IDEALIST Deliverable 7.1 Analysis of Common Challenges and Framework for EU Twin Transition

Abstract

Literature review of the relevant EU twin transition pathways which set up the framework conditions and lead to or speed-up the adoption of ATs/AMTs in SMEs.

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IDEALIST

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Contents

1. Executive Summary

This report, part of the IDEALIST project, identifies the primary challenges that Small and Medium-sized Enterprises (SMEs) encounter as they adopt Advanced Technologies (AT) and Advanced Manufacturing Technologies (AMT) under the European Union's twin transition strategy. This strategy combines digital and green transformations to create a sustainable, fair, and competitive future for Europe, with ambitious climate neutrality and digital leadership as core goals.

The EU has outlined ten key areas to support this transition, such as enhancing resilience in critical sectors, promoting green and digital diplomacy, and securing investments in future-ready technologies and infrastructure. Together, these initiatives are reshaping the ecosystems of interest of this report—Aerospace & Defense, Energy-Intensive Industries, and Mobility, Transport, and Automotive—by aligning industry practices and policies with decarbonization and digital innovation.

Representing over 99% of European businesses, SMEs are crucial to this transition. This report highlights both cross-sector and ecosystem-specific challenges facing SMEs within these industries.

Cross-sector challenges:

- Technological Complexities: SMEs often lack the resources to integrate advanced systems seamlessly with existing workflows, making it challenging to keep pace with rapid technological advancements. The steep learning curve adds to the difficulty of technology adoption.
- Financial Constraints: High initial costs, limited access to capital, and unpredictable returns on investment strain SMEs' budgets. These constraints make it harder for SMEs to remain competitive, as access to sufficient capital is often limited.
- Supply Chain Vulnerabilities: SMEs frequently struggle to secure Critical Raw Materials (CRMs), feed stocks and critical components, especially with increased competition from larger firms. Global supply chain disruptions lead to component shortages and feedstock variability, which hinders consistent production and quality control.

These cross-sector challenges create a complex environment where SMEs must navigate substantial obstacles to fully leverage technology, necessitating innovative solutions and targeted support to drive their successful integration into modernized, resilient operations.

Sector-Specific Obstacles:

Aerospace & Defense: Stringent Regulatory Requirements

Regulatory demands to ensure safety and compliance can consume up to 10-15% of operating budgets, with requirements such as export controls limiting market access and increasing administrative burdens. Lengthy certification processes for new technologies extend product development timelines by years, which constrains adaptability to fast-paced technological advances. These constraints increase costs and reduce funds available for research, hindering competitiveness in a rapidly evolving market.

Energy-Intensive Industries (EIIs): Balancing Energy Demands with Emission Reduction Targets

High energy consumption and emissions in EIIs, such as steel and cement, place significant pressure on these industries to decarbonize while meeting production needs. Steel production alone contributes nearly 7-9% of global CO_2 emissions, making regulatory compliance costly as firms invest in cleaner technologies. Transitioning to sustainable practices, like hydrogen-based reduction in steelmaking, could increase production costs by up to 30%. Failure to adopt these methods risks regulatory penalties and market share loss to more sustainable competitors, driving EIIs to make challenging financial and operational decisions.

Mobility, Automotive and Transport: Infrastructure Demands and Cybersecurity Concerns

The automotive sector's shift toward electric, autonomous, and connected vehicles requires vast investments in infrastructure, including EV charging stations, as well as robust data security to prevent cyber-attacks. Meeting EV infrastructure needs alone may cost an estimated $39 billion by 2030 in the U.S. Additionally, cybersecurity is paramount, with the cost of potential breaches projected to reach $24 billion by 2025. Companies that under-invest in infrastructure or cybersecurity risk losing consumer trust, facing costly recalls, and potentially falling behind competitors in the connected vehicle market.

This executive summary only highlights the most critical of these challenges, with additional issues explored in detail in the full report.

To support SMEs through these challenges, the EU has enacted policies such as the Critical Raw Materials Act and the Corporate Sustainability Due Diligence Directive, providing financial support, regulatory clarity, and sustainable resource access. These measures bolster SMEs' resilience and competitiveness, positioning them as crucial contributors to Europe's sustainability goals.

In identifying these significant cross-sector and sector-specific challenges, this report highlights the critical barriers SMEs face as they work to align with Europe's twin transition. This foundational analysis sets the stage for a forthcoming in-depth examination of the EU market conditions shaped by policy making and regulation, exploring how these factors impact SMEs' ability to adopt AT and AMTs. Future analysis will also assess the competitive standing of the EU27 within global market conditions, focusing on how EU policies influence the smart specialization and strategic positioning of SMEs.

2. Introduction

2.1. Objectives

Task 7.1 of the IDEALIST project involves a comprehensive literature review that investigates the challenges and opportunities for Small and Medium-sized Enterprises (SMEs) in adopting Advanced Technologies (AT) and Advanced Manufacturing Technologies (AMT) within the European Union's twin transition strategy, which integrates green and digital transformations. This review focuses on three key industrial ecosystems: Aerospace & Defence, Energy-Intensive Industries, and Mobility, Transport, and Automotive. Through this analysis, Task 7.1 aims to uncover the implications of the EU's twin transition objectives for SME adoption of AT/AMT, identifying cross-cutting challenges such as technological barriers, financial constraints, and supply chain vulnerabilities—particularly in securing critical raw materials, feedstocks, and component availability. In addition to assessing these broader challenges, Task 7.1 also evaluates ecosystem-specific obstacles that SMEs face within each industry.

Building on this, Task 7.2 will broaden the scope by examining EU market conditions shaped by policy and regulatory factors through both literature review and stakeholder interviews. This task will specifically assess how EU policies influence the smart specialization of SMEs adopting AT/AMTs and evaluate the competitiveness of the EU27 as a business environment amid global market dynamics.

2.2. Scope

The scope of this literature review encompasses:

1. EU Twin Transition Policies and Strategies: This establishes a foundational understanding of the policy landscape, ensuring that the review aligns with the EU's strategic objectives on digital and green transitions as they apply to SMEs and advanced technologies.
2. Common Challenges Faced by SMEs: Identifying cross-sector challenges provides a clear picture of general barriers that SMEs encounter with AT/AMT adoption, offering a baseline for comparison across different ecosystems.
3. Supply Chain Vulnerabilities: Highlighting vulnerabilities, particularly around Critical Raw Materials, feedstocks, and component shortages, adds depth by focusing on tangible, supply-related barriers that are highly relevant to SMEs' operational needs.
4. Ecosystem-Specific Challenges and Opportunities: This final point zooms in on unique factors within each target sector, enabling a tailored analysis that considers specific dynamics of Aerospace & Defense, Energy-Intensive Industries, and Mobility, Transport, and Automotive.

The review will primarily focus on recent literature, policies, and reports (generally within the last 5-10 years) to ensure relevance to current EU twin transition goals. It will cover academic publications, EU policy documents, industry reports, and other relevant sources that address AT/AMT adoption in the context of SMEs and the specified industrial ecosystems.

While the review will touch upon global trends and comparisons where relevant, the primary geographical focus will be on the European Union and its member states.

3. EU Twin Transition

The twin transition is a strategic framework that integrates green and digital initiatives. It aims to achieve a sustainable, fair, and competitive future by leveraging digital technologies to support environmental sustainability. The EU twin transition emphasis the simultaneous pursuit of digital transformation and environmental sustainability in the European Union and aims to harmonize these previously autonomous areas to create a sustainable and technologically advanced economy, addressing climate change while fostering economic growth [1], [2]. It also aims not only to maximize positive impact but also to mitigate potential conflicts between the two transitions, such as ensuring that the energy intensive digital infrastructure aligns with decarbonization objectives [3], [4]. The twin transition concept evolved from earlier EU policies that separately addressed environmental sustainability and digital transformation. Key milestones in its development include:

1. Digital Single Market Strategy (2015): An important precursor on the digital side, aiming to position Europe as a leader in the digital economy.
2. European Green Deal (2019): A significant predecessor to the twin transition approach, setting the goal for climate neutrality by 2050 and integrating sustainability across sectors.
3. EU Industrial Strategy (2020): The official introduction of twin transition as 'industrial goal' to be achieved throughout all European industrial sectors, to make EU industry more competitive globally.
4. COVID-19 Pandemic (2020): Accelerated the adoption of the twin transition approach, as the EU saw an opportunity to combine economic recovery with digital and green transformations.
5. Next Generation EU Recovery Plan (2020): Solidified the twin transition concept by allocating significant funds to both green and digital initiatives.
6. European Climate Law (2021): serves as the legal foundation for the European Green Deal. It sets a legally binding target for the EU to achieve climate neutrality by 2050 and establishes an interim target of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels.
7. "Fit for 55" Package (2021): Outlined specific measures to achieve the 55% emissions reduction target by 2030, further detailing the implementation of the green transition. It includes more than a dozen legislative proposals that touch upon a broad set of policies, including carbon pricing, energy efficiency, taxation, land use and forestry, transport, and renewables.[5]
8. New Agenda for the Mediterranean (2021): Extended the geographical scope of the twin transition to the EU's Southern neighborhood.

