020, ELT arisings and treatment have remained at the same level even when the number of new tyres on the market has dropped significantly. The reduction in mileage travelled and, subsequently, tyre replacement has not impacted ELT arisings either.

ELT management companies have thus collected more tyres than they needed under their obligations and taken their societal and environmental responsibility. While mileage travelled has reduced, impacting tyre replacement sales, ELT arisings remain at the same level. In 2021, collection and treatment remain consistent with previous years.

ELTs sent to granulation remain consistent from 2019, while ELTs sent to co-incineration have dropped by 200,000 tons. However, the potential of the sector remains untapped due to low levels of harmonisation around the end of life of tyres management in Europe.

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3.2.7 Exploring the potential and challenges of alternative fuels

The search for sustainable energy solutions has never been more critical as the world grapples with the twin crises of climate change and dwindling fossil fuel reserves. In this context, alternative fuels have emerged as a promising avenue to reduce greenhouse gas emissions, decrease dependence on oil, and foster a more sustainable future. From biofuels and hydrogen to electric and synthetic fuels, the landscape of alternative energy sources is diverse and rapidly evolving. However, the transition to alternative fuels is fraught with challenges, including technological hurdles, economic considerations, and infrastructural requirements. This exploration delves into the potential benefits and significant obstacles associated with alternative fuels, highlighting the complex but crucial path toward a cleaner energy paradigm.

The exploration of alternative fuels is essential in addressing the environmental impacts of traditional fossil fuels. Among the most promising alternatives are biofuels, hydrogen, and electricity from renewable sources. Here's an overview of some of the most promising alternative fuels:

1. **Biofuels**: Derived from organic materials, biofuels like ethanol and biodiesel are among the most established alternatives to conventional fuels. These fuels are considered carbon-neutral because the carbon dioxide they emit when burned is offset by the CO2 absorbed during the growth of the biomass used to produce them. Biofuels are particularly promising for reducing emissions in sectors like aviation and shipping, where electrification is more challenging[71][72].

2. **Green Hydrogen**: Hydrogen fuel, especially green hydrogen produced using renewable energy sources, is a clean alternative with vast potential. It can be used in fuel cells to power vehicles and generate electricity with water as the only byproduct. Green hydrogen is seen as a crucial component for decarbonising industries, heavy-duty transportation, and even power generation. However, its widespread adoption hinges on reducing production costs and developing efficient storage and transportation methods[73].

[71] *Perčić, M.; Vladimir, N.; Koričan, M.; Jovanović, I.; Haramina, T. Alternative Fuels for the Marine Sector and Their Applicability for Purse Seiners in a Life-Cycle Framework. Appl. Sci. 2023, 13, 13068. https://doi.org/10.3390/app132413068*
[72] *Reducing costs: The key to leveraging green hydrogen on the road to net zero, World Economic Forum, Jan 16, 2024, https://www.weforum.org/agenda/2024/01/green-hydrogen-the-last-mile-in-the-net-zero-journey/*
[73] *Everything you need to know about hydrogen in the clean energy transition, World Economic Forum, Jan 12, 2023, https://www.weforum.org/agenda/2023/01/hydrogen-clean-energy-transition-2023/*

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3. **Electricity from Renewables**: Electric vehicles (EVs) powered by renewable energy sources like solar and wind represent a significant shift towards sustainable transportation. The key benefits of EVs include zero tailpipe emissions and the potential for further emissions reductions as the electricity grid becomes greener. The deployment of EVs is accelerating, supported by advancements in battery technology and increased investment in charging infrastructure[74].

4. **Methanol and Ammonia**: These hydrogen derivatives are emerging as viable fuels, especially in the maritime sector. Methanol offers a cleaner alternative to traditional marine fuels, with lower greenhouse gas emissions and reduced life-cycle costs compared to diesel. Both methanol and ammonia can be used in internal combustion engines and fuel cells, making them versatile options for various applications[75].

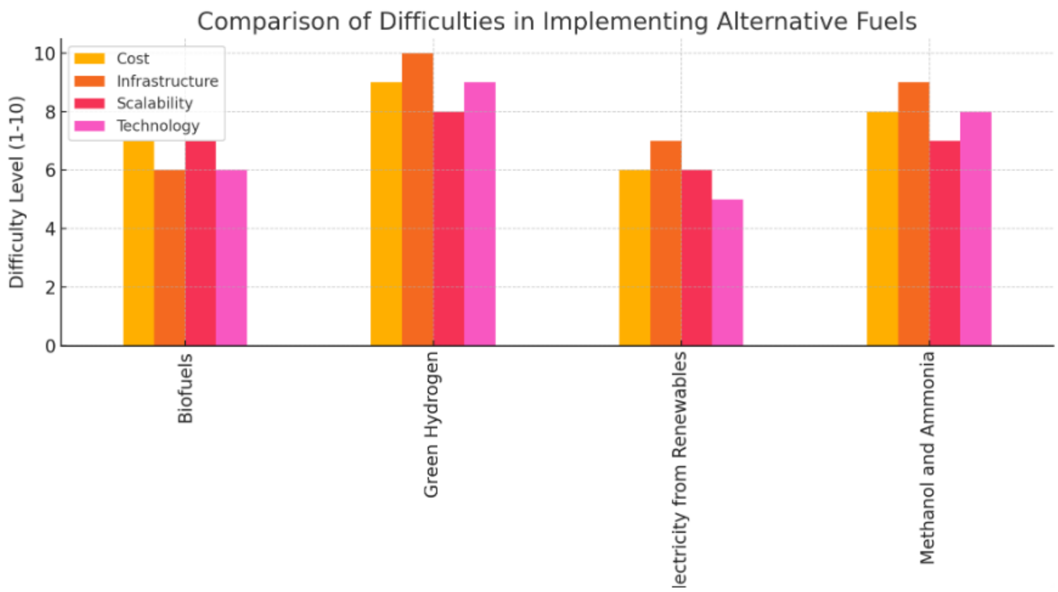

Figure 13: Difficulties with implementing alternative fuels (own analysis)

[74] *Hill, N., Raugei, M. et al. 2023, Research for TRAN Committee – Environmental challenges through the life cycle of battery electric vehicles, European Parliament, Policy Department for Structural and Cohesion Policies, Brussels. Research for TRAN Committee: Environmental challenges through the life cycle of battery electric vehicles, www.europarl.europa.eu/RegData/etudes/STUD/2023/733112/IPOL_STU(2023)733112_EN.pdf*

[75] *World Economic Forum, White Paper - Making Manufacturing Sustainable Design, 2019*

Alternative Fuel	Cost	Infrastructure	Scalability	Technology
Biofuels	7	6	7	6
Green Hydrogen	9	10	8	9
Electricity from Renewables	6	7	6	5
Methanol and Ammonia	8	9	7	8

Table 2: Comparison of alternative fuels

Alternative Fuel	Aspect	Difficulties
Biofuels	Cost	Producing biofuels can be expensive, particularly when compared to conventional fossil fuels. The cost of raw materials and the processes required to convert biomass into fuel add to the expense.
	Infrastructure	Existing infrastructure for fossil fuels needs significant modifications to handle biofuels. This includes storage facilities, distribution networks, and engines designed for biofuel compatibility.
	Scalability	Sustainable sourcing of biomass without impacting food supply and land use is a challenge. Large-scale production requires extensive agricultural resources and land.
	Technology	Advanced technologies for producing second-generation biofuels (from non-food crops) are still under development and not yet widely implemented.
Green Hydrogen	Cost	Producing green hydrogen via electrolysis is currently expensive due to high energy requirements and the cost of renewable energy sources.

