REUSE2030

D.1.4.1 REUSE2030 TRANSNATIONAL STRATEGY

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1. Introduction

The transformation toward a circular economy is redefining the foundations of industrial competitiveness in Europe. Over the past two decades, the EU has already begun to decouple value creation from resource use: resource productivity (GDP generated per kilogram of materials used) rose from about €1.55/kg in 2000 to €2.36/kg in 2024 which represent an increase of more than 50% in real terms [1]. This shift is not abstract. It reflects a structural change in how industry must operate in a world of finite resources, volatile prices, and tightening climate targets.

Within this context, mechanical engineering and machinery manufacturing occupy a particularly strategic position. The European mechanical engineering sector employs around 3 million people and generates about 9.5% of total EU manufacturing output, while Europe as a whole accounts for roughly 36% of the global machinery market [2]. In 2023, machinery and equipment sales in the EU reached approximately €908 billion, with exports worth €618 billion [3]. Central Europe—including Germany, Austria, Czechia, Slovakia, Poland, Hungary, Slovenia, Croatia and Italy—forms one of Europe's most integrated mechanical corridors, where specialised SMEs supply components, systems and production technologies to global value chains. In Bavaria alone, mechanical engineering is the largest industrial sector, employing about 236,800 people (around 18% of regional industrial employment) [4].

The aim of this Transnational Strategy is to guide mechanical and manufacturing SMEs in Central Europe through a coordinated transition from linear production models toward circular, resource-efficient and regenerative industrial practices. It offers a shared framework for understanding current pressures, identifying realistic opportunities and implementing practical steps that strengthen competitiveness while aligning with European and national policy objectives. The mechanical sector is both an engine of production and a multiplier of innovation: every improvement in how mechanical companies design, build and maintain machinery directly affects the environmental and economic performance of downstream sectors such as renewable energy, transport, construction and digital infrastructure.

At the same time, this sector remains among the most resource- and energy-intensive parts of Europe's economy. European manufacturing firms spend on average about 40% of their production costs on raw materials, and when energy and water are included, resource inputs can account for around 50% of total manufacturing costs, compared with roughly 20% for labour [5].While in energy-intensive industries such as iron and steel, materials alone can represent 58–68% of production costs, with energy adding up to 20%. This cost structure makes mechanical and manufacturing firms highly exposed to raw-material and energy price volatility, while also highlighting the enormous economic potential of resource and energy efficiency.

Mechanical and manufacturing SMEs are at the core of this transition. Across the EU, SMEs represent the overwhelming majority of firms; in Germany, for example, 99% of companies are SMEs [6]. EU-wide, about 25.8 million SMEs employ 88.7 million people, making them the backbone of Europe's economy and also a major driver of its environmental footprint [7]. A recent Eurobarometer shows that 93% of EU SMEs have already implemented at least one resource-efficiency measure (such as saving energy, minimising waste or recycling), yet many still lack a comprehensive strategy or the tools and finance needed to scale circular practices [8]. Many mechanical SMEs in Central Europe are highly specialised, often family-owned, with deep engineering know-how but limited internal capacity for systemic innovation, data management and cross-border collaboration.

Focusing on these SMEs therefore offers maximum leverage for measurable impact. Their cumulative material and energy footprint strongly shapes the region's resource balance, while their flexibility allows them to adopt new business models—such as remanufacturing, product-service systems or industrial symbiosis—more quickly than large corporations once barriers are removed. By equipping them with circular knowledge, digital tools and supportive policy environments, Central Europe can transform its mechanical base into a model region for regenerative industrial development. In this perspective, circularity is not a marginal environmental adjustment; it is a strategic industrial policy that strengthens technological sovereignty, reduces import dependency, mitigates cost volatility and opens new markets for sustainable machinery and services.

The following chapters explore how circular principles can be operationalised inside mechanical companies, analyse the main barriers they face, and outline the systemic interventions—technical, organisational, financial and regulatory—needed to turn circularity into a driver of competitiveness and resilience for the entire Central European region.

2. The Circular Economy in the Mechanical Sector: Vision, Framework, and Implementation Logic

The mechanical industry in Central Europe stands at a decisive moment in Europe's green and digital transformation. For more than a century, it has powered industrial productivity, technological innovation, and global competitiveness. Yet the very foundations of its success—high material throughput, energy-intensive production, and deep dependence on globalized value chains—are increasingly becoming sources of vulnerability. Volatile raw-material markets, rising energy prices, supply chain disruptions, and tightening EU climate and product regulations are exposing structural risks that threaten long-term resilience.

Against this backdrop, the circular economy emerges as a strategic pathway for securing the industry's future. By redesigning products, rethinking manufacturing processes, and optimizing resource use across the entire life cycle, mechanical companies can reduce material dependency, enhance economic stability, and align with Europe's sustainability ambitions. The shift from linear to circular manufacturing is no longer an option—it is becoming a competitive necessity.

2.1 The Transition from Linear to Circular Manufacturing

The exposure begins with raw materials. In 2023, the EU's extra-EU trade in raw materials reached €165 billion, with €97 billion of imports against €68 billion of exports, resulting in a €29 billion trade deficit. Raw materials accounted for 3.3 % of the EU's total extra-EU trade, with nearly half of imports (49 %) concentrated in metals, minerals and rubber; within that group, metal ores and scrap represented about four-fifths of traded volumes [9].For critical raw materials such as rare earth elements (REE+), the imbalance is even sharper: in 2022 the EU imported 2.7 tonnes for every tonne it exported, with most imports coming from a small number of supplier countries and the top three importers accounting for over 95 % of volumes for several key REE products [10]. Recent research on the EU-27 material footprint confirms this structural dependence, estimating import dependency at around 90.9 % for fossil fuels and 86.2 % for metal ores, underlining how strongly European industry still relies on external primary inputs [11].

At the system level, Europe's production model remains largely linear. In 2023, only 11.8 % of the EU's total material use came from recycled waste, a circular material use rate that has increased by just 1.1 percentage points since 2010 and is still considered "low" by the European Environment Agency—evidence that most value chains, including machinery and equipment, still depend predominantly on virgin inputs[12]. This slow progress contrasts sharply with the EU's political ambition to double the circularity rate by 2030, highlighting the gap between current practice and future requirements.

Against this backdrop, the circular economy is not simply an environmental agenda but a new industrial logic for Central Europe's mechanical companies. By redesigning products for longer life and easier remanufacturing, substituting primary with secondary materials, and integrating digital monitoring to manage assets over their full life cycle, mechanical SMEs can directly reduce exposure to imported raw materials, volatile energy prices and tightening carbon constraints. The circular model replaces the fragile "take-make-dispose", As shown in Figure 1, chain with regenerative loops in which design, use, reuse and recovery continuously feed one another. Instead of treating waste as an unavoidable by-product, it is reframed as a misallocated resource that can be recaptured, reprocessed and reinvested into competitiveness.