With the foundations of the twin transition established, the EU recognizes that achieving a cohesive and sustainable digital-green transformation will require targeted action across multiple sectors. To guide this ambitious endeavour, a framework of **10 key areas of actions** has been identified, ensuring that each component of the economy, from industry to infrastructure, aligns with both digital advancement and environmental stewardship. This multi-dimensional approach highlights specific focal points where initiatives must be implemented and potential conflicts mitigated to foster a robust, inclusive, and sustainable transition [6]:

1. Strengthening **resilience and open strategic autonomy** in sectors critical for the twin transitions via for instance, the work of the EU Observatory of Critical Technologies.
2. Stepping up **green and digital diplomacy,** by leveraging the EU's regulatory and standardization power, while promoting EU values and fostering partnerships.
3. Strategically managing **supply of critical materials and commodities**, by adopting a long-term systemic approach to avoid a new dependency trap.
4. Strengthening **economic and social cohesion**, by reinforcing social protection and the welfare state, with regional development strategies and investment also playing a significant role.
5. Adapting **education and training systems** to match a rapidly transforming technological and socio-economic reality as well as supporting labor mobility across sectors.
6. Mobilizing **additional future-proof investment** into new technologies and infrastructures – and particularly into R&I and synergies between human capital and tech –with cross-country projects key to pooling EU, national and private resources.
7. Developing **monitoring frameworks** for measuring wellbeing beyond GDP and assessing the enabling effects of digitalization and its overall carbon, energy, and environmental footprint.
8. Ensuring a **future-proof regulatory framework for the Single Market**, conducive to sustainable business models and consumer patterns, for instance, by constantly reducing administrative burdens, updating our state aid policy toolbox or by applying artificial intelligence to support policymaking and citizens' engagement.
9. Stepping up **a global approach to standard-setting** and benefitting from the EU's first mover advantage in competitive sustainability, centered around a 'reduce, repair, reuse and recycle' principle.
10. Promoting robust **cybersecurity and secure data sharing framework** to ensure, among other things, that critical entities can prevent, resist and recover from disruptions, and ultimately to build trust in technologies linked to the twin transitions.

It's important to note that there isn't a single, universally agreed-upon "twin transition framework" with a definitive list of points. The concept is more of a general approach being developed and implemented by various entities, particularly within the European Union context.

Building on these 10 key action areas, the EU has taken targeted steps to integrate digital and green transitions in a way that enhances both technological innovation and environmental stewardship. By focusing on sustainable digitalization, harnessing digital tools for environmental benefits, and fostering strategic investments, the EU aims to create a resilient framework that maximizes the synergies between these transitions. Alongside these efforts, a strong emphasis on policy coherence ensures that each initiative aligns with broader goals, providing a consistent foundation for sustainable growth:

- Sustainable digitalization: This approach focuses on making the digital transformation itself more environmentally friendly and socially responsible. It involves developing and using digital technologies with built-in sustainability considerations, aiming to minimize the negative environmental impacts of the digital sector while ensuring social benefits and long-term economic viability [7].

- Digital technologies for sustainability: This strategy leverages digital tools and innovations to address environmental challenges and achieve sustainability goals. For instance, it's projected that digital technologies could contribute to reducing CO_2 emissions by 0.08 Gt by 2030.
- Strategic initiatives: The EU has launched programs such as the Strategic Technologies for Europe Platform (STEP) and the Net Zero Industry Act (NZIA). These initiatives demonstrate the EU's commitment to fostering investment in both green and digital technologies, supporting the twin transition.
- Policy coherence: The European Commission has ensured alignment across its policy communications. Documents such as those on the European Growth Model and Shaping Europe's Digital Future consistently emphasize the need to support digital solutions while also promoting the greening of digital technologies. This approach ensures a coordinated strategy towards achieving both digital and sustainability objectives [1].

3.1. Overview of key policies affecting AT/AMT adoption in SMEs

The adoption of Advanced Technologies (AT) and Advanced Manufacturing Technologies (AMT) by Small and Medium-sized Enterprises (SMEs) within the EU is heavily influenced by several key policies. These policies are designed to drive the twin transition within the EU, while addressing the specific challenges SMEs face. This section outlines the most relevant cross-sectoral policies that shape AT/AMT adoption, enabling SMEs to align with the EU's sustainability and technological advancement goals.

1. European Green Deal (2019)

The European Green Deal is a cornerstone policy for advancing sustainability across the EU, with a significant focus on reducing carbon emissions and promoting environmental responsibility. It sets the ambitious target for climate neutrality by 2050 and encourages industries, including SMEs, to integrate green technologies and practices into their operations. SMEs adopting AT/AMTs can leverage this policy to innovate, reduce their environmental impact, and enhance energy efficiency.

2. "Fit for 55" Package (2021)

The "Fit for 55" package outlines the legislative steps required to reduce greenhouse gas emissions by at least 55% by 2030 [8]. This includes key measures such as carbon pricing, energy efficiency regulations, and renewable energy integration, all of which directly impact SMEs, particularly in **energy-intensive industries**. SMEs can utilize AT/AMTs to comply with these emission reduction targets and remain competitive while aligning with environmental regulations.

3. Next Generation EU Recovery Plan (2020)

As part of the EU's COVID-19 recovery strategy, the Next Generation EU Recovery Plan allocates substantial funding for green and digital initiatives [9]. This plan provides SMEs with access to financial support to invest in AT/AMTs, enabling them to improve operational efficiency, digitalize their processes, and adopt sustainable practices. The dual focus on economic recovery and the twin transition offers SMEs an opportunity to innovate while enhancing their resilience and competitiveness.

4. European Industrial Strategy (2020)

The European Industrial Strategy emphasizes the importance of innovation, digital transformation, and sustainability for the competitiveness of European industries [10]. It encourages SMEs to adopt AT/AMTs as part of their modernization efforts, which are essential for boosting productivity, reducing environmental impacts, and enhancing supply chain efficiency. The strategy provides a roadmap for the modernization of industries, making it easier for SMEs to transition to greener and more advanced manufacturing methods.

5. Strategic Technologies for Europe Platform (STEP)

The STEP initiative focuses on fostering investment in strategic technologies that support both green and digital transitions [11]. SMEs benefit from increased access to funding and innovation opportunities in areas such as digital manufacturing, renewable energy, and clean technologies. By aligning their adoption of AT/AMTs with the STEP framework, SMEs can drive innovation and maintain a competitive edge in the rapidly evolving industrial landscape.

6. Net Zero Industry Act (NZIA)

The Net Zero Industry Act is designed to accelerate the development and deployment of zero-emission technologies across industries, with a particular focus on manufacturing [12]. This policy encourages SMEs to invest in AT/AMTs that contribute to reducing carbon emissions and achieving sustainability goals. SMEs in sectors like **mobility, aerospace, and energy-intensive industries** can leverage this act to adopt cleaner technologies and improve their environmental performance.

7. Digital Single Market Strategy (2015)

The Digital Single Market Strategy laid the foundation for the EU's digital economy and remains highly relevant for SMEs adopting digital AT/AMTs [13]. By removing barriers to digital markets and promoting innovation in digital tools, this policy helps SMEs integrate technologies such as artificial intelligence (AI), Internet of Things (IoT), and automation into their operations. The strategy ensures that SMEs can fully participate in the EU's digital transformation while enhancing their productivity and efficiency.

8. Horizon Europe (2021-2027)

Horizon Europe [14], the EU’s key research and innovation funding program, provides substantial support for projects focused on green and digital technologies. SMEs can access financial resources to adopt AT/AMTs that improve sustainability, efficiency, and competitiveness. By participating in Horizon Europe projects, SMEs can collaborate with research institutions and larger industries to co-develop and implement innovative solutions that align with the twin transition.

9. Circular Economy Action Plan (2020)

The Circular Economy Action Plan [15] is a major initiative under the European Green Deal, focusing on reducing waste, promoting resource efficiency, and creating circular production models. This policy encourages SMEs to adopt AT/AMTs that enable recycling, remanufacturing, and efficient resource use. By transitioning to circular business models, SMEs can reduce costs, improve sustainability, and comply with EU regulations on waste management and resource efficiency.

10. Critical Raw Materials Act

The Critical Raw Materials Act (CRMA) has come into force as of May 2024. Its implementation is intended to enhance access to critical raw materials for EU industries, which aligns with the goals you outlined. The CRMA's measures will support small and medium-sized enterprises (SMEs) in sectors heavily dependent on critical raw materials, such as aerospace, defense, and manufacturing, by bolstering the stability and resilience of supply chains. The act also emphasizes innovation in recycling, development of alternative materials, and efficient resource management to support sustainable growth across industries [16].

In addition to the policies mentioned above, two recent regulatory initiatives are expected to influence the landscape for AT/AMT adoption among SMEs. The Corporate Sustainability Due Diligence Directive (CSDDD) and the EU Taxonomy Regulation, while not specifically aimed at SMEs, will have notable implications for their operations and technology choices. These regulations reflect the EU's broader commitment to sustainable and responsible business practices, creating both challenges and opportunities for SMEs as they adopt advanced technologies. By understanding and addressing the requirements of these regulations, SMEs can use AT/AMTs not only to enhance their operational efficiency but also to strengthen their role in sustainable value chains and access green financing opportunities.

Corporate Sustainability Due Diligence Directive (CSDDD)

The Corporate Sustainability Due Diligence Directive (CSDDD), also known as the EU Supply Chain Act, refers to the process of thoroughly investigating and assessing a business or individual before entering into a transaction or agreement. In the context of corporate sustainability, it involves identifying, preventing, and mitigating potential risks related to environmental, social, and governance (ESG) factors. This can include evaluating supply chain practices, human rights concerns, and environmental impact. The goal is to ensure that businesses operate responsibly and comply with legal and ethical standards [17]. While primarily targeting large companies, this directive will have cascading effects on SMEs in the supply chain:

- Supply Chain Pressure: Large companies subject to the CSDDD will likely pass down due diligence requirements to their SME suppliers, encouraging the adoption of sustainable technologies and practices.
- Competitive Advantage: SMEs that proactively adopt AT/AMTs aligned with sustainability goals may gain a competitive edge in securing contracts with larger companies.
- Digitalization Push: To meet the reporting and monitoring requirements, SMEs may need to invest in digital tools and technologies, accelerating their digital transformation.