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Alternative Fuel	Aspect	Difficulties
	Infrastructure	Hydrogen requires specialised infrastructure for production, storage, and transportation. Existing fuel infrastructure is not compatible with hydrogen.
	Scalability	Scaling up hydrogen production to meet global energy demands requires significant advancements in technology and infrastructure investment.
	Technology	Developing efficient and affordable electrolysis methods, as well as fuel cells for hydrogen use, is crucial. Current technology needs improvements in efficiency and cost reduction.
Electricity from Renewables	Cost	While the cost of renewable energy is decreasing, the initial investment in renewable energy infrastructure and battery storage systems remains high.
	Infrastructure	Extensive charging infrastructure is required for electric vehicles (EVs), along with improvements to the electricity grid to handle increased demand.
	Scalability	Scaling up renewable energy generation to meet global energy needs requires large investments and technological advancements.
	Technology	Battery technology needs significant improvements in terms of energy density, charging speed, and cost. Recycling and disposal of batteries also present challenges.
Methanol and Ammonia	Cost	Production costs for methanol and ammonia are high, particularly when produced using sustainable methods.
	Infrastructure	Existing infrastructure for fossil fuels is incompatible with methanol and ammonia, necessitating significant modifications.

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Alternative Fuel	Aspect	Difficulties
	Scalability	Production processes for methanol and ammonia at a scale that meets global demand require substantial investment and technological advancements.
	Technology	Efficient and cost-effective production methods are still under development. Technologies for using these fuels in engines and fuel cells need further refinement.

Table 3: Difficulties with implementing alternative fuels

Each of these alternative fuels presents unique challenges and opportunities. Biofuels require sustainable sourcing and production practices to avoid negative environmental impacts. Hydrogen infrastructure needs significant investment to become economically viable. The expansion of EVs depends on the rapid development of renewable energy and battery technologies. Methanol and ammonia still face hurdles in terms of scalability and infrastructure development.

In conclusion, while there are promising alternative fuels available, their successful implementation will require coordinated efforts in technology development, infrastructure investment, and policy support to overcome existing challenges and maximise their potential in reducing greenhouse gas emissions and mitigating climate change. Biofuels represent a viable alternative to fossil fuels, crucial for mitigating climate change. We find that there is an urgent need for integrated policies, investment in research, and public awareness to drive the shift towards sustainable energy. Overcoming challenges related to cost, infrastructure, and technology is vital for a cleaner and more sustainable energy future.

3.3 Resilience of value chains

Resilience of value chains is one of the key mega-trends in the automotive-mobility sector at the present time. The pandemic of COVID-19, post-pandemic economic impacts, the war in Ukraine, as well as other ongoing conflicts and crises have exposed the vulnerability of current

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global supply chains and the need for their security and resilience. Simultaneously, the automotive industry is facing a major transformation towards electromobility, profoundly impacting the established value chains. These developments are further compounded by advancements in the field of technology, such as artificial intelligence and machine learning.

3.3.1 Supply Chain Optimisation

The supply chain is central to the efficiency of the automotive industry with wide-ranging impacts. The introduction of hybrids (HEVs) and electric vehicles (EVs), as well as regulatory mandates and corporate sustainability objectives, have deepened the supply chain's complexity. Streamlining and optimising the supply chains through AI technologies and digitalisation is perceived as a means to deal with the challenges.[76]

A joint venture between automotive industry leaders including BASF, BMW Group, Henkel, Mercedes-Benz AG, SAP, Schaeffler, Siemens, T-Systems International, VW Group and ZF Group, has introduced Catena-X service, a decentralised data ecosystem for the automotive industry, as a mean to achieve fully digitised supply chain. The primary objective is to create an open and collaborative space for sovereign data exchange along the value chain, offering an "extensible ecosystem" where automotive manufacturers, suppliers, dealer associations, equipment providers, and application, platform and infrastructure providers can equally participate, addressing issues such as supply chain resilience, part traceability and circularity.[77]

Another trend of optimising supply chains is through collaborative supply chain models. As collaborative partnerships between automotive companies and suppliers become more common, the benefits of enabling shared resources and innovation, risk-sharing, and joint problem-solving to address complex supply chain issues and achieve shared goals become increasingly important.

For example, a collaborative supply chain model implemented by Toyota, the Toyota Production System (TPS), functions by working closely with suppliers to implement just-in-

[76] *Newell, J. (2024). Automakers use AI to manage their supply chain ecosystem. Smart Industry.* https://www.smartindustry.com/tools-of-transformation/artificial-intelligence/article/55130602/automakers-use-ai-to-manage-their-supply-chain-ecosystem

[77] *Ozsevim, I. (2023). VW Group accelerates digital supply chain transformation as part of Cofinity-X partnership. Automotive Logistics.* https://www.automotivelogistics.media/supply-chain-management/vw-group-accelerates-digital-supply-chain-transformation-as-part-of-cofinity-x-partnership/44838.article

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time (JIT) inventory practices, Kanban technology, and quality assurance processes, allowing the company to achieve efficiency gains through supplier collaboration, optimised lead times, and enhanced product quality.[78]

Optimising supply chains through AI-enabled technologies (e.g., identifying skill shortages, bottlenecks, logistical issues, and material costs and availabilities) is considered one of the ways to mitigate the increased risks related to the transition from internal combustion engine (ICE) vehicles to battery electric vehicles (BEVs), such as unfamiliar supply chain patterns, minimal-warning supply disruptions, and limited visibility of dependencies or exposures.[79]

Logical and conceptual continuation of these trends will be self-thinking supply chains. Enabled by developments in ICT (especially IoT and AI) – the self-thinking supply chains will be fully autonomous with predictive capabilities, bringing significant efficiency gains in an increasingly complex and uncertain environment.[80]

The supply chain of the future will increasingly be self-aware, think by itself and require minimum, if any, human intervention to manage risks. The self-thinking supply chain will continuously monitor supply chain performance by analysing data generated by objects; forecast and identify risks; and automatically take actions to prevent risks before they materialise. The supply chain will have the ability to autonomously learn from these activities and use the gained knowledge in future decision-making. Furthermore, large amounts of data and the use of powerful analytical and simulation models will allow the supply chain to predict the future with a decreasing margin of error and take actions to address shifts in demand.