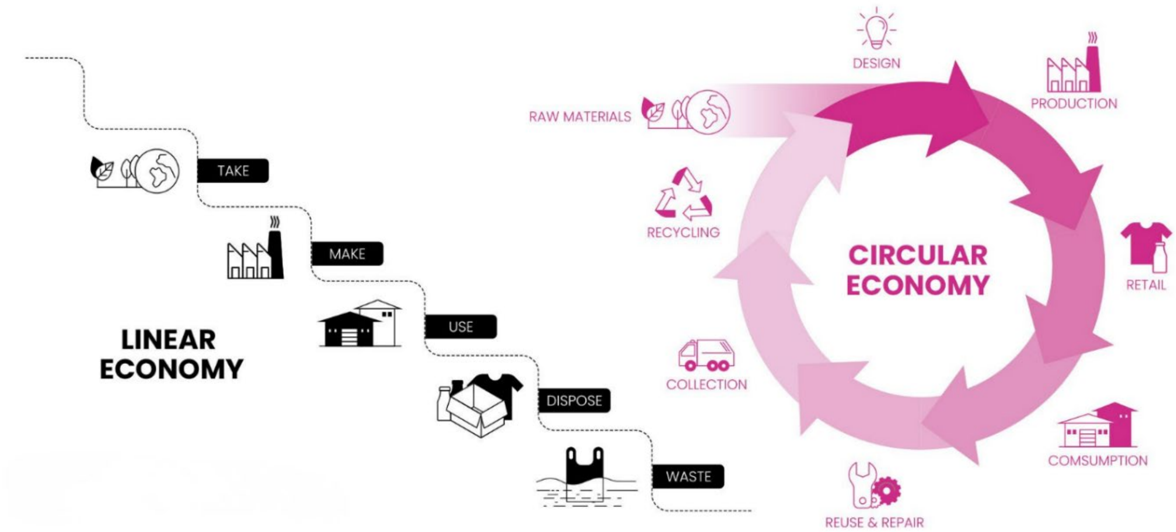

Fig (1): Linear economy vs Circular economy
Souce: https://repeatpack.com/blog/infographic-linear-and-circular-economy/

In this context, the transition from linear to circular manufacturing becomes a core strategy for risk management, cost control and market access. With EU product and climate regulations tightening, and with raw-material and energy security now recognised as strategic issues, mechanical SMEs in Central Europe can no longer treat sustainability as an external constraint. It has become a structural determinant of resilience—and a prerequisite for remaining part of European and global value chains in the coming decade.

2.2 How Circular Economy Functions Inside The Companies

Transitioning to circularity begins inside the company walls, where design decisions, sourcing choices, production methods, and maintenance strategies define environmental and economic performance long before a product reaches the customer. For mechanical SMEs, this means rethinking how value is created, delivered, and retained over time. Circularity starts with design: machinery and components are conceived to be modular, durable, repairable, and eventually recoverable. It continues in operations: processes are optimised to minimise scrap, improve material yield, reduce energy demand, and substitute critical raw materials with recycled or renewable inputs where possible. It extends into the use phase and beyond, through maintenance, remanufacturing, and reverse logistics that keep products and components in circulation instead of allowing them to become waste.

In practice, this is not a single project but a stepwise transformation. Circular economy at company level combines four types of change:

- strategic planning and target-setting,
- technological and process innovation,
- organisational and cultural evolution, and

- partnership and ecosystem building.

This strategy therefore distinguishes three interlinked layers through which circularity operates within firms:

1. the technological layer (how products and processes are designed, produced, and maintained),
2. the organisational layer (how value creation, governance, and skills are structured), and
3. the ecosystem and transnational integration layer (how companies connect to partners, markets, and policies beyond their own boundaries).

Together, these layers turn circularity from an abstract concept into a daily operating logic.

2.2.1 Technological Implementation

Circular transformation begins at the design desk and on the factory floor. At the technological level, mechanical SMEs apply circular principles directly to how machines and components are conceived, produced, used, and recovered.

Key elements include:

- Eco-design and material substitution: Engineers design products for long life, modularity, and disassembly. Components are standardised where possible, interfaces are simplified, and critical parts are made accessible for repair and replacement. Where feasible, primary materials are complemented or replaced by recycled, bio-based, or less critical alternatives, while still meeting performance and safety requirements.
- Smart manufacturing and process optimisation: Sensors, digital twins, and IoT-enabled systems allow companies to monitor machines, production lines, and utilities in real time. This enables early detection of inefficiencies—such as excessive scrap, abnormal energy peaks, or premature wear—and supports continuous improvement of process parameters. Over time, predictive maintenance and condition-based monitoring reduce unplanned downtime, extend asset lifetimes, and optimise spare-parts use.
- Additive manufacturing and remanufacturing: Additive processes are used to repair worn components, build near-net-shape parts with less material loss, or integrate functions that previously required multiple parts. Remanufacturing techniques restore used components to like-new performance, preserving the embedded material and energy. Design-for-remanufacture (e.g. using reversible joints, robust surfaces, and accessible interfaces) becomes a standard requirement for critical modules.
- Closed-loop production and internal symbiosis: Within the factory, production residues such as metal offcuts, coolant, lubricants, and waste heat are systematically captured, separated, and routed back into internal processes or into external loops with neighbouring firms. Material and energy flows are managed as assets, not as unavoidable losses.

Technological implementation is not limited to new plants or “greenfield” investments. For most mechanical SMEs, it means retrofitting existing equipment, integrating sensors into legacy machines, adjusting process parameters, and gradually replacing critical components with modular, repair-friendly designs. When done systematically, each factory becomes a micro-ecosystem of efficiency, where waste streams are minimised, data informs decisions, and every design change is evaluated over the full life cycle rather than only at purchase cost.

2.2.2 Organisational Transformation

Circular economy implementation is not purely technical. It fundamentally changes how companies define value and how they organise themselves to deliver it. For mechanical SMEs, this implies shifting from a product-only logic ("we sell machines") to a value-through-circularity logic ("we deliver functionality, reliability, and long-term performance with minimal resource use").

At the organisational level, circular principles are embedded in governance, business models, and people development:

- Business model innovation: Companies move beyond one-off sales toward service- and performance-oriented models: product-as-a-service, leasing, long-term maintenance contracts, upgrade programmes, and reverse logistics for returned components. Revenue increasingly comes from uptime, reliability, and extended life rather than from frequent replacements.
- Data-driven decision-making: Circular and environmental indicators—such as material recirculation rates, share of secondary materials, carbon intensity per unit, repair vs. replacement ratios, or energy use per operating hour—are integrated into ERP, MES, and accounting systems. Investment decisions, product-development gates, and supplier evaluations incorporate these metrics alongside traditional financial criteria.
- Workforce and culture: Engineers, designers, technicians, and managers are trained in life-cycle thinking, eco-design, circular business models, and green digital skills. Cross-functional teams (e.g. design-production-service) collaborate early in product development to avoid downstream waste and maintenance issues. Internal incentives and recognition systems reward ideas that reduce resource use, extend lifetimes, or improve reparability.
- Corporate governance and risk management: Circularity becomes part of strategic planning, internal auditing, and risk management. Responsibilities are clearly assigned—whether through sustainability officers, circularity coordinators, or integrated management systems. Reporting on circular performance is aligned with external requirements (e.g. sustainability reporting, customer questionnaires) to avoid duplication and build trust with stakeholders.