The CSDDD was proposed by the European Commission on 23 February 2022 and has entered into force on 17 January 2024. Member States now have two years to transpose the Directive into national law. The new rules will start to apply to companies in stages:

- From 2027: For companies with more than 1000 employees and €300 million worldwide net turnover.
- From 2028: For companies with more than 500 employees and €150 million worldwide net turnover in high-impact sectors.
- From 2029: For companies with more than 250 employees and €40 million worldwide net turnover in high-impact sectors.

This timeline gives SMEs time to prepare and adapt their operations. The directive will likely drive the adoption of AT/AMTs that enhance supply chain transparency, improve environmental performance, and ensure compliance with human rights standards. As the rules begin to apply to larger companies, SMEs in their supply chains will need to align their practices to meet the new sustainability and due diligence requirements.

EU Taxonomy Regulation

The EU Taxonomy Regulation is a classification system designed to guide investors, companies, and policymakers in identifying economic activities that are environmentally sustainable. It aims to provide clear criteria for determining whether an investment or business activity significantly contributes to environmental objectives, such as climate change mitigation, while avoiding significant harm to other sustainability goals. The regulation is a key part of the EU's efforts to promote green finance and support the transition to a low-carbon economy by directing capital towards sustainable activities. It also helps prevent "greenwashing" by setting transparent standards [18]. This regulation, though not directly targeting SMEs, plays a significant role in shaping the landscape for AT/AMT adoption by influencing regulatory frameworks, investment priorities, and sustainability practices.

- Sustainable Investment Guidance: The taxonomy provides clear criteria for environmentally sustainable economic activities, influencing investment decisions that can benefit SMEs adopting green technologies.
- Access to Finance: SMEs that align their operations with the taxonomy's technical screening criteria may find it easier to access green financing for AT/AMT investments.
- Market Signals: The taxonomy creates strong market signals about the types of technologies and practices considered sustainable, guiding SMEs in their technology adoption decisions.
- Reporting Pressure: While SMEs are currently exempt from direct reporting requirements, they may face indirect pressure to provide sustainability information to larger companies in their value chain, potentially driving the adoption of AT/AMTs that facilitate such reporting.

By incorporating these policies into their AT/AMT adoption strategies, SMEs can position themselves advantageously in the evolving European business landscape. The CSDDD and EU Taxonomy Regulation complement the existing policy framework by further emphasizing the importance of sustainable and responsible business practices. They encourage SMEs to view AT/AMT adoption not just as a means of improving efficiency and competitiveness, but also as a way to meet evolving sustainability standards and access new business opportunities in the green economy.

In general, the EU has developed a robust policy framework to support SMEs in adopting advanced technologies and manufacturing processes as part of the twin transition strategy. These policies provide financial, regulatory, and strategic support to help SMEs overcome barriers such as cost, technological expertise, and supply chain vulnerabilities. By aligning with these key policies, SMEs can improve their resilience, enhance sustainability, and strengthen their competitive position in the rapidly evolving industrial ecosystem of the European Union.

3.2. Implications for target ecosystems

The evolving landscape of EU policy initiatives shows a varied impact across the three industrial ecosystems of our interest: Aerospace & Defence, Energy-Intensive Industries, and Mobility, Transport & Automotive. The European Green Deal and Fit for 55 Package stand out as the most influential, demonstrating a strong impact across all three sectors due to their holistic focus on sustainability and emissions reduction.

The impact scores for each policy initiative across the three industrial ecosystems were determined by evaluating the relative influence of each policy on the sector's operations, regulatory requirements, and innovation trajectory (Table 1). Each policy was assessed on a scale from 1 to 3, where 1 indicates a low impact, 2 represents a moderate impact, and 3 signifies a high impact. This scoring considers various factors, including the degree of alignment with the sector's core activities, the scope of regulatory obligations introduced by the policy, and the extent to which the policy drives technological or environmental transformation within the sector. For instance, policies like the European Green Deal and Fit for 55 Package are assigned high scores for sectors heavily focused on emissions reduction, such as Energy-Intensive Industries and Mobility, while more specialized policies like the Digital Single Market Strategy have a greater influence on sectors undergoing digital transformation, such as Aerospace & Defense.

Policy/Initiative	Aerospace & Defense	Energy-Intensive Industries	Mobility, Transport & Automotive
European Green Deal	2	3	3
Fit for 55 Package	2	3	3
Next Generation EU Recovery Plan	2	2	3
European Industrial Strategy	2	3	2
Strategic Technologies for Europe Platform	2	2	2
Net Zero Industry Act	1	3	2
Digital Single Market Strategy	2	1	3
Horizon Europe	2	2	2
Circular Economy Action Plan	1	2	2
Critical Raw Materials Act	2	2	3
Corporate Sustainability Due Diligence Directive	2	2	2
EU Taxonomy Regulation	1	3	2

Table 1: Impact Assessment of Key EU Policy Initiatives Across Industrial Ecosystems

3.2.1. Aerospace & Defence

The Aerospace & Defence sector tends to experience a more moderate influence from EU policies compared to the other two ecosystems, primarily due to its specialized, high-tech nature and its reliance on security-sensitive operations. While aerospace is increasingly adopting sustainable practices, the pace of decarbonization is slower, as reflected in the lower impact scores for policies like the Net Zero Industry Act and the European Green Deal.

However, the Digital Single Market Strategy has a significant role in this ecosystem, particularly in the context of the sector's digital transformation. The DSM's focus on cross-border data flows, interoperability, and improved cybersecurity is vital for advancing the digitalization of aerospace operations. The industry benefits from improved digital infrastructure, which supports innovations in satellite technology, autonomous systems, and digital manufacturing (such as 3D printing for aerospace components).

Furthermore, the DSM promotes the adoption of standardized digital frameworks across Europe, which helps the aerospace sector operate more seamlessly across borders, particularly in multinational defence alliances. This digital integration is crucial for collaborative defence projects, where different countries' systems and technologies need to work together. The policy's support for cybersecurity initiatives is also particularly relevant, given the sensitive nature of the data handled by the aerospace and defence industries.

While aerospace may face less direct pressure from decarbonization policies, the sector still needs to focus on sustainable innovation to remain competitive in a global marketplace that is increasingly driven by environmental and digital transformation.

3.2.2. Energy-Intensive Industries

Energy-Intensive Industries, such as steel, cement, and chemicals, are particularly exposed to EU policy initiatives, as seen by their high-impact scores across multiple categories. Policies like the EU Taxonomy Regulation and the Net Zero Industry Act (NZIA) reflect the urgent push for decarbonization within this ecosystem. Energy-Intensive Industries face significant pressure to reduce emissions and improve energy efficiency as part of the EU's climate and environmental goals.

A key enabler for this transformation is the integration of smart grids. While traditionally more relevant to utilities and energy providers, smart grids are becoming increasingly important for EIIs. By providing real-time energy monitoring, dynamic pricing, and facilitating the use of renewable energy sources, smart grids allow these industries to optimize their energy consumption. Demand-side management and decentralized energy production—such as on-site renewables and energy storage—further support efficiency efforts, helping EIIs lower operational costs and carbon emissions.

The broader transition to green energy and the pressure to decarbonize is also driven by initiatives like the EU Taxonomy Regulation, which sets clear criteria for sustainable investments, encouraging the adoption of cleaner technologies. The Circular Economy Action Plan adds further urgency by focusing on resource efficiency and waste reduction, pushing these industries toward more sustainable practices. In this context, smart grids are a crucial tool for managing the energy transition in a sector where energy costs and emissions are both substantial and hard to reduce.

3.2.3. Mobility, Transport & Automotive

The Mobility, Transport & Automotive sector is undergoing rapid transformation, with a heavy focus on electrification and the transition to sustainable transport solutions. The European 'Sustainable and Smart Mobility Strategy' lays the foundation for how the EU transport system can achieve its green and digital transformation and become more resilient to future crises. Likewise, initiatives like the European Green Deal and Fit for 55 aim to drastically reduce CO_2 emissions from road and maritime transport by promoting the use of electric vehicles (EVs) and alternative fuels, while the railway sector – which is already heavily electrified – is leveraging batteries and hydrogen for traction. The sector's reliance on essential resources, highlighted by the Critical Raw Materials Act, underscores the challenges in securing the materials needed for battery production and other green technologies, as well as to support the heavy digitalisation, which is also a great source of use of critical raw materials.

One of the most important drivers of change in this ecosystem is the Digital Single Market Strategy (DSM), which plays a pivotal role in fostering smart mobility. The DSM enhances cross-border digital services, enabling the growth of car-sharing platforms, ride-hailing services, and Mobility-as-a-Service

(MaaS). These digital services rely on seamless access to real-time data and efficient cross-border integration, both of which are supported by the DSM's push for better digital infrastructure (like 5G networks) and standardized regulations.

The DSM is also critical in enabling the development of connected and autonomous vehicles (CAVs). Through improved data sharing and real-time communication between vehicles, transport infrastructure, and services, the DSM facilitates the rollout of intelligent transportation systems. These technologies are key to reducing congestion, improving road safety, and lowering emissions through more efficient mobility solutions.

In this sector, policies like the Critical Raw Materials Act and the Circular Economy Action Plan also play significant roles. The sector's high reliance on specific materials for battery production makes it vulnerable to resource availability and supply chain disruptions. The Circular Economy Action Plan encourages recycling and better management of these materials to create a more resilient and sustainable supply chain.

3.2.4. Conclusion

This differential impact across sectors highlights the complex relationship between EU policies and industrial ecosystems, emphasizing the need for sector-specific strategies. While Energy-Intensive Industries must focus on adopting smart grids and improving energy efficiency, the Mobility, Transport & Automotive sector is deeply impacted by the rise of smart mobility and the digital transformation enabled by the DSM Strategy. In the Aerospace & Defence sector, policies like the DSM Strategy help drive digitalization and innovation, though the focus on sustainability remains less intense than in other ecosystems. To navigate these evolving challenges, each sector must tailor its approach to maximize opportunities and mitigate potential disruptions stemming from EU initiatives.