3.3.2 Local Sourcing and Production

The automotive industry is increasingly gravitating towards regionalising and localising sourcing and production,[81] driven by a confluence of geopolitical and economic factors. Recent disruptions such as the COVID-19 pandemic, the Russia-Ukraine conflict, and ongoing trade tensions between major economies have underscored the vulnerabilities inherent in

[78] *Quloi (2024). Automotive Industry Supply Chain Trends 2024.* https://quloi.com/blog/automotive-supply-chain-trends/
[79] *Marsh (2024). Can AI strengthen supply chains as the auto industry decarbonises?* https://www.marsh.com/en-gb/industries/automotive/insights/can-ai-strengthen-supply-chains-as-the-auto-industry-decarbonise.html
[80] *Calatayud, A., Mangan, J., & Christopher, M. (2019). The self-thinking supply chain. Supply Chain Management, 24(1), 22–38.* https://doi.org/10.1108/scm-03-2018-0136
[81] *Jovanovic, D. (2024). Supply chain trends in the automotive industry. Log-hub.* https://log-hub.com/supply-chain-trends-in-the-automotive-industry/

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global supply chains. These disruptions have led to significant production delays and cost escalations, prompting automotive manufacturers to rethink their strategies.

One of the primary responses has been the creation and maintenance of local supply chains. By sourcing materials and components locally, automotive companies can mitigate risks associated with international logistics. This approach also reduces transportation costs and carbon footprints, aligning with contemporary sustainability goals.

Reducing dependency on single-source suppliers is another critical strategy.[82] The semiconductor shortage that severely impacted automotive production highlighted the dangers of over-reliance on a limited number of suppliers. To counteract this, manufacturers are diversifying their supplier base, seeking multiple suppliers across different regions. This not only ensures a steadier supply of essential components but also fosters competitive pricing and innovation through increased supplier competition.

Furthermore, regionalising production closer to key markets allows companies to respond more swiftly to local consumer demands and regulatory changes. This agility is crucial in an industry that is rapidly evolving with the advent of electric vehicles (EVs) and autonomous driving technologies. Local production hubs can adapt to regional preferences and compliance requirements more efficiently than distant, centralised manufacturing plants.[83]

Government policies also play a pivotal role in this shift, most notably in the key areas. Many countries are offering incentives for local production and the development of local supply chains. For instance, the European Chips Act launching the Chips for Europe Initiative to encourage domestic semiconductor production, which is crucial for modern vehicles.[84] In this context, the role of SMEs in the automotive ecosystem is crucial, especially in the retail, repair and maintenance part of the value-chain. Jobs provided by these companies are local, not transferrable.

[82] *Ibid.*
[83] *RSM (2022). White Paper: The rise of regionalization: How suppliers are rethinking supply chains.* *https://rsmus.com/insights/industries/automotive/the-rise-of-regionalization-how-suppliers-are-rethinking-supply-chains.html*
[84] *The European Chips Act (n.d.).* *https://www.european-chips-act.com/*

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3.3.3 Inventory Management

Inventory management in the automotive industry is undergoing significant transformation with the adoption of just-in-time (JIT) inventory systems and advanced analytics for demand forecasting. JIT inventory systems focus on reducing in-process inventory and associated carrying costs by aligning production schedules directly with customer demand. This approach minimises waste and optimises efficiency, ensuring that parts and components arrive precisely when needed for production, thus reducing storage costs and minimising overproduction risks.[85]

The integration of advanced analytics for demand forecasting further enhances inventory management. Utilising big data, machine learning, and AI, these analytics provide more accurate predictions of customer demand patterns.[86] This allows manufacturers to fine-tune their inventory levels, adapt to market fluctuations more swiftly, and mitigate the risk of stockouts or excess inventory. Predictive analytics consider various factors such as historical sales data, market trends, and external economic indicators, enabling a more dynamic and responsive supply chain.

In the automotive sector, where product complexity and demand variability are high, combining JIT with advanced analytics offers a competitive edge. It ensures leaner operations, better capital utilisation, and improved customer satisfaction by maintaining optimal inventory levels and timely delivery of parts and vehicles. This integration of technology in inventory management is pivotal for automotive manufacturers striving to enhance efficiency and agility in a rapidly evolving market.[87]

[85] *Think Inventory Solutions (2024). Driving efficiency and agility, the importance of just in time (JIT) and just in sequence (JIS) for the automotive industry.* https://www.thinkinventorysolutions.com/driving-efficiency-and-agility-the-importance-of-just-in-time-jit-and-just-in-sequence-jis-for-the-automotive-industry/

[86] *Deloitte (n.d.). Predicting needs to improve profits: How Advanced Analytics can Help Automakers and Car Dealers Better Prepare for Success. Deloitte France: Point de vue.* https://www.deloitte.com/fr/fr/pages/manufacturing/articles/predicting-needs-to-improve-profits.html

[87] *Arnaiz, A. P. A., Cristal, L. S., Fernandez, A. O., Gubaton, M. R. F., Tanael, N. D. V., & Centeno, C. J. (2023). Optimizing inventory management and demand forecasting system using time series algorithm. World Journal of Advanced Research and Reviews, 20(3), 021–027.* https://doi.org/10.30574/wjarr.2023.20.3.2456

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3.3.4 Risk Management

The pandemic of COVID-19, post-pandemic economic impacts, the war in Ukraine, as well as other ongoing conflicts and crises have prompted the automotive industry to prioritise resilience and risk management.[88]

Risk management in the automotive industry has become increasingly sophisticated, incorporating scenario planning and strategic stockpiling to address uncertainties and disruptions. Scenario planning involves creating detailed, plausible future scenarios based on varying assumptions about external conditions, such as economic shifts, technological advancements, regulatory changes, and supply chain disruptions. By analysing these scenarios, automotive companies can develop flexible strategies to navigate potential challenges, enhancing their resilience. This process helps identify vulnerabilities within the supply chain and allows companies to prepare contingency plans, ensuring continuity in operations.[89]

Strategic stockpiling complements scenario planning by maintaining a buffer stock of critical components and materials. This approach mitigates the impact of supply chain interruptions, such as natural disasters, geopolitical tensions, or supplier bankruptcies. In the automotive industry, where production lines depend on the timely availability of numerous parts, strategic stockpiling ensures that manufacturers can continue operations without delays.