Organisational transformation ensures that technological innovation is actually used and scaled. New machines or digital tools alone do not make a company circular; people, processes, and incentives must support new ways of working. When circular KPIs sit next to financial ones on management dashboards, and when employees see resource savings and life-extension as part of their daily job, circular economy stops being a project and becomes part of the company's identity.

2.2.3 Ecosystem and Transnational Integration

Circular transformation cannot be completed only within company walls. Many circular practices—industrial symbiosis, secondary-material markets, shared repair and remanufacturing infrastructure, or digital product data—only become viable when companies cooperate across value chains and borders.

At the ecosystem level, mechanical companies connect into regional and transnational circular ecosystems:

- Transnational industrial symbiosis: Firms across Central Europe exchange residual materials, by-products, and waste streams through physical networks and digital marketplaces. Production residues from one company become inputs for another, reducing demand for primary raw materials and strengthening regional resource sovereignty.
- Regional cooperation and cluster initiatives: Development agencies, chambers, and industry clusters coordinate circular pilot zones where SMEs, large companies, research institutes, and universities jointly test circular solutions: shared remanufacturing lines, common recycling platforms, repair hubs, or training programmes. Successful pilots are scaled across the region, creating learning effects and reducing individual risk.

- Policy and finance alignment: Public authorities harmonise standards and procedures (e.g. waste codes, end-of-waste criteria, cross-border movement of secondary materials) and design funding instruments that support circular investments, especially for SMEs. Financial institutions and public banks align their products with circular and climate objectives, rewarding companies that can demonstrate credible transition plans.
- Shared digital infrastructure and data spaces: Data platforms, digital product passports, and circular inventory tools allow SMEs to trace material content, document repairs and remanufacturing, and share verified information with customers, regulators, and financiers. Interoperable standards and secure data-sharing arrangements help smaller firms participate in complex, multi-country supply chains without disproportionate administrative burden.

Through these mechanisms, Central Europe can evolve into a single circular economy region, where mechanical companies operate collaboratively rather than as isolated national actors. Ecosystem integration scales the impact of individual company actions: secondary raw materials, data, and know-how circulate more freely; investments in circular infrastructure are shared; and policy support is aligned with real industrial needs.

The three layers—technological, organisational, and ecosystem—do not operate in isolation. They interact dynamically as shown in fig (2):

- Technological innovation provides the tools and capabilities for circularity (better design, cleaner processes, smarter maintenance).
- Organisational transformation ensures uptake and governance, aligning strategy, culture, and incentives with circular objectives.
- Ecosystem and transnational integration scale and stabilise circular practices, turning individual initiatives into robust regional systems.

Together, they create a self-reinforcing loop of industrial circularity. Each successful design change, each remanufacturing project, each new service model, and each symbiosis partnership feeds back into the company's knowledge base and the region's collective learning. Over time, this transforms the mechanical sector from a resource-intensive base industry into a regenerative engine of the European economy—one that delivers competitiveness, resilience, and environmental stewardship in a single, integrated model.

Figure 2: Circular Implementation Framework (showing the three interlinked layers: technology, organisation, ecosystem)

2.3 Benefits for Companies Adopting the Circular Transition

For mechanical SMEs, embracing circularity does far more than improve environmental compliance – it reshapes what competitiveness means in practice. European analyses increasingly frame the circular economy as a source of industrial strength, highlighting its potential to enhance efficiency, stimulate innovation and open new markets, rather than as a constraint on growth [13].

By redesigning products and operations around reuse, efficiency and data-driven management, companies gain greater control over their cost structure. Resource-efficient design, remanufacturing and smarter maintenance extend equipment lifetimes and reduce dependency on volatile input prices, while lower waste and disposal needs free up working capital for innovation and digitalisation. Studies on circular business models emphasise that such improvements not only support environmental goals but also strengthen margins and operational stability by reducing material input, extending product use and lowering residual waste [14].

At the same time, market access is increasingly tied to demonstrable sustainability performance. In sectors such as automotive, energy and high-tech manufacturing, large OEMs now expect suppliers to provide robust data on product carbon footprints, material composition and recyclability, and in some cases make this information a prerequisite for supplier nomination [15]. For mechanical SMEs, circular practices – traceable materials, design for repair, documented lifetimes, take-back or remanufacturing options – therefore act as a gateway to preferred supplier lists, long-term framework contracts and participation in more demanding, higher-value supply chains.

Circularity also fuels service and business-model innovation. When companies systematically collect and use life-cycle and maintenance data, they can move beyond one-off machine sales towards service-oriented offerings such as predictive-maintenance contracts, performance guarantees, pay-per-use or leasing models. Research on servitization in machinery and industrial equipment shows that such models can generate more stable, recurring revenue streams, deepen customer relationships and increase the lifetime value of each installed asset [16]. Circular design and circular data thus become the foundation for new value propositions built on uptime, reliability and long-term performance.

Financial institutions are gradually integrating this logic into their products. ESG-linked and sustainability-linked loans tie interest conditions to the achievement of environmental or circularity targets, rewarding firms that can demonstrate credible performance improvements. Banks and investors increasingly look for clear signals of transition readiness: robust governance, reliable data on emissions and material use, and concrete plans for aligning business models with climate and resource objectives. For mechanical SMEs, the ability to quantify and communicate circular progress strengthens their position in discussions with lenders, public development banks and impact-oriented investors, improving access to capital for modernisation and growth.

All these effects converge in greater resilience. Companies that embed circular principles into design, sourcing and operations are less exposed to supply disruptions, price spikes and regulatory shifts because they rely more on secondary materials, local recovery loops and service-based income, and less on linear flows of virgin inputs [17]. They are better positioned to respond to new regulations on product sustainability and corporate reporting, and to changing customer expectations.

For mechanical SMEs in Central Europe, circularity is therefore not a marginal compliance task but a strategic upgrade of the business model. It aligns profitability with innovation and sustainability, turning resource efficiency, service innovation and transparent data into long-term competitive advantages in an industrial landscape shaped by the green and digital transitions.

3. Current Situation and Key Challenges

3.1 Overview of the Mechanical Industry in Central Europe

Central Europe's mechanical industry forms one of Europe's most tightly connected production systems. From southern Germany and Austria through the Czech Republic, Slovakia, Poland, Hungary, Slovenia, Croatia and Italy, this belt of countries is part of an EU machinery and equipment sector that generates close to €900 billion in annual turnover. In 2023, machinery and equipment manufacturers based in the EU reached a turnover of about €908 billion, making this the third-largest industrial sector in the EU (after automotive and the food & feed sector) [18].In 2024, the EU machinery sector is estimated to have generated around €871 billion, corresponding to roughly 27 % of global machinery turnover in a world market of about €3.26 trillion [18].

This industrial strength is closely linked to employment and regional development. Across the EU-27, about 3.1 million people worked in machinery and equipment manufacturing in 2023, with roughly 41 % of these jobs located in Germany and about 16 % in Italy—both core countries of Central Europe [18].At the same time, the wider EU manufacturing sector comprises 2.2 million enterprises employing 30 million persons and generating €9.8 trillion in turnover in 2022, roughly one quarter of the EU's total business-economy net turnover [19]. Structurally, the EU economy is overwhelmingly SME-based: in 2022, 99 % of all enterprises were micro and small firms (up to 49 employees), and in 2023 99.8 % of all EU enterprises were SMEs overall [20]. While in the EU manufacturing sector more than half of all employment is generated by SMEs [19]. Mechanical engineering in Central Europe is embedded in this SME fabric, with dense networks of small and medium-sized suppliers around large system producers.