4. Cross-Ecosystem Challenges in AT/AMT Adoption for SMEs

SMEs are crucial to the success of the EU's twin transition strategy. Small and medium-sized enterprises represent an overwhelming 99% of all businesses within the European Union, firmly establishing them as the backbone of the European economy. These companies generate more than half of the EU's total GDP, with their contributions spanning across diverse sectors from manufacturing to services. Furthermore, SMEs serve as the primary source of employment throughout Europe, providing livelihoods for approximately 100 million people. This impressive employment figure underscores their fundamental role not only in job creation but also in maintaining the stability and dynamism of the European labor market.

The widespread adoption of Advanced Technologies (ATs) and Advanced Manufacturing Technologies (AMTs) by these SMEs plays a vital role in shaping Europe's future. By embracing these technologies, SMEs contribute significantly to enhancing the overall economic competitiveness of the European Union, helping European businesses maintain their edge in an increasingly competitive global market. Moreover, these companies act as crucial drivers of innovation across various sectors, fostering new solutions and approaches that benefit the entire economic ecosystem. Their technological transformation is also instrumental in achieving the EU's ambitious sustainability and digital transformation goals, making them key players in Europe's journey toward a more sustainable and digitalized future.

Despite their pivotal role in the European economy, SMEs face considerable challenges in their journey to adopt advanced technologies. These obstacles manifest across three critical dimensions, each presenting unique hurdles that need to be carefully addressed.

The first major challenge lies in **technological barriers**, which create significant implementation hurdles for many small and medium-sized enterprises. These companies often struggle with the inherent complexity of new technologies, finding it difficult to understand and effectively implement advanced systems within their operations. Integration challenges are particularly pronounced, as many SMEs face substantial difficulties in incorporating new technologies with their existing systems and workflows. Adding to these complications is the relentless pace of technological evolution, which requires companies to constantly adapt and update their technological capabilities, often before they have fully mastered their existing systems.

Financial constraints represent the second major dimension of challenges. Many SMEs find themselves constrained by the substantial initial investment costs required to implement advanced technologies, which can strain their often-limited financial resources. The uncertainty surrounding returns on investment adds another layer of complexity to their decision-making process, as companies struggle to accurately predict when and how their technological investments will pay off. Furthermore, SMEs frequently encounter difficulties in accessing capital, with traditional financing options often proving insufficient or inaccessible for their technological transformation needs.

The third dimension involves **supply chain vulnerabilities,** which have become increasingly apparent in recent years. SMEs face ongoing challenges in securing critical raw materials necessary for their operations, often competing with larger corporations for limited resources. Feedstock challenges present additional complications, affecting production capacity and operational efficiency. Component shortages, exacerbated by global supply chain disruptions, further complicate their ability to maintain consistent operations and implement new technologies effectively.

Understanding these challenges is crucial for policymakers, industry leaders, and SMEs themselves to develop effective strategies for technology adoption and to ensure the success of the EU's twin transition initiatives.

The following sections will delve deeper into each of these challenge areas, examining how they specifically impact SMEs in their journey to adopt and implement advanced technologies in the context of the EU's digital and green ambitions.

4.1. Technological barriers

4.1.1. The key technologies driving the twin transition

The twin transition in Europe is being propelled by several key technologies that seamlessly integrate digital capabilities with environmental sustainability. These technologies form the foundation of Europe's transformation toward a more sustainable and digitalized future.

Renewable Energy Technologies stand at the forefront of this transformation. Solutions such as solar panels, wind turbines, and bioenergy systems are revolutionizing how we generate electricity by harnessing natural resources. These technologies play a pivotal role in reducing greenhouse gas emissions and facilitating the transition away from fossil fuels. Their effectiveness is further enhanced through digital integration, with artificial intelligence and Internet of Things (IoT) systems optimizing their performance and enabling seamless integration with smart grids, while fundamentally providing clean, sustainable energy sources.

Smart Grids represent another crucial technological advancement in this transition. These sophisticated electrical grid systems employ advanced digital communication technology to detect and respond to local changes in usage patterns. Through the deployment of sensors, automation systems, and intelligent data analytics, smart grids enable real-time monitoring and control of energy distribution. This digital infrastructure is particularly valuable for its ability to efficiently integrate renewable energy sources while simultaneously reducing energy waste, demonstrating a perfect synthesis of digital and green objectives.

Energy Management Systems and Energy Efficiency Technologies form another vital component of the twin transition. From smart thermostats to energy-efficient appliances and LED lighting, these systems and devices are transforming how we monitor, control, and optimize energy consumption. Many of these solutions are IoT-enabled and leverage artificial intelligence and data analytics for optimization, directly contributing to reduced energy consumption and lower emissions through smart, digitally enabled management.

In the transportation sector, **Sustainable Mobility Solutions**, including electric and hydrogen vehicles, are reshaping how we move. Electric cars, hydrogen fuel cell vehicles, and shared mobility platforms exemplify this category. These technologies incorporate digital elements, such as IoT systems for vehicle-to-grid communication, smart charging capabilities, and autonomous features, while simultaneously addressing the critical need to reduce transportation-related emissions.

The Internet of Things (IoT) serves as a foundational technology that underpins many aspects of the twin transition. This vast network of interconnected devices facilitates real-time data collection and device control across numerous applications. While primarily digital in nature, IoT technology plays a crucial role in enabling efficient resource use across various sectors, from smart homes to industrial applications, thereby supporting both digital advancement and environmental sustainability goals.

Blockchain technology represents a powerful force influencing both digital and green transitions. This decentralized, distributed ledger technology, which records transactions across multiple computers, is revolutionizing how we approach data security and transparency. Its impact extends far beyond its original financial applications, proving particularly valuable in enhancing supply chain transparency and enabling innovative approaches to renewable energy trading. In the context of green initiatives, blockchain facilitates peer-to-peer energy trading in microgrids, allows for transparent tracking of carbon credits, and enables accurate monitoring of environmental impacts throughout supply chains. The technology's ability to create immutable records while reducing the need for intermediaries makes it an essential tool in building trust and efficiency in both digital and sustainable transformations.

4.1.2. Technologies Crucial for Digital Transition

The digital transformation of Europe's economy is being driven by several key technologies that work in concert to revolutionize how businesses operate and interact.

At the forefront of this transformation is **Artificial Intelligence** (AI), which represents a fundamental shift in how systems and machines operate. These AI systems, designed to mimic human intelligence, perform complex tasks while continuously improving based on the information they collect. Their impact reaches across various sectors, fundamentally transforming operations through process optimization, enhanced decision-making capabilities, and predictive maintenance systems that anticipate and prevent equipment failures before they occur.

Working hand-in-hand with AI, **Big Data and Analytics technologies** have become increasingly crucial in the modern digital landscape. These sophisticated technologies and techniques enable organizations to analyze extremely large datasets that would be impossible to process through traditional methods. By processing vast amounts of information, these systems provide valuable insights into consumption patterns, environmental impacts, and operational efficiencies, enabling businesses to make data-driven decisions and identify opportunities for improvement that might otherwise remain hidden.

Cloud Computing has emerged as another cornerstone of digital transformation, fundamentally changing how organizations access and utilize IT resources. This technology enables the on-demand delivery of computing power, database storage, applications, and other IT resources through cloud services platforms via the internet. Its significance lies in its ability to democratize access to advanced digital solutions, allowing businesses of all sizes to adopt sophisticated digital tools without the burden of heavy upfront infrastructure investments. This accessibility has proven particularly valuable for SMEs, enabling them to compete more effectively in an increasingly digital marketplace.

The foundation supporting these digital technologies is **5G, Advanced Connectivity and high-performance computing**. As the fifth generation of cellular network technology, 5G represents a quantum leap in communication capabilities, offering unprecedented speeds and significantly lower latency compared to previous generations. This enhanced connectivity serves as a crucial enabler for other digital technologies, facilitating faster data transfer and supporting the widespread deployment of IoT devices. The impact of 5G extends beyond simple improvements in communication speed, enabling new applications and services that were previously impractical or impossible due to connectivity limitations. High-performance computing complements 5G by enabling the processing and analysis of vast amounts of data generated by IoT devices and other digital technologies.

4.1.3. Technologies Crucial for Green Transition

The green transformation of Europe's economy relies on a diverse array of technologies designed to reduce environmental impact and promote sustainability across various sectors. These technologies work together to create a more sustainable and environmentally conscious industrial landscape.

Energy Storage Solutions represent a critical component of the green transition, particularly in managing the intermittent nature of renewable energy sources. Technologies such as lithium-ion batteries, flow batteries, and pumped hydro storage systems provide essential capabilities for storing energy when it's abundant and releasing it when needed. This flexibility is crucial for maintaining stable power supply in renewable energy systems, effectively addressing one of the primary challenges in the transition to clean energy sources.

In the agricultural sector, **Sustainable Agriculture Technologies** are revolutionizing how we produce food while preserving natural resources. Precision farming tools, vertical farming systems, and agroecological practices are transforming traditional farming methods into more efficient and environmentally conscious operations. These technologies enable farmers to optimize resource use, reduce chemical inputs, and maintain soil health while improving yields, demonstrating how technology can balance productivity with environmental stewardship.

Green Building Technologies are reshaping the construction industry's approach to sustainability. Through the implementation of sustainable materials, energy-efficient design principles, and innovations like green roofs, these technologies are significantly reducing the environmental impact of both new and renovated buildings. These advancements not only improve energy efficiency but also enhance occupant comfort and well-being while minimizing the construction sector's substantial environmental footprint.

Waste Management and Recycling Technologies play a pivotal role in advancing the circular economy. Advanced recycling processes, waste-to-energy technologies, and sophisticated composting systems are transforming how we handle waste materials. These technologies enable the recovery of valuable resources from waste streams, reduce landfill usage, and create new value chains from previously discarded materials, supporting the transition to a more circular and sustainable economy.