European car manufacturers have exhibited a positive trend in cash conversion cycle and days inventory outstanding (DIO) in recent quarters while previously increasing inventories and stockpiling raw materials in response to the supply chain crisis and geo-political conflicts.[90]

3.3.5 Manufacturing and production technologies innovation

Innovation in manufacturing and production technologies is revolutionising the automotive industry, particularly through robotisation, scaling, and production ramp-up strategies. Robotisation has become a cornerstone of modern automotive manufacturing, with

[88] *Jovanovic, D. (2024, May 28). Supply chain trends in the automotive industry. Log-hub.* https://log-hub.com/supply-chain-trends-in-the-automotive-industry/

[89] *Onica, T. (2020, January 21). Surviving in the New World of Tech: How Future Scenario Planning is Key to Survival for the Automotive Supply Chain. Assembly.* https://www.assemblymag.com/articles/95420-surviving-in-the-new-world-of-tech-how-future-scenario-planning-is-key-to-survival-for-the-automotive-supply-chain

[90] *KPMG (n.d.). Supply chain and auto market growth: Supply chain resilience is the key to sustainable automotive market growth.* https://kpmg.com/xx/en/home/insights/2023/12/supply-chain-and-auto-market-growth.html

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advanced robotics systems taking on tasks ranging from welding and assembly to painting and quality inspection, enhancing precision, consistency, and efficiency, reducing human error and operational costs. Collaborative robots, or cobots, work alongside human workers, further optimising the production process by combining the strengths of human dexterity and robotic precision.

Scaling production efficiently is another critical aspect of innovation in the automotive sector. As demand fluctuates and new models are introduced, manufacturers must adapt their production capacity rapidly. Flexible manufacturing systems (FMS) and modular production lines enable this adaptability. FMS allows for quick reconfiguration of production equipment to accommodate different models or production volumes without significant downtime.[91] Further innovative solutions to challenges encountered in scaling production to meet global demand are, however, limited.

A production ramp-up, defined as 'the period of time during which a manufacturing process is scaled up from a small laboratory-like environment to high-volume production', typically after a new model launch, or alternatively to meet rising demand, is greatly enhanced by digital twin technology and predictive analytics. The automotive industry has experienced a shortening of product life cycles, increasing the number of production ramp-ups. Production in the automotive industry takes place at globally dispersed facilities, and products are distributed to customers located in globally situated markets. Ramp-up planning must be conducted for a global network, considering the interdependencies between ramp-ups.[92]

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[91] *Javaid, M., Haleem, A., Singh, R. P., & Suman, R. (2022). Enabling flexible manufacturing system (FMS) through the applications of industry 4.0 technologies. Internet of Things and Cyber-Physical Systems, 2, 49–62.* https://doi.org/10.1016/j.iotcps.2022.05.005

[92] *Becker, A., Stolletz, R., & Stäblein, T. (2016). Strategic ramp-up planning in automotive production networks. International Journal of Production Research, 55(1), 59–78.* https://doi.org/10.1080/00207543.2016.1193252

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3.3.6 Predictive maintenance

Predictive maintenance (PdM), a novel trend in the area of vehicle maintenance, is driven mainly by advancements in artificial intelligence (AI) and machine learning, like the traditional maintenance strategies in the automotive sector that have been either reactive, that deal with issues as they occur, or preventative, where maintenance is performed at set intervals regardless of need, the predictive maintenance utilises data analytics and AI to anticipate and address potential problems before they even arise.

Vehicle manufacturers will offer over-the-air (OTA) software maintenance and product upgrades and options, which will have an impact on workshops' revenues as OTA maintenance will result in fewer workshop passages. The shift to battery electric vehicles (BEV) will also have a huge impact on the automotive repair sector. It is estimated that the repair on BEV will reduce drastically, 30-50% less in comparison to ICE cars[93] with the exception of tyres.

The predictive maintenance is expected to help reduce vehicle downtime and maintenance costs, extend vehicle lifespan, and enhance safety, however, it may pose additional challenges, such as ensuring further data security and privacy, integration with existing systems, as well as high costs of initial implementation.[94]

Some of the different predictive maintenance solutions are Cloud-based Solutions (BMW), Collaborative Data Sharing (Ford), Vehicle Sensor data + Machine Learning algorithm utilisation (Intuceo), Digital Twin technology, Vehicle Maintenance Workbench (Infosys), Sound-based detection (HMG), Vehicle Health Management Platform (Questar), Over the Air (OTA) Updates.[95]

Škoda car manufacturer employs a production-line predictive maintenance system, MAGIC EYE, a device installed onto the travelling trolley of the overhead conveyor at the assembly

[93] *Grosso, M., Raileanu, I. C., Krause, J., Raposo, M. A., Duboz, A., Garus, A., Mourtzouchou, A., & Ciuffo, B. (2021). How will vehicle automation and electrification affect the automotive maintenance, repair sector?. Transportation Research Interdisciplinary Perspectives, 12, 100495.*
[94] *Gohari, K. (2024). Revving up reliability: The future of predictive maintenance in the auto industry. Canvas Intelligence.* https://www.canvasintelligence.com/revving-up-reliability-the-future-of-predictive-maintenance-in-the-auto-industry/
[95] *Cadence PCB Solutions (2023). Predictive Maintenance for the Automotive Industry.* https://resources.pcb.cadence.com/blog/2023-predictive-maintenance-for-the-automotive-industry

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line. The system uses seven cameras and artificial intelligence neural networks to predict and recognise 14 types of defects and avoid stops on the production line.[96;97]

Predictive maintenance trend also adds to the requirements of a higher-skilled workforce, as maintenance specialists are not only to be skilled technicians and mechanics, but also need to possess an advanced digital skillset.

[96] *Škoda (2022). MAGIC EYE - Fablab.* *https://fablab.skoda-auto.cz/en/magic-eye*

[97] *Volkswagen Group Italia (2022). AI and predictive maintenance: no stops for more efficient production.* *https://modo.volkswagengroup.it/en/mobotics/ai-and-predictive-maintenance-no-stops-for-more-efficient-production*

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3.4 New Business Models

The automotive industry is undergoing a massive change given the key trends like vehicle electrification, autonomous driving, shared mobility, software-as-a-service (SaaS), sustainability and the circular economy. Certain demand-side and supply-side challenges have led to dwindling or stagnant profits and forced automakers to reevaluate and revamp their present business models. No wonder, automakers want to enable higher transparency of their revenue streams, adopt better prediction and simulation models, and integrate ESG analytics, to boost their corporate performance[98].

In the era of connectivity, cars are no longer just a means of transportation; they are evolving into smart, interconnected devices. The Internet of Things (IoT) is playing a pivotal role, enabling features like remote vehicle monitoring, over-the-air updates, and enhanced safety measures[99].

3.4.1 Mobility as a Service (MaaS)

Traditional notions of car ownership are being challenged by the rise of Mobility as a Service (MaaS). Ridesharing, car-sharing, and other MaaS platforms are further gaining popularity, offering convenient alternatives to owning a vehicle. These new mobility options will lead to a dramatic change in how the people and the society will build /organise the cities of the future.