Yet this success model is highly resource- and energy-intensive and relies on global supply chains for critical inputs. Eurostat shows that the EU is strongly dependent on imports for several critical raw materials used in mechanical engineering and related industries. For example, in 2022 around 97 % of EU magnesium imports came from China, while 84 % of ferro-niobium imports originated in Brazil, with the EU importing 11 tonnes of ferro-niobium for every tonne exported. For borates, about 90 % of imports came from Türkiye, and for gallium 96 % of imports were sourced from China [10].This high concentration of supply in a few third countries makes Central Europe's machinery clusters structurally vulnerable to trade disruptions and geopolitical tensions.

Energy costs have added a second layer of risk. During the 2022–2023 energy crisis, European gas and electricity prices reached unprecedented levels. Analysis of wholesale electricity markets shows that in August 2022, wholesale power prices in parts of Europe peaked at more than ten times their 2019 level [21]. For natural gas, historical analysis indicates that spot prices in 2022 rose to levels more than ten times higher than the average over the previous 15 years [22]. Despite a sharp reduction in gas demand, the EU's gas import bill in 2022 still approached €400 billion, more than three times the level of 2021[23].

In summary, Central Europe's mechanical companies are embedded in a powerful EU industrial system that:

- generates hundreds of billions of euros in machinery turnover and employs millions of workers
- depends heavily on imported critical raw materials from a small number of third countries,
- has recently experienced severe energy price volatility with gas and electricity prices reaching many times their pre-crisis levels.

This combination means that the region's traditional strengths—highly specialised SMEs and dense cross-border value chains—now face structural pressure. To remain competitive under EU climate and circularity policies, Central Europe's mechanical base must shift from a model built primarily on cost efficiency and reliable imports toward one based on resource intelligence, energy resilience and circular innovation.

3.2 Barries for mechanical companies

3.2.1 Technical and Financial Barriers

Across Central Europe, most mechanical SMEs run equipment that is technically modern but not yet future-proof for a circular economy. Survey data from Central, Eastern and South-Eastern Europe (CESEE) show that while 78% of firms invested in 2022, only a limited share of this spending was transformative: on average, 45% of investment went into replacing existing buildings, machinery and equipment, whereas just 17% was directed towards new products and processes (21% in manufacturing), with the rest focused on capacity expansion and other areas. This confirms that many production lines have been optimised for reliability and throughput rather than for modularity, remanufacturing or recycling. At the same time, around 65% of CESEE firms use at least one advanced digital technology—most commonly the Internet of Things (45%), robotics (45%) and digital platforms (37%)—indicating that digitalisation is progressing, but not yet systematically aligned with circular design, predictive maintenance or closed-loop material flows. When it comes to green and circular practices, 91% of firms in CESEE report taking at least one action to reduce greenhouse-gas emissions, with 74% engaged in waste minimisation and recycling and 60% investing in energy efficiency, yet only 35% set and monitor concrete climate targets [24]. At EU level, a dedicated Eurobarometer survey finds that 93% of SMEs have implemented at least one resource-efficiency measure, but only 25% have a formal strategy to cut their carbon footprint or reach climate neutrality, underscoring the gap between incremental efficiency measures and fully strategic circular transformation [25]. In this context, technologies such as additive manufacturing, sensor-based monitoring and closed-loop material handling are recognised by many entrepreneurs as economically attractive but remain out of reach for a large share of smaller firms that must prioritise short-term survival in highly competitive export markets.

Access to finance amplifies this gap between intention and implementation. In the CESEE region, 9.1% of firms are classified as finance-constrained, rising to 12.8% among SMEs, compared with an EU average of 6.1%, and dissatisfaction with the cost of external finance has more than doubled (from 7% to 15% of firms between 2022 and 2023) [24]. Across the EU, the European Investment Fund reports that around one in four SMEs continue to face severe access-to-finance challenges, despite some post-crisis improvements [26]. A Eurochambres survey shows that almost 60% of SMEs are already investing in their sustainable transition, yet only 35% of those investments are financed by external sources, leaving most green and circular projects reliant on internal cash flow [27]. At the same time, forthcoming European Commission research indicates that only 9–10% of SMEs have obtained a green or sustainability-linked loan from a bank in the last two years, highlighting how difficult it is to match circular projects with suitable financial products. This is particularly problematic given that SMEs account for over 50% of EU GDP and more than 63% of enterprise greenhouse-gas emissions, meaning their transformation is central to the EU's climate and circularity goals [28]. The outcome is a structural financial asymmetry: large manufacturers with stronger balance sheets can accelerate their circular transformation, while smaller mechanical suppliers, despite high technical competence and awareness of resource risks, struggle to secure patient capital for long-term circular investments.

3.2.2 Regulatory and Institutional Gaps

Even when motivation and technology exist, regulatory fragmentation across Central Europe creates friction for circular economy practices. EU-level evidence shows that cross-border flows of secondary materials are still the exception, not the norm: in 2018, only about 6% of total EU waste generated (excluding major mineral waste) was shipped across borders within the Union, while more than 90% was treated in the country where it was generated [29]. A recent example from Umicore, a major recycler of critical minerals, illustrates this: bringing electronic scrap from across the EU to its Belgian facility can require at least a month of navigating divergent national shipment rules along a single route [30]. Industry representatives explicitly warn that, with this “ununified waste market”, internal hurdles are so high that a very large share of waste still leaves the EU instead of being recycled within it.

Fragmentation is also evident in the way EU directives on waste, recycling and producer responsibility are transposed and enforced. An in-depth comparative study of extended producer responsibility (EPR) schemes in Europe concludes that differences in national legislation have produced an “extremely heterogeneous” EPR landscape, with large discrepancies in scope, definitions, data requirements and cost coverage across Member States. These discrepancies, the study warns, “can create inefficiencies and adversely affect the functioning of the EU single market.”[31]. Similar concerns are raised for specific waste streams: analyses of the WEEE and packaging directives show that national laws differ in product scope and even in the definition of “producer”, creating additional compliance and reporting burdens for companies operating in several countries [32]. Stakeholder position papers on the revision of the Waste Framework Directive call for a “real single market for waste, recycled and secondary raw materials” and highlight diverging national labelling, end-of-waste criteria and information requirements as barriers that contradict the free movement of goods [33]. For mechanical SMEs in Central Europe, this means that a remanufactured component or recycled material stream considered compliant in one country can still face additional documentation, permits or re-classification steps when crossing a nearby border, discouraging cross-border circular business models.

Institutional coordination also remains uneven. The OECD’s recent survey of 64 EU cities and regions shows that key governance dimensions for the circular economy—such as coordination, policy coherence, financing and data—are mostly rated as “not fully implemented” rather than fully in place, indicating gaps between environmental, economic and innovation policies at sub-national and national levels. In practice, ministries responsible for economy, environment and innovation often design strategies in parallel rather than through integrated circular economy roadmaps, and industrial policy instruments still rarely include binding circularity or resource-efficiency targets. Regional development agencies and innovation clusters in Central and Eastern Europe have begun to bridge these gaps through pilot projects and networks, but their mandate, staffing and funding differ widely between countries, leading to very uneven support for SMEs along the same cross-border value chains [34].