Water Management Technologies are becoming increasingly crucial as water scarcity concerns grow globally. Smart irrigation systems, water recycling technologies, and advanced desalination solutions are revolutionizing how we use and conserve water resources. These technologies are particularly vital in agriculture and urban areas, where they enable more efficient water use while maintaining or improving water quality standards.

Carbon Capture and Storage (CCS) has emerged as an essential component in addressing industrial CO2 emissions. In sectors such as cement production, steel manufacturing, and certain chemical processes, CO2 emissions remain an inherent part of current production methods. While industries strive to reduce their carbon footprint, these sophisticated CCS systems provide a practical solution by capturing CO2 emissions directly from industrial processes and storing them securely underground. By preventing these inevitable emissions from entering the atmosphere, CCS technology serves as a vital bridge in our climate action strategy, particularly in hard-to-abate sectors where alternative zero-emission technologies are still developing or may not be feasible in the near term. The technology's ability to handle large volumes of CO2 makes it an indispensable tool in meeting climate goals while maintaining essential industrial operations that support economic stability and growth.

4.1.4. Potential barriers

In the transition towards a more sustainable and digitally integrated economy, several barriers may impede progress. These can be categorized into technical and infrastructure limitations, data privacy and security concerns, skills and workforce readiness, and regulatory and policy challenges.

Technical and Infrastructure Limitations

- Renewable Energy and Smart Grids: Renewable energy sources, including wind and solar, are inherently intermittent, requiring a resilient grid infrastructure with enhanced energy storage. Without advanced storage solutions and smart grid integration, delivering a reliable energy supply remains a major challenge.
- 5G and Advanced Connectivity: In rural or underdeveloped regions, limited 5G infrastructure constrains the deployment of IoT and AI-driven technologies, which depend on high-speed, low-latency networks for real-time data processing and efficient operation.
- Carbon Capture and Storage (CCS): The deployment of CCS is both complex and costly. The necessary infrastructure—such as transport pipelines and storage facilities—is scarce, particularly in regions where CCS is not yet established, slowing the adoption of this important carbon reduction technology.

Data Privacy and Security Concerns

- IoT, Blockchain, and AI: These technologies rely on vast data collection and analysis, which raises concerns about privacy and security. Strict data protection regulations, such as General Data Protection Regulation (GDPR) in Europe, create high standards for data security, which may constrain the implementation of data-intensive solutions.
- Blockchain Transparency: Although blockchain offers security, its requirement for transparency may deter some industries due to concerns about disclosing proprietary information or sensitive operational details.

Skills Gap and Workforce Readiness

- Specialized Skill Requirements: The integration of digital and sustainable technologies demands specific skills that are currently limited. For example, managing smart grids, blockchain-based energy trading systems, and AI-driven energy solutions requires a combination of technical expertise and industry-specific knowledge.
- Workforce Limitations: A shortage of qualified personnel, particularly in sectors like manufacturing and agriculture, where digital and green competencies are less prevalent, poses an obstacle to implementing advanced technologies.

Regulatory and Policy Challenges

- Regulatory Uncertainty: While European policies are adapting to support sustainability and digital transformation, some outdated or inconsistent regulations continue to present obstacles. For instance:
    a) Energy storage and decentralized renewable systems face regulatory ambiguities, complicating investments and slowing deployment: in some regions, storage is classified as a generation asset, which results in higher operating costs, such as double charging for network usage, as storage systems are charged for both charging and discharging. Although the EU classifies energy storage as a unique technology, national grid codes in several countries, including Germany and the Netherlands, still treat it as generation, imposing additional grid fees and connection barriers. Germany has recently responded by extending grid fee exemptions for large-scale storage until 2029, yet this approach is not uniform across Europe. Inconsistent implementation of EU directives in national markets has created a fragmented regulatory landscape, impeding investment and the overall scalability of storage solutions across the region [19].

    b) In some areas, legacy subsidies for fossil fuels create substantial competitive disadvantages for renewable energy sources by maintaining artificially low prices for traditional energy. In 2022, global fossil fuel consumption subsidies reached $1 trillion, a record high, as governments sought to mitigate the impact of the energy crisis on consumers. While fossil fuel subsidies decreased slightly in 2023, they remained significantly higher than subsidies for clean energy investments, which received only $70 billion for initiatives like electric vehicles and energy efficiency. This disparity distorts the market by lowering the cost of fossil fuel energy relative to renewables, undermining the economic case for cleaner alternatives. Additionally, when considering unpriced externalities like environmental and health costs, the true cost of fossil fuels vastly overshadows that of renewables, impeding the transition to a sustainable energy future [20].
- Infrastructure Approval Delays: Approval processes for infrastructure projects, such as CCS facilities and smart grids, can be lengthy, hindering timely development and deployment. According to the IEA, a staggering 3,000 GW of renewable power projects are currently stalled in

grid connection queues globally—five times the solar and wind capacity added in 2022—creating a major bottleneck for clean energy transitions. One key issue is that grid infrastructure, which typically takes 5 to 15 years to plan, permit, and build, lags behind the faster timelines for renewable projects, which often take only 1 to 5 years. Regulatory barriers, such as Germany's complex authorization procedures and slow grid connection processes, further exacerbate these delays, leading to a fragmented and sluggish deployment of essential infrastructure. In response, some strategies, including Germany's BMWK electricity storage strategy, seek to standardize connection procedures and simplify permitting to mitigate these issues. However, without broad regulatory reform and streamlined processes, infrastructure delays will continue to impede the timely advancement of renewable energy initiatives and associated technologies like energy storage [21].

4.2. Financial constraints

SMEs face significant financial hurdles as they navigate the twin transition toward digital and green technologies. These challenges manifest in several interconnected ways distinctly across the Aerospace & Defence, Energy-Intensive Industries, and Mobility, Transport and Automotive ecosystem, and require careful consideration and targeted solutions.

High initial investment costs represent one of the most formidable barriers for SMEs. In the Aerospace & Defence sector, SMEs must invest heavily in advanced manufacturing technologies and digital twin capabilities, while also meeting stringent environmental compliance requirements. Energy-Intensive Industries face substantial costs in retrofitting existing facilities with energy-efficient equipment and implementing industrial heat pumps or electrification solutions. In the Mobility and Automotive sector, SMEs, particularly those in the supply chain, must invest in retooling their production lines for electric vehicle components and developing new competencies in battery and hydrogen fuel cell technologies.

The **uncertainty surrounding return on investment (ROI**) further complicates the financial landscape. Aerospace & Defence SMEs face extended development cycles for sustainable aviation fuels and lightweight materials, with uncertain market adoption rates. In Energy-Intensive Industries, investments in decarbonization technologies like hydrogen-ready equipment or electric furnaces involve complex calculations about future energy prices and carbon costs. Automotive suppliers investing in EV-specific manufacturing capabilities must navigate uncertain market dynamics and varying adoption rates across regions.

Limited access to capital compounds these challenges. Aerospace SMEs often struggle to secure financing for R&D in novel sustainable materials or more efficient propulsion systems because these projects combine extremely long development cycles (typically 5-10 years), high technical uncertainty, and stringent certification requirements, making them particularly unattractive to traditional lenders who seek more predictable returns and shorter payback periods. Energy-Intensive Industry SMEs face difficulties in obtaining funding for large-scale industrial process transformations, especially when competing with larger corporations. In the automotive sector, traditional lenders may be hesitant to fund SME transitions from conventional to electric vehicle component manufacturing, viewing it as a high-risk transformation.

The **challenge of ongoing costs** adds another layer of financial pressure. Aerospace SMEs must continuously invest in cybersecurity and digital certification processes. Energy-Intensive Industries face rising operational costs related to energy consumption and emissions monitoring systems. Automotive suppliers must maintain dual production capabilities during the transition period while investing in new skills and technologies for electric mobility, creating sustained financial burdens that SMEs must carefully manage.

4.3. Supply chain vulnerabilities

The twin transition's reliance on key technologies exposes several supply chain vulnerabilities. These vulnerabilities, including the critical raw materials dependencies (CRMs), feedstock availability, as well as component shortages, must be addressed to ensure the successful implementation of green and digital transformation. These challenges, while manifesting differently across sectors, share common underlying patterns that demand coordinated strategic responses at both EU and industry levels.

4.3.1. Critical Raw Materials (CRMs) Issues

The essence of critical raw material (CRM) issues across the three ecosystems—Aerospace & Defence, Energy-Intensive Industries, and Mobility, Transport, and Automotive—centers on their shared reliance on rare, geographically concentrated resources. Each ecosystem depends on CRMs like rare earth elements (neodymium, dysprosium), cobalt, lithium, and platinum group metals, which are essential for powering the technologies driving the twin transition. However, this reliance exposes them to several shared vulnerabilities:

Geopolitical and Supply Risks: Many CRMs are concentrated in regions with geopolitical tensions or unstable political environments, such as China, the Democratic Republic of Congo (DRC), and Latin America's lithium triangle. This exposes EU industries to potential supply disruptions and price volatility that could impede the adoption of advanced technologies.

Sector-Specific Dependencies: Each ecosystem has specific CRM needs. Aerospace & Defence requires materials like neodymium and titanium for high-performance applications, Energy-Intensive Industries depend on dysprosium and platinum group metals for robust industrial operations, while the Automotive sector's shift to electric and hydrogen vehicles heightens its reliance on cobalt, lithium, and rare earth elements for batteries and electric motors.

Strategic Imperative for EU Resilience: Given these dependencies, all three sectors face a strategic imperative to reduce reliance on external suppliers, mitigate supply chain risks, and ensure stable CRM access. Coordinated efforts to secure alternative sources, develop recycling programs, and innovate material substitutes are essential to achieving the EU's twin transition goals.