Currently, 42% of all new vehicle registrations within the EU are made by private buyers. This percentage is expected to potentially decrease in the near future. Millennials and Gen Z'ers, who are projected to account for 75% of all new vehicle acquisitions by 2025, place less emphasis on vehicle ownership compared to older generations and exhibit a heightened awareness of their environmental impact, making them the most environmentally conscious consumers. Consequently, a shift in how individuals acquire mobility is anticipated. There is a strong tendency among these demographics to opt for leasing /subscription models to more effectively manage their mobility expenses.

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98 *Mazar, G. (2022). Changing times: New business models pose challenges to automakers. KPMG.* *https://kpmg.com/xx/en/home/insights/2022/08/changing-times-new-business-models-pose-challenges.html*
99 *Driving the automotive agenda: Five key trends shaping the automotive industry in 2024. (n.d.).* *https://www.shoosmiths.com/insights/articles/driving-the-automotive-agenda-five-key-trends-shaping-the-automotive-industry-in-2024*

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In this context, the automotive industry is at a crossroads, with innovation steering the way forward. The convergence of electric vehicles, autonomous driving, connectivity, sustainability, and MaaS is shaping a future where cars are not just modes of transportation but integral parts of a connected, sustainable ecosystem.[99] In this way, we could say that the car maintains more and more a device (an extremely necessary one) that will have an important contribution to the progress of the entire society.

MaaS provides instant access to many forms of transport: ride-hailing (Uber, Lyft, Grab), car-sharing (Get Pony, Zipcar), or micro-mobility services (Lime Scooters, Bolt Scooters).[100]

In recent years, advances in technology have enabled platform-based businesses (also referred to as marketplaces or digital business ecosystems) to emerge. In addition to platforms, technological progress has also led to an increase in the type of urban travel services, such as bike-sharing, scooter-sharing, carsharing, and e-hailing. This development potentially contributes to more sustainable urban mobility but also creates complexity for the customer. This fragmentation makes it difficult for travellers to find the optimal offer that matches their needs best. To address this issue, multimodal mobility platforms have emerged. These platforms aim at simplifying customer offerings, by functioning as marketplaces where customers can purchase integrated multi-modal mobility services from different suppliers. Such platforms are referred to as Mobility-as-a-Service (MaaS) platforms.[101]

In a broader sense, it refers to the offer and use of various means of transportation. However, this alone does not adequately explain the concept since, in a narrower sense, MaaS stands for software solutions based on specific platforms on which the services of several mobility providers can be bundled into one application. It is a promising solution, offering numerous benefits for people, businesses and most importantly, the environment. Since MaaS includes a wide range of services such as *ride-hailing, car-sharing, bike-sharing, taxis, air, and water transportation, as well as public transportation services,* all provided through a single platform or app, it is quick and easy to use. With the development of artificial intelligence in the

[100] *Bhavin. (2024). Mobility as a Service (Maas) is Shaping the Future of the Fleet Management Software | GlobalLogic Romania. GlobalLogic.* https://www.globallogic.com/ro/insights/blogs/mobility-as-a-service-maas-is-shaping-the-future-of-the-fleet-management-software/
[101] *Boer, Merijn & Turetken, Oktay & Adalı, Onat. (2022). A Review of Business Models for Shared Mobility and Mobility-as-a-Service (MaaS): A Research Report. 10.13140/RG.2.2.27170.35524.*

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automotive sector, Mobility as a Service will more and more change the way we perceive mobility.[102]

The implications of MaaS will lead to skills and jobs for Intelligent Transport Systems (ITS), digital platforms, connected vehicles, and intelligent infrastructure, activities that can contribute to delivering clean, safe, accessible, affordable and efficient mobility. In this respect, other skills that could be seen as being urgent for the new business models are those for Platform solutions such as Mobility as a Service (MaaS) and Transport /Logistics as a Service (TaaS /LaaS). These are meant to bring all modes together in an efficient mobility ecosystem that optimises the use of transport infrastructure and vehicles.[103]

3.4.2 Tyre as a Service (TaaS)

In a broader sense, Tyre-as-a-Service (TaaS) is much more than tyres, and today, tyre makers have already developed a diversified pool of telematics solutions for data sharing, connected vehicles and mobility.

In a narrower sense, Tyre-as-a-Service (TaaS) describes the concept of providing tyres and the associated services under a subscription model with strong consideration of all direct and indirect safety, environmental, economic and usability impacts for the customers and society. The optimisation of TaaS requires an in-depth understanding of all specific aspects of each application case. The development of this understanding requires the availability, collection, and processing of vehicle, environmental, and operational data[104].

Using in-vehicle data for smart, sustainable and safe mobility, TaaS uses data from connected vehicles to integrate telematics solutions and provide essential services to drivers and society. TaaS can help drivers and fleet operators increase road safety, save fuel, decrease CO2 emissions, reduce congestion and increase vehicle uptime, helping society reach the Green Deal's objectives.[105]

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[102] *Mobility as a Service revolutionizes mobility. (2023). IAA MOBILITY.* https://www.iaa-mobility.com/en/newsroom/news/urban-mobility/mobility-as-a-service-revolutionizes-mobility

[103] *ACEA position paper-Shared sustainable urban mobility. (n.d.).* https://www.acea.auto/files/ACEA_position_paper-Shared_sustainable_urban_mobility.pdf

[104] *Tyre-As-A-Service: How the tyre industry drives sustainable change - ETRMA. (2022). ETRMA.* https://www.etrma.org/news/tyre-as-a-service-how-the-tyre-industry-drives-sustainable-change/

[105] *Tyre-As-A-Service. (n.d.).* https://www.etrma.org/wp-content/uploads/2022/12/Tyre-As-A-Service-brochure.pdf

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TaaS is an innovative approach where tyre manufacturers[106;107;108;109] and service providers offer tyre solutions as a service rather than a one-time product purchase. This model focuses on providing comprehensive tyre management services, including installation, maintenance, and replacement, through a subscription-based model.

TaaS is especially beneficial for fleet operators, providing tyre management services that include regular inspections, pressure monitoring, and tread depth analysis to ensure optimal performance and safety.