Taken together, these findings show that the absence of harmonised governance translates into real economic frictions: cross-border circular business models face additional administrative costs and risks; SMEs must navigate a patchwork of EPR rules, labelling obligations and shipment procedures; and public procurement still sends mixed signals about the value of circular innovation. For Central Europe’s integrated mechanical corridor, this regulatory uncertainty slows investment decisions, discourages cross-border cooperation in secondary material markets and limits the speed at which circular practices can scale from isolated pilots to mainstream industrial practice.

3.2.3 Knowledge and Skills Limitations

Human capital is another decisive constraint. Central Europe’s engineers and technicians are internationally recognised for mechanical precision and production efficiency, and science- and engineering-technician jobs are heavily concentrated in manufacturing: in 2021, 41% of all science and engineering technicians in the EU worked in manufacturing, with the highest employment shares in countries such as Austria, Czechia and Slovakia—core parts of Central Europe's mechanical corridor [35]. However, these professionals were trained primarily for linear production, not for circular design, life-cycle thinking or sustainability accounting. Studies on circular economy education in Europe conclude that circular economy is still an emerging academic discipline, with most initiatives limited to pilot courses, specialised master's programmes or project-based activities rather than systemic integration into engineering and VET curricula. Cedefop similarly emphasises that VET systems now need to "supply skills for core circular economy jobs in repair, redesign and reuse," but warns that this requires deliberate reorientation of programmes and closer collaboration with employers [36]. As a result, the pool of professionals who can connect mechanical design, process engineering and data analytics with circular performance indicators is still narrow compared with the scale of the manufacturing base.

Research on European SMEs also shows that lack of environmental expertise is explicitly perceived as an obstacle to implementing resource-efficiency and circular practices [37]. In a large Eurobarometer-based study, Bassi & Guidolin find that firms without workers dedicated to "green jobs" are significantly less likely to adopt resource-efficiency measures, while SMEs that recognise the need for additional environmental skills are more inclined to plan circular actions in the future [38]. qualitative work with SMEs across Europe and Switzerland confirms this pattern: interviews show that a "lack of knowledge" and "shortage of internal resources" are among the key internal barriers to circular economy implementation, alongside short-term economic thinking and risk aversion [39]. In practical terms, many SME managers see sustainability as desirable but peripheral—something aligned with corporate image—rather than as a core driver of product-strategy, cost structure or risk management.

This skills and knowledge gap also affects cooperation between universities, research institutes and industry. Reviews of circular-economy education stress that collaborations with companies are still too often organised as short-term projects or isolated pilots, rather than as long-term, institutionalised knowledge-exchange systems [40]. At the same time, an OECD analysis of "greening SMEs" finds that only about one-third of SMEs can be classified as environmentally engaged, even though most have heard of resource efficiency or circular concepts [41]. This suggests that technological potential—digitalisation, advanced manufacturing, data analytics—often runs ahead of organisational learning: companies may be aware of circular opportunities, but lack the internal expertise and stable partnerships needed to translate awareness into concrete redesign of products, processes and business models.

Taken together, the evidence indicates that Central Europe's mechanical sector is not primarily constrained by a lack of technology, but by a skills architecture that still reflects the linear industrial model. Engineers, technicians and managers are highly competent in precision manufacturing and productivity optimisation, yet too few are equipped—with education, tools and institutional support—to systematically link technical innovation to circular performance and long-term competitiveness.

3.2.4 Global Competition and Trade Pressures

A further structural barrier to circular transformation in Central Europe's mechanical sector is intensifying global competition, particularly from China and the United States. Over the past years, Germany's industrial base has come under significant pressure. Recent analyses show that German industry has lost around a quarter of a million jobs since 2019, with approximately 245,500 industrial jobs cut and employment in industry shrinking by more than 4% over six years [42]. The heaviest losses are concentrated in automotive and machinery-related activities, precisely the sectors that anchor mechanical value chains in Central Europe. These developments are not simply cyclical; they reflect a deeper shift in the global competitive landscape, where high energy costs, slower global demand, and mounting competition from Asia weigh on European manufacturers [43]. China plays a central role in this shift. Its state-supported industrial strategy, including programmes such as "Made in China

2025", has upgraded domestic capabilities in key technology and machinery sectors and fostered substantial overcapacity in areas like green technologies, electrical equipment, and transport [44]. European producers increasingly face price competition from Chinese firms that benefit from lower energy costs, large-scale domestic markets, and coordinated policy support. This exerts downward pressure on margins in mechanical supply chains, leaving SMEs with less financial space and risk appetite to invest in long-term circular upgrades such as remanufacturing lines, digital product passports, or material-tracking systems.

At the same time, access to the US market has become more complex due to evolving tariff regimes. In 2018, the Trump administration imposed 25% tariffs on steel and 10% on aluminium imports under Section 232, explicitly targeting EU exports among others [45]. Although some measures were later adjusted, recent decisions have reinstated and expanded protection: in 2025, the administration restored the full 25% tariff on steel and raised aluminium tariffs to 25%, while tightening "melted and poured" rules and extending coverage to key downstream products [46]. For mechanical and metalworking SMEs in Central Europe, these policies increase input and export costs along transatlantic value chains, and they contribute to a more fragmented and uncertain trade environment. The prospect of renewed or additional tariffs on European industrial goods forces companies to devote management attention and financial buffers to short-term risk management rather than to circular innovation.

For many mechanical SMEs, this results in a strategic dilemma: they recognise that circularity is essential for long-term resilience and alignment with EU policy, but they operate in global markets that reward short-term cost cutting and speed more than long-term resource intelligence. Without targeted support—such as de-risking instruments for circular investments, stronger trade-defence tools against unfair practices, and industrial policies that level the playing field on energy and capital costs—the risk is that only the strongest or largest firms can afford to pursue ambitious circular strategies. A coherent response to global competition is therefore not separate from the circular agenda; it is a precondition for enabling Central Europe's mechanical SMEs to invest in circularity at the necessary scale and speed.

3.3 Emerging Enablers and Opportunities

Despite these obstacles, the landscape across Central Europe is changing rapidly. The same forces that expose the limitations of the linear model are also creating unprecedented incentives for transformation – through funding, digitalisation and fast-evolving market expectations.

3.3.1 Funding and Incentives

At EU level, the Recovery and Resilience Facility (RRF) – the core of NextGenerationEU – mobilises about €648 billion in grants and loans, with Member States required to dedicate at least 37% of their plans to the green transition; by mid-2024 they actually reached an average of 42%, and around €184 billion was earmarked for energy-related measures alone [47]. In parallel, every national plan must allocate at least 20% of RRF resources to digital objectives, making the facility not only the largest green but also the largest digital funding instrument in EU history; the European Court of Auditors estimates that nearly €150 billion of RRF money is directed to digitalisation[48]. Horizon Europe adds a long-term innovation layer: with a total budget of €93.5 billion for 2021–2027, at least 35% (about €33.4 billion) is ring-fenced for climate-related objectives, including circular industry, low-carbon materials and eco-innovation [49]. In Central Europe specifically, the Interreg CENTRAL EUROPE programme manages a total budget of about €280.8 million, of which €224.6 million comes from ERDF funds, and explicitly dedicates an entire priority – "Cooperating for a greener Central Europe" – to energy transition, climate resilience and "taking circular economy forward in central Europe" [50]. Across all Interreg strands, nearly €10 billion of ERDF co-funding is available in 2021–2027 for cross-border and transnational cooperation, much of it aligned with the European Green Deal and circular economy objectives.