4.3.2. Feedstock Availability

In the twin transition context, the primary challenge for Aerospace & Defence, Energy-Intensive Industries, and Mobility, Transport, and Automotive ecosystems lies in ensuring sustainable, reliable, and high-performance feedstocks that meet both green and digital goals while maintaining cost-effectiveness and resilience. This challenge involves multiple dimensions:

Scarcity of Sustainable Alternatives: Transitioning to low-emission and environmentally friendly materials is hindered by limited availability and scalability of bio-based, recyclable, or carbon-neutral feedstocks. Such materials are essential for advanced manufacturing but often lack the necessary performance durability, posing constraints on ecosystems' abilities to pivot towards greener materials.

Cost and Economic Viability: Sustainable or alternative feedstocks, such as bio-composites or recycled metals, are typically more expensive than conventional resources, posing financial barriers, especially for SMEs. In material-intensive sectors like Energy-Intensive Industries, the high cost of adopting sustainable feedstocks can limit broader uptake of advanced technologies essential for digital transformation.

Technical Compatibility and Performance: Many advanced technologies require materials with precise properties, such as high strength-to-weight ratios, thermal resistance, or magnetic capabilities. Alternative feedstocks that meet these rigorous technical standards are limited. For example, in Aerospace, finding bio-composites that match the lightweight yet durable properties of traditional alloys remains challenging.

Supply Chain Dependencies and Vulnerabilities: Feedstocks essential for advanced manufacturing are often concentrated in specific global regions, creating dependency on imports and exposing industries to geopolitical risks, trade restrictions, and price volatility. Lithium and cobalt, essential for energy storage in the automotive sector, exemplify this issue, where geopolitical vulnerabilities could disrupt production or increase costs, delaying the adoption of critical technologies.

Regulatory and Standardization Barriers: Evolving regulations, such as emissions standards and circular economy targets, drive the demand for alternative feedstocks. However, inconsistencies in regulatory frameworks and a lack of unified standards can complicate compliance, deterring investment in sustainable feedstocks, particularly where new materials lack established quality benchmarks.

Quality Control Across Ecosystems: For many SMEs, integrating sustainable materials like bio-composites, recycled metals, and alternative feedstocks is essential but fraught with challenges related to variability, regulatory demands, and resource limitations. Here's how feedstock inconsistencies impact key sectors and why these materials are critical in their transitions:

Aerospace & Defence: SMEs adopting sustainable bio-composites and recycled metals aim to reduce emissions and reliance on scarce resources. However, these sustainable materials often display variability in properties like strength, density, and thermal resistance, which can jeopardize safety and reliability. Aerospace applications have exceptionally stringent regulatory standards and maintaining them requires intensive testing and certification—a costly hurdle for SMEs with limited resources. For these enterprises, ensuring feedstock availability and quality consistency is essential to confidently incorporate greener materials without compromising the rigorous demands of aerospace applications.

Energy-Intensive Industries: Sectors like steel, cement, and chemicals rely heavily on energy and resource-intensive processes. Transitioning to alternative feedstocks, such as scrap steel and alternative cements, is a promising way to lower emissions and improve sustainability. However, inconsistent quality in these feedstocks can disrupt production flows, reduce efficiency, and even increase emissions if manufacturing processes cannot adapt to material fluctuations. For SMEs, which may lack access to sophisticated quality control systems, maintaining feedstock availability and meeting emissions standards is challenging. Without reliable and consistent inputs, SMEs struggle to achieve the cost-efficiency and emissions reductions needed to thrive in this transitional phase.

Mobility, Transport, and Automotive: These industries rely on recycled metals, plastics, and biofuels to advance their environmental goals. Recycled materials often come with variances in durability and corrosion resistance, which can undermine component longevity and safety. Likewise, biofuels—despite their promise as renewable alternatives—often exhibit quality variations that impact engine performance and emissions consistency. For SMEs, the availability of high-quality, consistent recycled materials and biofuels is essential to meeting regulatory demands while integrating AT to enhance efficiency. However, variability in these materials makes it challenging to balance sustainability with reliability, - as well as to comply with strict regulations set by the railway sector, which prevent materials substitution for safety reasons -, especially as AT adoption places additional demands on precision and quality.

Geopolitical and Supply Chain Vulnerabilities: Strategic industries face unique vulnerabilities due to their dependence on feedstocks from geopolitically sensitive regions. This challenge is particularly acute for SMEs, which typically lack the buffer resources to weather supply chain disruptions or rapid market changes. The concentration of critical minerals and metals in specific geographical areas creates inherent risks that can significantly impact production capabilities and costs.

The rare-earth elements sector provides a telling illustration of these vulnerabilities. These materials, crucial for both EV production, defence systems and railway control systems, are predominantly sourced from a limited number of regions. This geographical concentration leaves SMEs particularly exposed to diplomatic tensions, export restrictions, or other geopolitical events that can disrupt supply chains.

Material Innovation and Adaptation Costs: The transition to sustainable feedstocks presents significant technical and financial challenges, particularly in terms of research and development requirements. SMEs often struggle to allocate sufficient resources for developing and testing sustainable alternatives that must meet rigorous industry standards for safety, durability, and performance. This challenge is compounded by the need to maintain competitive pricing while investing in innovation.

In the aerospace sector, for instance, the adoption of bio-composites as sustainable alternatives to traditional composite materials requires extensive research, testing, and certification processes. These requirements create substantial financial barriers for SMEs seeking to implement more sustainable material solutions while maintaining compliance with industry standards.

End-of-Life Feedstock Management and Circular Economy Integration: The growing emphasis on circular economy principles presents both opportunities and challenges for SMEs in strategic industries. The expectation to manage end-of-life materials as future feedstock introduces new complexities in terms of logistics, processing capabilities, and technical expertise. This transition requires significant investments in infrastructure and technology, which can be particularly challenging for smaller organizations.

The automotive manufacturing sector exemplifies these challenges, particularly in the context of EV battery recycling. SMEs often face significant obstacles in establishing effective systems for retrieving and repurposing valuable metals from end-of-life batteries. These challenges stem from both technological limitations and the substantial infrastructure requirements needed to support circular economy practices.

Through understanding and addressing these challenges, stakeholders can work toward developing more sustainable and resilient feedstock management practices that support both environmental goals and industrial growth. Support mechanisms and innovative solutions will be crucial in helping SMEs navigate these complex challenges while maintaining competitiveness in their respective markets.

4.3.3. Component Shortages

In the pursuit of the twin transition, component supply chain challenges across Aerospace & Defence, Energy-Intensive Industries, and Mobility, Transport, and Automotive sectors are acute.

Global Concentration and Geopolitical Dependence

Many advanced technology components, such as microelectronics, semiconductors, and specialized machinery, are produced predominantly within a limited number of countries, resulting in high dependency on these regions and exposing supply chains to geopolitical tensions, export restrictions, and global market fluctuations. For instance, semiconductor shortages—exacerbated by recent disruptions in East Asia due to geopolitical and pandemic-related issues—have delayed production timelines and raised costs in the automotive and aerospace industries globally.

Component-Specific Material Shortages and Delays

The production of components essential for twin transition technologies relies heavily on specific raw materials that are frequently limited in availability. For example:

Aerospace & Defence: Key components, such as those for avionics and precision instruments, depend on materials like neodymium and titanium. Variability in these materials' availability and costs introduces risks, given their crucial role in producing high-precision, safety-critical parts.

Energy-Intensive Industries: Components needed for renewable infrastructure, including wind turbine generators and high-efficiency motors, rely on rare earth elements and specialized alloys, which face significant supply constraints. Delays or shortages in these materials can disrupt production timelines, undermining green transition objectives.

Automotive, Mobility and Transport: The rapid adoption of electric vehicles has driven demand for lithium-ion batteries, which require specific materials often subject to supply chain bottlenecks. Ensuring a stable supply of battery components is essential for advancing EV production and broader mobility innovations.

Supply Chain Complexity and Fragmentation

Supply chains for advanced components are intricate and often fragmented, involving a wide network of global suppliers, manufacturers, and intermediaries. This complexity is particularly challenging for SMEs, which may lack the resources to negotiate with multiple suppliers or to establish alternative supply routes. Fragmented supply chains can also introduce delays, increase costs, and complicate compliance with sustainability and traceability requirements, especially where the origins of materials need careful tracking.

Quality Control and Compliance with Standards

High-stakes industries like Aerospace & Defence require components that meet stringent quality standards. Supply chain disruptions can make it challenging to ensure consistent quality across suppliers, affecting reliability and performance. SMEs face unique difficulties here, as they often have limited access to alternative suppliers that meet these rigorous standards. Additionally, as environmental and digital compliance standards evolve, ensuring components adhere to these new requirements remains a challenge, particularly when such standards are not yet uniformly adopted across global supply chains.

Increasing Demand and Competition for Advanced Components

The acceleration of the twin transition has surged demand for high-tech components like semiconductors, specialized sensors, and electric vehicle parts across various sectors, creating competition for these limited resources. For instance, the automotive sector's demand for battery cells and electric drivetrains is straining availability, affecting other sectors that depend on similar components. Aerospace & Defence and Energy-Intensive Industries often compete with automotive manufacturers, resulting in increased costs and reduced availability, which complicates secure and timely component access at predictable prices.

Sustainability and Circularity Challenges

Integrating sustainable supply chain practices introduces complexities in component sourcing, particularly in adopting circular economy principles. Few advanced components are designed for easy recycling or reuse, and where they are, processes remain costly and technically challenging. As sectors like automotive and aerospace push for green materials and circularity, they face sourcing difficulties in components that align with these principles. Circular supply chain initiatives require substantial redesign efforts and new end-of-life logistics, posing further barriers, especially for SMEs, due to the high cost and technical demands of such transitions.