3.4.3 Maintenance as a Service (MaaS)

Maintenance as a Service, or MaaS, transforms how businesses manage and maintain equipment. It's not just about fixing what breaks anymore. Thanks to cloud computing's scalability and cost-effectiveness, we are seeing the rise of predictive maintenance solutions that aim to prevent breakdowns before they happen. MaaS, once a simple routine of upkeep, has evolved into an advanced service paradigm fuelled by advancements in digital technology. Cloud computing is pivotal in this transformation, enabling vendors to build powerful online platforms for fault detection and maintenance management services. This evolution marks a shift towards proactive maintenance strategies that save time and money. IoT has transformed the landscape of equipment maintenance, enabling real-time data collection that once seemed like a distant dream, thus revolutionising our approach to preventively addressing machine malfunctions. *Manufacturers are now providing online tools that will allow plant operators to monitor the health of their equipment continuously*. These instruments offer nuanced perspectives on machinery behaviour, facilitating preventive actions to avert expensive malfunctions.[110]

Predictive maintenance – or Maintenance as a Service - represents a new era in automotive care, where data-driven insights and AI innovation lead to safer, more reliable, and more efficient vehicles. As technology continues to advance and overcome current challenges, we

[106] *Groupe Michelin | Leader mondial des composites et expériences qui transforment notre quotidien. (n.d.).* https://www.michelin.com/
[107] *Bridgestone Corporation. (n.d.). Bridgestone Global website. Bridgestone Global Website.* https://www.bridgestone.com/
[108] *Continental Tires | Discover Tires online. (n.d.).* https://www.continental-tires.com/
[109] *Goodyear Tires | Shop for tires online. (n.d.). Goodyear.* https://www.goodyear.com/
[110] *Diem, C. (2024). The rise of Maintenance as a service (MAAS). MicroMain.* https://www.micromain.com/the-rise-of-maintenance-as-a-service-maas/

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can expect predictive maintenance to become an industry standard, revolutionising our approach to vehicle maintenance and care.[111]

3.4.4 Trends in customer preferences and services

Mobility is first and foremost about consumer choices and studies show that preferences are indeed shifting. While private cars still dominate the road, 40 percent of survey (McKinsey Mobility Consumer Pulse Survey [112]) respondents now use multiple mobility modes, including eco-friendly options such as e-bikes, and 62 percent are beginning to change their transportation habits because of sustainability concerns. In a development that could affect vehicle sales, 20 percent of respondents say they would consider replacing their private vehicles with other mobility options over the next ten years, and many are open to using autonomous shuttles if they become available.

On the other side, the automotive industry is experiencing a dynamic transformation driven by evolving consumer preferences and technological advancements. Understanding consumer trends is vital for navigating the rapidly evolving automotive industry. From the rise of electric and autonomous vehicles to the increasing demand for sustainability and connectivity, these trends are shaping the future of mobility. As automakers and industry stakeholders adapt to these changes, they must remain agile and innovative to meet consumers' evolving needs and preferences[113].

Additionally, companies will need to focus on customer preferences and services, offering personalized experiences and seamless integration of different modes of transportation. This requires new skills oriented to collaboration and partnerships between business operators in order to face the changes foreseen along the automotive value chain.

In this regard, as technology continues to evolve, the industry will likely see even more innovative solutions that enhance the digital retail experience. Digital retail in the automotive industry represents a significant shift from traditional dealership-based sales models to more

[111] *Gohari, K. (2024). Revving up reliability: The future of predictive maintenance in the auto industry - Canvas Intelligence. Canvas Intelligence.* https://www.canvasintelligence.com/revving-up-reliability-the-future-of-predictive-maintenance-in-the-auto-industry/

[112] *Heineke, K., Kampshoff, P., & Möller, T. (2024). Spotlight on mobility trends. McKinsey & Company.* https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/spotlight-on-mobility-trends#section-header-1

[113] *Mohamed, A. (2024). Consumer Trends for the automotive industry: Key insights and future directions - AIM Technologies. Aim Technologies.* https://www.aimtechnologies.co/consumer-trends-for-the-automotive-industry-key-insights-and-future-directions/

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flexible, customer-centric approaches. This new business model emphasises convenience, transparency, and efficiency while also addressing the challenges of security, compliance, and consumer trust.

The digital retail business model in the European automotive industry incorporates several core components that are transforming traditional car sales and enhancing customer experiences, such are:

- **Online Sales Platforms**: they have become increasingly popular, offering consumers the ability to browse, compare, and purchase vehicles from the comfort of their homes[114;115;116]
- **Virtual showrooms**: use advanced technology to create an immersive online shopping experience, utilising VR and digital technologies to offer virtual tours and customisation of vehicles. These typically include: 360-Degree Views, Augmented Reality (AR) (users can visualise the car in their driveway), Virtual Test Drives, and other detailed specifications for in-depth information about the vehicle's features[117;118;119]
- **Digital Financing and Paperwork Solutions**: In Europe, auto finance providers are reinventing the auto finance process by introducing digital identity verification[120]. This includes automated capabilities such as:
    - Digital verification of identity documents (passport, driver's license, or national ID card). This can take place in a dealership with the applicant or online with a remote applicant.
    - Facial recognition (comparing a selfie with the image on a passport or ID card) for remote scenarios where the customer is applying for financing from their home, office, or anywhere.

[114] *New and Used cars marketplace AutoScout24. (n.d.). https://www.autoscout24.com/?*
[115] *Gebrauchtwagen & Neuwagen » mobile.de. (n.d.). mobile.de. https://www.mobile.de/*
[116] *Cazoo. (n.d.). Cazoo | The better way to buy and sell a car online. https://www.cazoo.co.uk/*
[117] *Startseite | Volkswagen Deutschland. (2024). https://www.volkswagen.de/de.html*
[118] *PEUGEOT UK | Explore new cars, SUVs, vans & electric vehicles. (n.d.). https://www.peugeot.co.uk/*
[119] *Mercedes-Benz. (2024). Mercedes-Benz brand experience. https://www.mercedes-benz.com/en/*
[120] *Leasing Life. (2024). Global Trends in Digital Auto Finance: How Four Automotive Lenders are Transforming Auto Loans - Leasing Life. https://www.leasinglife.com/thought_leaders/digital-auto-finance/*

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Seen these evolutions, automotive distributors shall seek for alternative sources of revenues through various value-added services, such as for example EV battery and charging solutions (battery leasing and EV charging are expected to be the key services offered by dealerships to their EV customers. Battery leasing and battery swapping solutions can be offered by dealers in collaboration with the EV OEMs).

Connectivity and smart mobility solutions: As connected vehicles become more common, distributors and dealers expand their offerings related to digital apps and solutions. Their portfolio may include digital services such as driver monitoring (e.g., for younger drivers), predictive maintenance, digital fleet management, concierge services, infotainment, roadside assistance and SOS services. These solutions can typically be priced with a fixed-plus-variable model and may be offered to both B2C and B2B /fleet customers.

Financial services: Dealers may also want to look at new financial service offerings to enhance their revenue pool. This could include full-service leasing services in collaboration with financial institutions to offer tailor-made products to customers.

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4 FIRST CONCLUSIONS

The study has provided an overview of the state-of-the-art of the automotive-mobility sector, giving a quantitative and qualitative evaluation of its main sectoral trends for 2030-2050. The trends were analysed following their relevance, urgency and implications on skills and jobs forecasting, to support the digital and green transition towards the future of the automotive-mobility sector in the European Union, and to share the need for new training and education.

We have provided an insight into interlacing historical background, legal implications, technological trends and opportunities, environmental, social and governance challenges, and emerging business models. The results and data from the report will feed into the other Work Packages of the TRIREME project, and will be enriched by the results coming from the other parallel tasks part of Deliverable 2.1 (namely, Task 2.2 “Periodic continuous survey and interviews” and Task 2.3 “Continuous periodic expert workshops and webinars”.