On the finance side, sustainable and "sustainability-linked" lending is becoming more mainstream. The European Banking Authority has documented the rapid growth of green loans, while the OECD and Eurochambres highlight that many SME-oriented credit lines now link interest rates to environmental performance indicators such as energy efficiency, waste reduction or CO_2 cuts [51]. New EU initiatives – such as a proposed SME Sustainable Finance Standard – aim to give smaller firms a simplified framework for demonstrating their environmental performance and accessing dedicated capital, directly addressing one of the main barriers for circular investments in mechanical SMEs [52]. These instruments do not remove all financing constraints, but they noticeably narrow the historic investment gap that kept many smaller suppliers from adopting circular technologies.

3.3.2 Digital and Innovative Tools

The digital revolution is lowering the threshold for entry into data-driven circular management. At EU level, 59% of enterprises – and 58% of SMEs – had reached at least a basic level of digital intensity by 2023 (using at least four digital tools such as cloud, CRM, e-commerce or AI), although this is still far from the EU's 2030 target of 90% of SMEs [53]. Cloud services, once a privilege of multinationals, are now widely used: in 2023, 45.2% of EU enterprises purchased cloud computing services, up 4.2 percentage points compared with 2021; among large enterprises, cloud use is almost universal (77.6%), but even 41.7% of small firms already rely on cloud-based tools [54]. Advanced analytics and automation are also spreading. In 2024, 13.5% of EU enterprises used at least one AI technology, with adoption reaching 11.2% of small, 21.0% of medium and 41.2% of large firms [55]. Robotics penetration continues to rise, with Europe installing over 84,000 industrial robots in 2022 and maintaining a strong global position in robot density in manufacturing [56]. These trends mean that affordable sensors, cloud platforms and analytics are no longer experimental: they are becoming standard ingredients of European factory modernisation.

In this context, sector-tailored tools such as the Digital Circular Inventory (DCI) and Zero Carbon Tool (ZCT), developed within the REUSE2030 framework, fit into a broader ecosystem: they build on the availability of cloud infrastructure to translate abstract sustainability goals into operational dashboards. While Eurobarometer data show that 93% of EU SMEs have already implemented at least one resource-efficiency measure (e.g. saving energy, minimising waste, recycling), most still lack robust measurement tools [57]. DCI ,ZCT and other tools directly respond to this gap by turning waste streams, material composition and product life-cycle emissions into quantified indicators, helping mechanical SMEs visualise hotspots, compare scenarios and document improvements in ways that bankers, regulators and large customers increasingly expect.

3.3.3 Market Demand and Sustainability Standards

Market dynamics may be the most decisive driver of circular transformation. EU firm-level surveys by the European Investment Bank show that 45% of EU companies are already investing to address climate change, with Western, Northern and parts of Central Europe among the most active regions [58]. Consumer data point in the same direction: a European Commission-linked study reports that about 67% of European consumers prefer to buy more environmentally friendly products even if they cost more, signalling a durable shift in demand [59].

On the corporate side, supply-chain pressure is intensifying. Through CDP's Supply Chain initiative, more than 340 large purchasing companies – representing around $6.4 trillion in procurement spend – now ask their suppliers to disclose environmental and climate data, including Scope 3 emissions [60]. A UK Net Zero Business Census illustrates how this translates at firm level: 46% of organisations, including 37% of SMEs, have already received customer requests for carbon data, which is consistent with the growing number of EU firms requiring footprint information and reduction plans from their suppliers [61].

Regulation reinforces these market signals. The Corporate Sustainability Reporting Directive (CSRD) expands mandatory sustainability reporting from about 11,700 companies under the old NFRD to roughly 50,000 companies worldwide, including around 10,000 non-EU firms with substantial EU operations [62]. Even if many mechanical SMEs are not directly in scope, they are embedded in the value chains of CSRD-reporting customers and will increasingly be asked to provide reliable carbon, material and circularity data. At the same time, the Digital Product Passport (DPP), introduced under the Ecodesign for Sustainable Products Regulation, will start with batteries and textiles and gradually extend between 2025 and 2030 to other high-impact products such as electronics, steel, aluminium, chemicals and potentially machinery [63]. This will make detailed product-level environmental information – durability, reparability, recycled content, carbon footprint – a default requirement for accessing EU markets.

Business attitudes are adapting quickly. Recent European surveys show that almost six in ten (59%) business leaders support sustainability reporting for their company if it is proportionate and meaningful; among mid- to large-size companies this rises to 70% [64]. Another survey in 2025 found that about 61% of European firms are satisfied with CSRD in its current form, despite lobbying to weaken sustainability rules [65]. At the same time, an Influence Map analysis of 200 major European companies shows that the share whose lobbying is aligned with Paris-compatible climate goals has risen from 3% in 2019 to 23% in 2025, while the share actively misaligned fell from 34% to 14%, indicating that more firms now see ambitious climate and circular policies as compatible with competitiveness [66].

Taken together, these trends signal a clear transition. Central Europe's mechanical industry, though still constrained by fragmented regulation, limited SME finance and skills gaps, now operates in a funding landscape where tens of billions of euros are earmarked for green and digital projects; in a technological context where more than half of SMEs already have at least a basic level of digitalisation and nearly half of all enterprises use cloud computing; and in markets where both regulators and large buyers treat circularity and transparency as preconditions for doing business rather than optional extras.

Under these conditions, Central Europe is well-positioned to move from being primarily an efficient production base to becoming a model region for circular manufacturing. If mechanical SMEs can leverage targeted funding, adopt digital tools such as DCI and ZCT, and respond proactively to CSRD, DPP and buyer requirements, sustainability and competitiveness increasingly reinforce each other instead of competing, turning circularity into a core element of industrial advantage, not a compliance burden.

4. Circular Economy Roadmap for Mechanical Companies

For decades, Central Europe's mechanical companies have served as engines of precision, innovation, and industrial strength. They form a critical pillar of Europe's manufacturing landscape, powering exports, supplying global value chains, and shaping engineering excellence worldwide. Yet the very model that once guaranteed their competitiveness is now under mounting pressure. Intensifying global competition, volatile raw-material markets, and increasingly ambitious environmental regulations are fundamentally reshaping the conditions under which manufacturers operate.

In this context, the strategic question for mechanical companies is no longer simply how to produce faster or cheaper, but how to produce smarter and longer with fewer critical inputs, lower emissions, and more value retained over time. Circularity provides a practical answer. It is not an ideology, but a business strategy: a way to reduce exposure to volatile raw-material markets, comply with tightening EU regulations, differentiate on quality and reliability, and unlock new revenue streams from services, remanufacturing, and secondary materials.