Just-in-Time Manufacturing Risks

With many advanced manufacturing processes reliant on just-in-time principles, supply chain disruptions pose substantial risks. Smart factories, for instance, are dependent on timely component arrivals; semiconductor delays can halt entire production lines, leading to costly downtimes. While efficient, the just-in-time approach adds vulnerability when sudden disruptions occur, especially in semiconductor delivery, impacting output across sectors that rely on advanced manufacturing.

5. Ecosystem-specific AT/AMT Adoption Challenges

Different industries face unique challenges when adopting Advanced Technologies (AT) and Advanced Manufacturing Technologies (AMT). These challenges stem from the specific operational, regulatory, and market conditions in each ecosystem. This chapter will outline the key adoption hurdles in the aerospace & defence sector, energy-intensive industries, and mobility, transport, and automotive sectors.

5.1. Aerospace & Defense

The aerospace and defense industry is characterized by its high technological intensity, stringent safety and security requirements, and significant economic and political importance[22], [23]. These three sub-industries form the core components of the aerospace and defence industry:

Aeronautics: develops and manufactures civil and military aircraft, helicopters, drones, aero-engines, and other advanced systems and equipment. This field focuses on achieving optimal performance, safety, and efficiency, often balancing lightweight design with durability to meet rigorous safety standards. Aeronautical engineering also addresses noise reduction, fuel efficiency, and cutting-edge technologies for both manned and unmanned flight, ensuring reliable performance across various operational environments.

Space: encompasses launch vehicles, spacecraft, satellites, and ground control systems, all of which require unique engineering to withstand the extreme conditions of space. These systems must be designed to handle intense temperature fluctuations, radiation, and the challenges of operating in a vacuum. Additionally, space engineering emphasizes weight reduction and fuel efficiency due to launch constraints, along with highly reliable, autonomous systems given the limited repair options once in orbit.

Defense: covers core military technologies and applications focused on national security, including combat systems, communication networks, cyber platforms, and intelligence infrastructure. This sector emphasizes advanced capabilities for land-based systems, command and control networks, and secure information systems to support mission-critical operations. With a focus on both innovation and resilience, defence engineering incorporates redundancy, secure communications, and adaptability to handle diverse and evolving security challenges.

Key characteristics of the industry include:

- Complex supply chains composed of large system operators and integrators down to high-tech specialized SMEs.
- High-precision manufacturing requirements.
- Stringent safety and certification standards.
- Long product development and lifecycle periods.
- Significant R&D investment.
- Critical role in national security and economic prestige.

The industry's core manufacturers generated a turnover of EUR 250 billion (125 for aeronautics, 12 for space, and 110 for defense), with globally competitive companies [23]. European technology institutes and academia play a particularly important role in this ecosystem due to its high-tech nature, acting as knowledge transfer channels.

The aerospace and defense sectors are among the most technologically advanced, yet they face significant challenges in adopting AT and AMT due to stringent safety standards, long development cycles, and complex supply chains. These challenges arise from the unique characteristics of the industry, which include the need for precision, high initial investment costs, and the sector's reliance on globally dispersed supply chains.

Key Challenges for AT/AMT Adoption in Aerospace & Defense

1. Regulatory Constraints

Aerospace and defense technologies must comply with strict safety and certification standards. Introducing new technologies, such as renewable energy systems, sustainable mobility solutions, and cybersecurity-enhancing tools like blockchain, requires extensive testing, validation, and regulatory approval, which can delay AT/AMT adoption. The integration of Big Data, AI, and IoT solutions in aerospace and defense operations, for example, demands compliance with stringent security protocols, further complicating the regulatory process.

2. Long Product Development Cycles

The lengthy development and lifecycle of aerospace and defense products—such as aircraft, satellites, and defense systems—complicate the integration of rapidly evolving technologies. As a result, the sector faces risks of technology obsolescence if advancements cannot be smoothly incorporated mid-cycle. For instance, integrating new energy efficiency technologies or smart grid solutions within existing product cycles poses both operational and financial risks.

3. Supply Chain Complexity

Aerospace and defense rely on highly specialized supply chains with a global footprint. The adoption of AT/AMT requires that suppliers meet high standards for quality control, cybersecurity, and material specialization, creating additional pressures. Technologies like blockchain and AI can support increased transparency and security within these complex supply chains but require extensive reorganization and collaboration across supply chain partners.

4. High Initial Investment:

Implementing advanced manufacturing technologies, including additive manufacturing and automation, entails high costs due to the precision and stringent quality controls required in aerospace and defense manufacturing. Adopting energy management systems, sustainable agriculture technologies (in defense contexts), and waste management or recycling technologies are also investment-heavy endeavors that may take time to yield returns.

5. Workforce Skill Gaps

With the rise of AI, Big Data, cloud computing, and advanced analytics, the sector faces skill shortages, especially in the specialized fields required to operate these technologies effectively. Upskilling programs are essential to ensure that workers can competently manage new AT/AMTs, including energy storage solutions and sustainable building technologies, where applicable to defense infrastructure.

Relevant AT/AMTs in Aerospace & Defense

Aerospace and defense manufacturers are exploring a variety of AT/AMTs to enhance their operational efficiency, sustainability, and innovation capacities. Some of the most relevant technologies include:

- **Renewable Energy Technologies and Energy Management Systems**: Used for sustainable operations and to reduce the carbon footprint within manufacturing facilities and defense installations.
- **The Internet of Things (IoT), Big Data and Analytics**: Facilitates real-time data collection and analysis, supporting predictive maintenance and asset management across complex aerospace systems.
- **Blockchain Technology**: Enhances supply chain transparency and cybersecurity, critical for protecting sensitive data across global supply networks.
- **Artificial Intelligence (AI):** Supports automation in manufacturing, decision-making, and cybersecurity defenses.
- **Cloud Computing and 5G/Advanced Connectivity**: Enables seamless connectivity and data management across global operations, facilitating remote monitoring and control of equipment and infrastructure.
- **Energy Storage Solutions and Carbon Capture and Storage**: Applicable in sustainable manufacturing processes and long-term energy strategies, especially as the sector moves towards decarbonization.
- **Green Building Technologies and Waste Management**: Used in the construction and operation of sustainable aerospace and defense facilities.

5.2. Energy-Intensive Industries

Energy-intensive industries (EIIs) encompass sectors that require substantial amounts of energy to produce goods. The primary energy-intensive sectors include steel and metals, chemicals and petrochemicals, cement, paper and pulp, glass, and mining. These industries play a pivotal role in the global economy, contributing to sectors like construction, manufacturing, infrastructure, and consumer goods. These industries account for about 25% of total global CO_2 emissions, making them a critical focus for decarbonization efforts[24]. Given their centrality to industrial supply chains and infrastructure, these sectors face increasing regulatory and social pressure to reduce their environmental impact while meeting the global demand for goods.

Key Characteristics of Energy-Intensive Industries

High Energy Consumption: EIIs account for a significant share of global energy use, often relying on fossil fuels as their primary energy source, which contributes substantially to greenhouse gas emissions. In 2019, EIIs were responsible for 22% of total EU greenhouse gas emissions [25].

Environmental and Carbon Footprint: Due to their energy needs, EIIs are among the largest industrial sources of CO_2 emissions. For instance, steel, cement, and chemicals production are some of the most carbon-intensive activities globally. Between 1990 and 2015, EIIs reduced their emissions significantly, with an average yearly rate of 15% since 2014, mostly through energy efficiency measures. However, to achieve climate neutrality by 2050, a fundamental shift to sustainability is required, including accelerated and deep decarbonization and a transition to a circular economy [26].

Capital-Intensive Operations: EIIs are characterized by high fixed costs and capital requirements, as they rely on specialized equipment and infrastructure that are expensive to upgrade. In 2018, there were 547,745 firms in the ecosystem, with SMEs representing about 99% of these companies.49.1% of workers are employed in large companies, which account for 62.7% of the ecosystem's value added [27].

Long Product Lifecycles: Production facilities within EIIs typically have long lifecycles, with equipment that may operate for decades. This longevity often complicates the adoption of new technologies and makes frequent upgrades challenging.

Regulatory and Social Pressures: With global movements toward sustainability and climate protection, EIIs are under growing regulatory scrutiny to meet emissions reduction targets, adopt cleaner technologies, and implement sustainable practices. The European Green Deal aims to decrease greenhouse gas emissions by at least 55% (compared to 1990 levels) by 2030 and achieve climate neutrality by 2050. The EU Emission Trading System (ETS) has been strengthened and extended, including a substantial increase in the size of the Innovation Fund to support decarbonization efforts [26].

Key Challenges for AT/AMT Adoption in Energy-Intensive Industries

1. Decarbonization and Renewable Integration

High Carbon Emissions: The dependence on fossil fuels for high-temperature processes (e.g., in steel, cement, and glass production) makes decarbonization particularly challenging. While energy-efficient technologies exist, integrating them without compromising productivity and quality is costly and technically demanding.

Integration of Renewable Energy: EIIs face challenges in integrating renewable energy sources, such as wind or solar power, due to the variability in renewable energy supply, which may not align with the continuous energy demand of these industries.

2. Process Optimization and Cost Constraints

High Operational Costs: The costs of implementing advanced manufacturing technologies, such as carbon capture and storage (CCS), waste management, and recycling, are significant. Due to thin margins, many EIIs struggle to justify the initial investment required for such upgrades without government subsidies or regulatory mandates.

Complexity of Process Optimization: Optimizing processes with technologies such as AI, IoT, and big data analytics can improve efficiency but often requires substantial upfront investment in equipment, training, and infrastructure. Moreover, fine-tuning these processes without disrupting production is a significant challenge.

3. Supply Chain and Material Constraints

Availability and Cost of Raw Materials: The shift to more sustainable materials and recycling processes is limited by raw material costs and availability. For example, recycled or alternative materials may not always meet the quality and consistency standards required in industries like steel or cement.