In future reports (for D2.2 and D2.3), we will refresh the overview of the state-of-the-art of the automotive-mobility sector, provide gap analysis for the researched areas with the evaluation of the challenges that need to be taken into consideration. This will ultimately provide a better overview of the skills intelligence and occupations and consequent need for training.

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ANNEX 1: TRAINING PROVISION AND METHODS FOR THE AUTOMOTIVE-MOBILITY ECOSYSTEM: ESTABLISHING A FRAMEWORK

Humans learn constantly and everywhere, not just in organised educational settings. While schools often require that skills or theoretical understanding be learned and tested within their classrooms to be recognised as valid, workplaces typically do not have such requirements for individual skills, except in occupations with certification demands.

For this reason, it is important to continue supporting institutional forums focused on technical knowledge standards in terms of common evaluation metrics, technological contents, and training processes within the industries. Public and private actors involved in value chains have to be enabled to work in synergy, pursuing common targets in terms of active policies, labour market, and integration of supply chains.

With this perspective, we have established a Framework that intends to serve both as a common ground for developing considerations and to ensure project and methodological coherence across the various WPs of the project. Relying on this work, in the following section, the objective is to explore those dimensions considered pivotal for the automotive sector, with WP4 placing greater emphasis on these.

In this chapter, we aim to support a configuration of effective training recognition that could represent a standard, in order to replicate these practices in both universities and workplaces to concretely support the evolving market needs.

Training Provision and Methods: Data Framework Proposal

The following proposal aims to support a coherent and scientific process of Recognition of Training, providing all the elements that must be considered and evaluated; at the same time, it has the aspiration to offer a methodological path that, for coherence, must also be followed in the phases of Design and Delivery of training.

- Curriculum,
- Learning Outcomes,
- Course Classification,
- Learning Session Type (time),

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- Attendance Type (space),
- Flexibility,
- Structure,
- Training Platform,
- Training Material and Assets,
- Delivery Method of Learning Units,
- Accessibility,
- EU and International Recognition /Comparison Tools.

In the following sections, we will discuss just those training dimensions that have a significant influence on the development of the mobility-automotive sector.

Curriculum

A preliminary step for training needs analysis is to establish:

- The expected educational and market impacts: the main trends that require actions (as identified and developed in the previous chapter of the present report), the segments of the value chain that are targeted, and the types of learners /workers that need to enhance their employability.
- The relevant domains (subjects or areas of knowledge): the main topics that the training path should cover and the number and nature of the scientific disciplines that are involved.
- The depth level (e.g., Basic, intermediate, advanced): the degree of detail and complexity that the training course should deliver.

Learning Outcomes

This item should convey the purpose and benefits of the Learning Outcomes, which are statements that describe the knowledge, skills, and competencies that learners will acquire after completing the training course. The Learning Outcomes should be aligned with the learners' expectations and the organisation's needs and should demonstrate how the training course is relevant for real-world scenarios and industrial use cases. The Learning Outcomes

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should also be linked to the ESCO framework, which classifies occupations, skills, and qualifications in the European Union.

- Description of Intended Learning Outcomes[121]: "*learning outcomes are 'statements regarding what a learner knows, understands and is able to do on completion of a learning process, which are defined in terms of knowledge, skills and responsibility and autonomy*" (Council of the European Union, 2017).
- ESCO linkage (occupations /skills /qualifications)
- Coverage of Real-World Application /Industrial Use Case

Even before the specific needs of a single enterprise, in this historical phase of the automotive industry, the learning outcomes are crucial for clearly connecting training with immediate /near-future industry requirements due to technological advancements trends and, consequently, with the rising of new needed roles and expertise.

Course Classification

The dimension is closely related to the targeting of learners in terms of the life stage they belong to and /or the stage of the employee life cycle within an enterprise; therefore, for instance, IVET is crucial for preparing young people for their first job in the automotive and mobility sectors, CVET is essential for up-skilling and re-skilling the existing workforce to keep up with technological advancements.

Higher Education (HE)

- Bachelor
- Master
- Doctoral
- Professional Degree

Vocational Education and Training (VET)

- Diplomas
- Advanced Diplomas

[121] *Cedefop, Defining, writing and applying learning outcomes – A European handbook – Second edition, Publications Office of the European Union, 2022,* *https://data.europa.eu/doi/10.2801/703079*

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- Traineeship
- Apprenticeship

Initial Vocational Education and Training (IVET)

- School-based Vocational Education
- Apprenticeship /Dual Education
- Accredited Training Center Initiative

Continuing Vocational Education and Training (CVET)

- Professional Development Course
- Adult Education Program
- Workplace Training Initiative

The analysis of the Course Classification dimensions is closely related to the "EU & International Recognition & Comparison Tools". For instance, the IVET initiatives benefit from a Mobility Scoreboard[122] provided by Cedefop, which facilitates and improves the mobility of learners /workers from the countries where they completed their training to the countries where they seek work opportunities.

Learning Session Type (time)

Time-Based Blended Learning[123] is straightforward and familiar to all teachers. It involves a combination of synchronous (real-time) and asynchronous (independent) learning activities:

- **Synchronous Learning**: Teachers and students meet in real-time for interactive lessons, discussions, and immediate feedback.
- **Asynchronous Learning**: Students complete assignments, readings, and other tasks on their own time before a set deadline, such as the next class meeting or the end of the course.

[122] *Cedefop, Mobility Scoreboard – "The scoreboard provides detailed country information on the conditions for IVET learner mobility in Europe. It addresses 10 key action areas (…) recognition of learning outcomes", https://www.cedefop.europa.eu/en/projects/mobility-scoreboard*

[123] *See Norberg, A., Dziuban, C. D., & Moskal, P. D. (2011). A time-based blended learning model. On the Horizon, 19(3), 207-216, available at https://www.diva-portal.org/smash/get/diva2:706050/FULLTEXT01.pdf and Dziuban, C., Graham, C. R., Moskal, P. D., Norberg, A., & Sicilia, N. (2018). Blended learning: the new normal and emerging technologies. International journal of educational technology in Higher education, 15, 1-16, available at https://link.springer.com/article/10.1186/s41239-017-0087-5*

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This shift between synchronous and asynchronous learning creates a flexible and effective educational experience.

Blended learning effectively integrates traditional teaching methods with modern, often digital, technologies, creating a new mix that enhances teaching practices. This approach leverages digital tools, content, and platforms to develop new norms in education.

Blended learning is often perceived as a mix of in-person and online teaching or as a combination of technical and non-technical methods, but a more useful approach is to consider blended learning in terms of "time" rather than "place" or "technology." This perspective, known as "time-based blended learning," focuses on the timing of learning activities. In this perspective, we prefer to use “Blended” to point out a mix of real-time and self-paced learning activities, while “Hybrid” emphasises the combination of physical and virtual attendance, a sub-category that we are going to associate with the following dimension “Attendance Type”.