Becoming a circular company is not a single leap, but a managed transformation that unfolds in five connected stages. Each stage builds new capabilities, reinforces the next, and creates a self-reinforcing cycle of learning, redesign, and renewal, enabling Central Europe's mechanical firms to stay competitive in an industrial landscape where sustainability and profitability are increasingly two sides of the same coin.

4.1. Awareness and Assessment: Seeing the Invisible

Every transformation begins when a company learns to observe itself differently. For mechanical SMEs, the first material-flow mapping or resource audit acts like an X-ray of the factory's "industrial metabolism." Instead of seeing only output and turnover, managers begin to see where materials enter, where they accumulate in stocks, where they leak as scrap, and where waste quietly drains profit.

This is not just a theoretical point. Across European manufacturing, material costs are usually the single largest cost block: studies for the European Commission show that raw materials account for around 40% of total manufacturing costs, and when energy and water are added, resource costs can reach about 50%, while labour often represents only around 20% [67].That means that even small percentage improvements in material use can translate into significant financial gains.

Detailed audits confirm that a surprising share of these expensive inputs never become final products. An Austrian "Material Efficiency Laboratory" working with 10 manufacturing SMEs found that the share of wasted materials ranged from 5% to 70% of total material input, and estimated that 10–15% of this waste could be avoided or recycled simply through better process control, equipment use, and awareness [68]. Similarly, a meta-analysis of 100 projects under the German Materials Efficiency Programme showed an average annual raw-material saving potential of about 7% per company, achieved mainly through low- and medium-cost measures such as optimised cutting patterns, process adjustments, and improved recycling of offcuts [69].

Material Flow Cost Accounting (MFCA) studies add another layer of evidence. In a set of 15 manufacturing case studies, researchers found that 20–30% of total production costs were tied up in "negative products"—material losses, scrap, emissions, and waste streams—that generate no value for the customer [70]. When these flows are quantified in physical and monetary terms, companies often realise that what they previously saw as "normal" scrap represents tens or hundreds of thousands of euros per year.

The "hidden cost multiplier" behind waste is also well documented. A European guide on resource-efficient manufacturing notes that saving €1 in disposal cost often reveals €7–12 of additional upstream costs (for buying, transporting, storing and processing the wasted material) [67]. The German Environment Agency similarly estimates that manufacturers can cut up to 20% of their material costs through resource-efficiency measures, many of which require modest investment but significant process insight [71].

Taken together, these findings validate the core idea:

- Inefficiencies that feel "normal" often hide large value losses - with 40–50% of manufacturing costs tied to materials and energy, even single-digit percentage improvements can be financially significant.

- Resource and material-flow audits routinely reveal double-digit saving potentials, whether through reduced scrap, better use of offcuts, improved maintenance, or more efficient energy use.

So the narrative you propose is fully consistent with the evidence: circularity in SMEs rarely starts with ideology. It starts with curiosity and with a first diagnostic step that makes the invisible visible. Once companies see how much money is literally being thrown away as scrap, excess energy use, or unnecessary process steps, redesign and collaboration follow much more naturally.

4.2. Vision and Strategic Design: Turning Insight into Direction

Once a company understands itself, it must decide where it wants to go. Circularity requires intention, and intention requires design. Across the EU, most SMEs are already doing “something green”: a 2024 Eurobarometer shows that 93% of SMEs have implemented at least one resource-efficiency measure such as saving energy or minimising waste. Yet only 25% have developed a formal strategy to reduce their carbon footprint or achieve climate neutrality [72]. In other words, action is widespread, but strategic direction is still the exception rather than the rule.

The gap is similar in Central and Eastern Europe. The EIB Investment Survey for the CESEE region finds that 74% of firms engage in waste minimisation and recycling and 60% invest in energy efficiency, but only 35% set and monitor climate-related targets—a share below the EU average [24]. National data from Central European countries confirm this pattern: for example, in Slovakia around 55% of manufacturing companies have established GHG reduction targets, while other sectors lag behind [73]. This shows why “Vision and Strategic Design” is a distinct stage: most firms are doing isolated measures, but relatively few have turned circularity into a coherent set of goals.

Where companies do define clear, measurable targets, their behaviour changes measurably. The European Investment Bank reports that firms with better “green management practices”—including setting and monitoring climate targets or appointing dedicated climate staff—invest in energy efficiency almost twice as much as firms without such practices[74]. Another EIB analysis shows that firms with established climate targets are around 60% more likely to invest in climate projects than comparable firms without targets [75]. In short, targets act as a trigger: once goals are formalised, investment follows.

For mechanical SMEs in Central Europe, the lesson is clear. When circular ambitions are turned into explicit targets—such as increasing the share of recycled inputs, reducing waste per unit, extending machine lifetimes, or lowering carbon intensity—those targets become internal compasses. They align engineers, procurement teams, production managers, and financial officers around a shared direction. Evidence from Eurobarometer-based studies on European SMEs shows that firms with a clear commitment to resource-efficiency actions are significantly more likely to adopt additional green measures and to plan further improvements, confirming that commitment and strategic intent foster deeper sustainability transitions [76].

Targets also function as external signals. Banks, investors, and public programmes increasingly rely on climate and resource-efficiency targets when assessing projects against frameworks like the EU Taxonomy or new SME sustainable-finance standards. A recent analysis for Eurochambres finds that nearly 60% of SMEs are already investing in their sustainable transition, but only 35% of those investments are financed from external sources, and that clearer, demonstrable environmental strategies are crucial to unlock green finance [27]. Large buyers subject to CSRD and other regulations likewise favour suppliers who can show progress against quantified goals, not only ad hoc measures.

In practice, the companies that progress fastest are those that treat circularity as a design challenge and a strategic narrative, not a compliance burden. They articulate what their factory should look like in five or ten years—machines designed for upgrades rather than obsolescence, waste streams feeding new production lines, suppliers sharing responsibility for sustainability—and then translate that vision into a small set of measurable targets. Once those goals exist, engineers start experimenting with alternative materials, accountants track life-cycle costs rather than just purchase prices, and procurement gradually shifts from “cheapest today” to “most resilient and efficient over time”.

In short, this second stage provides direction—and direction provides agency. The statistics are clear: firms that set and monitor climate and resource-efficiency targets invest more, innovate faster, and are better positioned to access finance and markets in a Europe where circular performance is quickly becoming a condition for staying in business.

4.3. Transformation in Practice: Redesigning Products and Processes

Every mechanical engineer knows that design determines destiny. European and international studies repeatedly show that around 80% of a product’s environmental impact is decided at the design stage - long before the first screw is turned or the first chip is cut [77]. For complex equipment such as machine tools, researchers estimate that up to 80% of life-cycle costs (materials, energy, maintenance, and disposal) are effectively locked in by early design decisions [78]. In this context, circular transformation becomes truly real when companies redesign the logic of their products and processes, not just their end-of-pipe treatment.

- Circular design demands that every component be examined through new questions:
- Can it last longer?
- Can it be repaired without destroying surrounding parts?
- Can it be disassembled quickly?
- Can it be upgraded instead of replaced?
- Can it use fewer materials, or recyclable and secondary ones?