Supply Chain Transparency and Resilience: Implementing IoT and blockchain to improve supply chain transparency is essential but requires significant restructuring of existing systems and collaboration across various suppliers, many of whom are not technologically equipped.

4. Regulatory Compliance and Complex Environmental Standards

Stringent Environmental Regulations: EIIs are subject to strict regulatory requirements to reduce emissions, manage waste, and minimize environmental impact. Meeting these standards often requires costly technological upgrades and can disrupt long-established processes.

Compliance with International Standards: As EIIs operate globally, they must comply with diverse regulatory frameworks. Ensuring compliance across regions is resource-intensive and may necessitate additional technological investments, such as waste management, water management technologies, and environmental monitoring systems.

5. Workforce Skill Gaps and Anticipated Increase in Training for Technology Adaption

Specialized Skills for New Technologies: The transition to digitalized and automated processes, particularly those involving AI, IoT, data analytics, and advanced automation, requires a skilled workforce with expertise in data analytics, industrial IoT, automation engineering, and process optimization. Many EII firms face talent shortages in these areas, as professionals with these skills often work in tech-centric sectors that offer competitive salaries and advanced innovation opportunities. This shortage makes the adoption of AT/AMTs challenging for EIIs, which may struggle to attract and retain the specialized talent needed for successful implementation.

Safety and Operational Training: Safety remains a top priority in EIIs, and introducing new technologies demands updated safety protocols and training. This requires both financial and time investments, particularly for technologies that alter operational processes, such as automation, robotics, and AI-powered systems.

6. Sustainability and Circular Economy Integration

Shift to Circular Economy Models: The adoption of sustainable manufacturing and circular economy models, where waste is minimized and resources are reused, requires significant changes to operations and design. While technologies like green building solutions, carbon capture, and waste recycling are available, integrating them into high-volume, high-energy processes can be expensive. This is due to the need for substantial upfront investments in new equipment and infrastructure, as well as the challenges of retrofitting existing facilities to accommodate these technologies. Additionally, the complexity of customizing and installing these systems to work seamlessly with current processes drives up costs. Ongoing operational and maintenance expenses also add to the financial burden, making full integration a costly and complex process.

Pressure to Reduce Water Usage: Many EIIs are water-intensive, particularly in cooling and production processes. Technologies for water recycling and efficient water management are available but add additional operational costs and infrastructure requirements.

5.3. Mobility, Transport and Automotive

The Mobility, Transport, and Automotive (MTA) industries are fundamental to modern life, supporting global commerce, personal mobility, and infrastructure. These industries include sectors such as automotive manufacturing, public transport systems, logistics, and freight transportation, each of which is facing an unprecedented transformation driven by digitalization, sustainability goals, and shifting consumer preferences. As global demand for mobility continues to increase, MTA companies are under pressure to transition to greener, smarter, and more efficient technologies.

Key Characteristics of the MTA Industries

Sustainability and Emissions Goals: The automotive and transport industries are among the largest contributors to global carbon emissions, accounting for approximately 24% of global CO2 emissions from fuel combustion. Excluding rail transport, road transport constitutes 72% of these emissions, followed by marine transport at 14%, aviation at 13%, and rail at just 0.4% [28]. These sectors collectively represent significant opportunities for decarbonization and the adoption of sustainable practices. There is a growing focus on electric vehicles (EVs), alternative fuels, and sustainable materials to reduce the environmental impact. Electric vehicle sales grew by 41% in 2020, despite overall car sales dropping by 16% due to the pandemic. The global market for electric vehicles is expected to grow from 8.1 million units in 2022 to 39.2 million units by 2030 [25].

Complex and Globalized Supply Chains: MTA companies rely on extensive, complex supply chains with a high degree of interdependence and global reach, requiring careful management to maintain efficiency and reduce risks. The automotive supply chain involves over 10,000 suppliers globally. A typical car contains about 30,000 parts, sourced from multiple countries. Supply chain disruptions in 2021 led to a production loss of approximately 7.7 million vehicles worldwide [25].

Consumer-Centric and Regulatory Pressures: Shifts in consumer expectations toward cleaner, connected, and more autonomous transport solutions are pushing the industry toward rapid technological transformation. Over 60% of car buyers consider connectivity features important when making a purchase decision. The global market for autonomous vehicles is projected to reach $556.67 billion by 2026, growing at a CAGR of 39.47% from 2019 to 2026 [25]. Regulatory requirements for safety, emissions, and data security add additional layers of complexity. Upcoming regulatory emissions standards such as Euro 7 in Europe aim to reduce vehicle emissions by up to 75% compared to Euro 6, which is currently the latest exhaust emissions standard. [25].

Key Challenges for AT/AMT Adoption in Mobility, Transport, and Automotive

1. Shift to Electric and Alternative Fuel Vehicles

Infrastructure Limitations for Electric Vehicles (EVs): While there is a strong push for EVs, the supporting infrastructure, such as charging stations and EV-friendly power grids, is still underdeveloped in many regions. Automotive manufacturers face challenges in scaling EV production without a well-established support network.

Battery Technology and Supply Chain Constraints: The transition to electric and hybrid vehicles depends heavily on advancements in battery technology and the availability of critical raw materials like lithium and cobalt. High demand and geopolitical tensions add to the supply chain risks, making sourcing both sustainable and affordable materials a significant challenge.

2. Digitalization and Data Management

Integration of IoT and Connectivity: Vehicles are increasingly connected, with IoT technology providing real-time data on everything from location to vehicle health. However, managing the vast amount of data generated and ensuring interoperability with legacy systems and third-party applications is a significant challenge.

Cybersecurity Risks: As vehicles become more digital and connected, cybersecurity concerns grow, particularly for autonomous vehicles and smart transport networks. Protecting against data breaches and unauthorized access is essential but requires substantial investment in security technologies and ongoing vigilance.

3. Autonomous and Smart Vehicle Technology

High R&D Costs for Autonomous Vehicles (AVs): Developing fully autonomous vehicles requires significant investment in AI, machine learning, and advanced sensors. Testing and refining AV systems is a complex, resource-intensive process, and achieving full autonomy remains technically challenging.

Regulatory Hurdles for Autonomous and Connected Vehicles: The deployment of autonomous vehicles and smart infrastructure is subject to stringent regulatory scrutiny. Compliance with safety standards and navigation through regulatory variations across regions adds to the complexity and cost of implementation.

4. Environmental and Emissions Regulations

Decarbonization and Emissions Standards Compliance: MTA industries are subject to increasingly strict emissions standards, especially in urban areas and developed markets. Meeting these requirements involves investment in emissions-reduction technologies, such as carbon capture and exhaust treatments, and adherence to diverse standards across global markets.

End-of-Life Recycling and Circular Economy Challenges: With a growing emphasis on sustainability, MTA companies are pressured to develop circular economy practices, including recycling and reclaiming materials from old vehicles. Adopting ATs for efficient material recovery and waste reduction remains complex and costly.

5. Supply Chain Resilience and Transparency

Globalized and Interdependent Supply Chains: The automotive and transport sectors rely on intricate, interconnected supply chains for components and materials, often from multiple countries. Disruptions due to geopolitical tensions, trade restrictions, or natural disasters create significant risks.

Sourcing of Sustainable Materials: To meet environmental standards, there is a growing demand for sustainable materials, such as recycled metals and bio-based composites. Ensuring consistent quality and scalability of these materials across global supply chains presents additional sourcing and quality control challenges.

6. Consumer and Market Shifts

Evolving Consumer Preferences for Mobility: Consumers are increasingly moving towards shared and connected mobility solutions, such as ride-sharing and car-sharing, particularly in urban areas. Traditional automotive companies must adapt to this shift by integrating digital and connected services into their offerings.

Competitive Landscape with New Market Entrants: The MTA sectors are now seeing new entrants, particularly from technology companies and EV-focused startups, which increases competition and pressures legacy companies to innovate and embrace AT/AMT faster.

6. Conclusions

Small and Medium-sized Enterprises (SMEs) form the backbone of the European economy, representing over 99% of all businesses and playing a critical role in advancing the EU's dual goals of green and digital transformation, collectively known as the "twin transition." For these ambitious objectives to succeed, the adoption of Advanced Technologies (AT) and Advanced Manufacturing Technologies (AMT) by SMEs is essential across core industrial ecosystems, including Aerospace & Defense, Energy-Intensive Industries, and Mobility, Transport & Automotive. Despite their importance, SMEs encounter formidable obstacles in embracing AT/AMT. Key cross-sector challenges include technological integration issues, high costs coupled with uncertain returns on investment, and vulnerabilities related to global supply chain disruptions, particularly in obtaining Critical Raw Materials (CRMs).

Each industry ecosystem also faces specific challenges: Aerospace & Defense must navigate complex regulatory standards and high precision requirements; Energy-Intensive Industries are constrained by high emissions and energy demands, complicating efforts to integrate green technologies; and the Mobility, Transport & Automotive sector requires significant investment in infrastructure for electric and smart mobility solutions, while digitalization heightens cybersecurity needs. The European Union offers robust support to address these barriers, providing financial backing, research initiatives, and regulatory frameworks through programs like Horizon Europe, Next Generation EU, the Net Zero Industry Act, and the Critical Raw Materials Act, all aimed at fostering sustainability and reducing foreign resource dependencies.

The report underscores that targeted actions are necessary to accelerate AT/AMT adoption. Increased funding and financial incentives are needed to alleviate high initial costs, while dedicated R&D and skill development programs will address critical workforce gaps. Strengthening supply chain resilience through material substitution, recycling, and alternative sourcing for CRMs is also crucial. Ultimately, the EU's environmental and economic aspirations depend on the digital and green transformation of SMEs. Achieving these goals requires a coordinated, sector-specific approach that combines tailored support mechanisms with strategic investments, empowering SMEs to drive Europe's competitiveness in a sustainable, advanced global market.

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