Effective learning requires a combination of workplace learning, classroom instruction, school workshops or labs, and home study, tailored to suit the teacher, learners, and learning objectives. Today, various online platforms and tools enable flexible learning and real-time communication, allowing for numerous combinations of teaching and learning environments.

Referring to the Annex for a complete description of all the options offered by the two types of attendance, we are going to highlight the more critical aspects of the project.

On-Site Learning: On-the-Job Training (OJT)

The original method of teaching and learning is through apprenticeships at the workplace.

In this model, the learner (apprentice) follows and learns from a skilled person (master) during daily work. Research on situated learning shows that this environment is ideal because the knowledge is applied where it is learned. The apprentice’s role is peripheral but participatory, allowing active learning through legitimate participation in work activities. This form of learning is as ancient as human learning itself.

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In many European countries, work-based learning is a crucial part of vocational education. In some countries, most training happens in the workplace. However, in emerging industries, workplaces may not yet exist or may be focused on development and production, leaving little time for interns and apprentices. Initially, there may not be personnel available to train others. As companies mature, they can assume responsibility for training and offer apprenticeships and internships.

OJT has always played a crucial role in Automotive (and Manufacturing in general), and it could represent an important pillar of the green skilling process.

Beyond the support of young people joining the labour market, it potentially has a pivotal role in maintaining the employability of experienced workers, assisting them during the technological transition from an industry based on internal combustion engines to the new EV technologies (reskilling).

On-Site Learning: Traditional Classroom Training

When training needs to be scaled up, a master can only handle a limited number of apprentices while still maintaining production. This is why specialised learning environments like classrooms and workshops have been developed. In these settings, teachers or trainers can regulate information flow and organise teaching and learning activities. Classroom instruction can be blended with workshop learning, workplace learning, and flexible learning through media.

E-Learning: Massive Open Online Courses

Massive Open Online Courses (MOOCs) come in various forms, and the interpretation of the MOOC concept is broad and diverse. Each component of the MOOC abbreviation is subject to debate, leading to alternative formats such as SPOCs, COOCs, NOOCs, and DOCCs, which often limit the original accessibility and tailor the course for specific uses. Generally, a traditional c-MOOC and its variations are digital, globally available, asynchronous courses aimed at creating a global market for subjects that universities consider globally relevant, often backed

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by outstanding research. These courses also serve as marketing and public relations tools for universities.

MOOCs can be utilised in the following various ways, from which educators and learners can benefit from the flexibility and wide range of topics offered by these courses:

- Employee Development and Career Planning: MOOCs offer a cost-effective, customisable, and flexible solution for professional development.
- Upskilling and Reskilling: MOOCs can be customised for individuals seeking new job roles or tasks.
- Group Study: Study groups at workplaces or community learning centers can use MOOCs together, providing mutual support and regular discussion sessions.
- Integrated into Regular Courses: Universities and educational providers can validate MOOC certificates and incorporate them into other courses, using them as learning materials while conducting labs, seminars, and examinations locally.
- Teacher Training: MOOCs can be an excellent resource for teachers entering new fields, providing both knowledge and innovative teaching ideas.

Flexibility

After examining the dimensions of training that relate to the concepts of time and space, it becomes evident how the concept of flexibility encompasses both simultaneously, and that flexibility could imply not only the opportunity to choose whether to attend but also the possibility to attend remotely and /or even personalise the pace and the duration of the training path.

- Mandatory Attendance
    - Physical
    - Virtual
- Optional Attendance
- Time Schedule
    - Fixed Terms
    - Flexible Span (Min <> Max)
    - Training Materials and Asset

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The technologies listed and described below represent critical training domains for workers, experiencing increasing adoption within the sector. Here are some provided benefits:

- Enhancing the safety and time to market,
- Leading to better performance and reduced errors,
- Enabling precise adjustments and continuous improvement.

Virtual Reality (VR) technology

VR provides a safer alternative to traditional live systems training, eliminating the risks associated with hands-on practice on actual equipment. This method can be more effective than conventional e-learning by immersing trainees in realistic, risk-free environments.

Augmented Reality (AR) technology

AR combines virtual elements with the real world, offering a unique approach to training. Unlike traditional exams, which may not fully capture a trainee's understanding of real-world applications, AR allows for hands-on assessments while collecting crucial data. This data helps identify and correct errors such as improper part usage, incorrect assembly sequences, extended task durations, and safety risks, thereby enhancing overall training effectiveness.

Factory Simulation

Factory simulation is crucial for more than just optimising manufacturing processes; it also explores different options and improves communication. Siemens Digital Industries Software, for instance, offers comprehensive solutions for battery factory simulation. These systems accelerate battery design by virtually exploring various configurations and evaluating performance at multiple levels, from system simulation to 3D and CFD simulations. Engineers can model different cell chemistries, assess battery pack designs, and optimise charging, thermal management, and control strategies for optimal performance.

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Digital Twin Technology

A digital twin is a virtual replica that enhances traditional VR, bridging the gap between development and reality, especially in complex industries. It uses artificial intelligence to visualise numerous parameters, providing real-time information and future insights. This technology improves safety, sustainability, and the overall manufacturing process.

Artificial Intelligence (AI)

AI, particularly machine learning, plays a significant role in optimising battery cell development. By analysing the multitude of parameters affecting cell quality, AI can enhance manufacturing efficiency and quality. Current efforts focus on using machine learning for process optimisation, with significant potential for further development when combined with digital twins. This integration allows precise adjustments in a controlled digital environment, reducing the need for extensive experimental testing. AI also aids in predicting electrochemical properties, accelerating development processes and facilitating the discovery of new materials.

Another AI related application is Topological Optimization. This technology is already leading significant improvements in weight reduction, material efficiency, and overall performance in automotive components.

Remote Instrumentation

Remote instrumentation involves using and controlling physical equipment, machines, or scientific instruments from a distance via digital communication. This practice allows educational institutions, training centers, and companies to share laboratory equipment, enhancing learning opportunities and resource utilisation.

EU and International Recognition /Comparison Tools

The educational initiative should also enhance mobility and career opportunities across the EU, as the automotive industry is a typical example of an integrated EU supply chain that

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spans national borders, with significant implications for the mobility of learners, workers and enterprises.

According to this goal, it would be relevant to consider not only the official recognition patterns that European institutions have established but also the ongoing developments such as recommendations, guidelines, examples of EU countries best practices, and ideally propose further suggestions dedicated to the mobility-automotive sector, refining and advancing those works.

- Macrocredentials
    - Bologna Process
    - International Industry Certification / Standard
- Microcredentials
- Comparison Tools
    - Cedefop European Database on Apprenticeship Schemes
    - IVET mobility scoreboard
    - European guidelines for validation of non-formal and informal learning

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