When companies answer these questions boldly, machines stop being disposable objects and become long-term value assets. Evidence from remanufacturing and “value-retention processes” is clear: studies across multiple sectors find that remanufactured products can deliver 50-80% lower energy use and 20-80% lower production costs compared with manufacturing a new product, while keeping performance comparable [79]. In automotive components, for example, remanufacturing has been shown to achieve about 88% material savings, 56% lower energy requirements, and around 53% reductions in CO_2 emissions relative to new production. A broader review of remanufactured products reports 26–90% reductions in raw-material consumption and 79–99% lower greenhouse-gas emissions in many cases, underlining how powerful design for reuse, repair, and remanufacture can be when applied systematically [80]. Vision becomes reality only when translated into design and engineering. At this stage, circularity moves from conference slides to factory floors. The goal is no longer just to “reduce harm” but to rebuild value loops within the company. European resource-efficiency studies at factory level show that typical manufacturing firms can realise 7–10% material savings on average through better design of products and processes, with additional savings in energy and labour [81].

Across Central Europe, this shift is already visible in practice. In metalworking and machinery case studies, workshops that once scrapped worn-out gear parts now remanufacture and reintegrate them, extending component life over several production cycles and capturing both material and energy savings. Austrian and German briefs on remanufacturing emphasise that such approaches lower material and energy expenditure while retaining the original high value added and reducing dependence on imported critical raw materials [82]. In parallel, modular design is gaining traction: systematic reviews show that modular architectures improve maintainability and upgradability, prolong service life, and significantly reduce waste and emissions over the product life cycle [83]. Instead of replacing entire machines, customers can upgrade or swap modules—cutting lifecycle costs and carbon footprints simultaneously.

Digital tools reinforce this design shift. When Central Europe SMEs introduce sensor-based monitoring and data analytics, they plug directly into a wider trend: predictive-maintenance studies indicate that data-driven monitoring can cut unplanned downtime by up to 50% and reduce maintenance costs by 10–40%, while specialised case studies show cost reductions of around 35% in some industrial applications [84]. Energy-audit programmes across Europe find that SMEs typically identify around 5% energy-consumption reductions on average – often more – once they start measuring loads, peaks, and idle times properly [85]. These same insights frequently uncover redesign opportunities: resizing drives, optimising process sequences, or changing control strategies so that machines consume less energy and experience less wear.

What unites these examples is not technology alone, but mindset. They reflect a design philosophy in which products are intended to last and to come back; processes are designed to learn from data; and engineering craftsmanship is rediscovered as a modern form of innovation. The statistics confirm the intuition: when design is reoriented toward durability, repairability, modularity, and remanufacture, most of the environmental and cost savings follow.

4.4. Business Model Reinvention and Collaboration: From Selling to Sustaining

A company that redesigns its products eventually realises that value no longer lies in the one-time sale, but in the long-term relationship. Across Europe, manufacturing is already moving in this direction: studies show that the vast majority of European manufacturing firms now offer services alongside products, even though services still account for a smaller share of total turnover [86]. This shift reflects a deeper recognition that selling a machine once is often less advantageous than supporting its performance, upgrades, and renewal over decades.

This realisation sparks new business models: leasing machines instead of selling them outright; offering maintenance-as-a-service or “uptime guarantees”; selling refurbished components at attractive margins; and designing equipment so that it can return “home” for remanufacture. Globally, the remanufactured-equipment market alone is projected to reach around USD 500 billion by 2034 [87], while specific estimates for industrial machinery remanufacturing indicate extremely rapid growth, with forecasts of several hundred billion dollars in additional market value over the coming years [88]. A European Commission study on remanufacturing calculates that existing remanufacturing activities in Europe already avoid about 2.3 million tonnes of landfill waste and 8.3 million tonnes of CO_2-equivalent emissions annually, underlining that “designing for return” is not just a niche idea but an established source of environmental and economic value. Additional analysis from VDI ZRE shows that remanufactured products can be sold at 20–80 % of the price of a new product while requiring far less material and energy, helping both customers and manufacturers reduce costs [82].

Collaboration becomes the catalyst that brings these models to life. No company can become fully circular alone. Industrial symbiosis—where one firm’s by-product becomes another’s feedstock—has been identified as a practical way to “close the loop” of manufacturing processes. Mapping studies find dozens of active industrial-symbiosis networks across Europe, linking hundreds of companies in shared material, water, and energy flows [89]. Recent life-cycle and policy analyses highlight that such networks can significantly reduce waste generation and resource consumption, cut operating costs, and create new revenue streams from previously discarded materials [90]. In practice, that may mean a coolant waste from one machining facility becomes an input for a chemical recycler, waste heat is captured and fed into local district-heating systems, or discarded metal scrap is sorted and re-melted within the same industrial park rather than exported as low-value waste.

In this phase, the company stops operating as a silo and starts behaving like part of a regional circular ecosystem, where cooperation on materials, energy and data often outperforms pure price competition. As internal transformation matures, firms realise that the greatest value lies not in what they produce once, but in what they can keep in motion—machines that are upgraded instead of discarded, components that come back for remanufacture, materials that circulate in local loops.

The concrete forms of this shift vary, but the pattern is consistent. In many European regions—including Central Europe—manufacturers are experimenting with shared equipment platforms, service-based contracts and collaborative maintenance networks to raise utilisation of high-cost assets and reduce idle capacity. Studies on product-service systems and servitisation describe exactly these models—leasing, pay-per-use, guaranteed availability, and maintenance-as-a-service—as some of the most promising levers for sustainable competitiveness in machinery and industrial equipment[91].

Partnerships also extend horizontally. When suppliers, recyclers, technology providers and universities work together, they form regional ecosystems of exchange that no single company could build alone. Evidence from European industrial-symbiosis and eco-industrial-park initiatives shows that joint remanufacturing lines, shared recycling infrastructure and co-developed innovation projects can simultaneously lower costs, reduce emissions and improve resource security [90]. A single SME can rarely close its loops by itself—but a cluster can. In this sense, Central Europe's dense network of mechanical SMEs, suppliers, and research institutions is not just an industrial legacy; it is a structural advantage for building circular, service-oriented business models where recurring income, customer loyalty and reputational strength grow out of long-term stewardship rather than one-off transactions.

4.5. Measurement, Transparency, and Continuous Learning

A company becomes circular the moment it learns to measure what matters. Without measurement, circularity is a story; with measurement, it becomes a strategy. Across the EU, this shift has already begun: 47% of firms now set and monitor targets for their own greenhouse-gas emissions, turning environmental performance into a managed indicator rather than a vague aspiration. Among SMEs, 93% have implemented at least one resource-efficiency measure such as saving energy, reducing waste or recycling, and 41% of those that act on resource efficiency report lower production costs—clear proof that what is measured can be improved and pays off [8].

Tracking material efficiency, machine lifetime, component return rates, recycled content and carbon intensity creates a feedback loop that guides continuous improvement. Once these metrics are captured, patterns emerge: which machines draw disproportionate power at certain hours, which components fail most often, where scrap peaks occur in a shift, or where remanufactured parts perform as well as—or better than—new ones. Studies on energy and resource audits show that firms that monitor their flows and costs are significantly more likely to adopt efficiency measures and unlock savings than those that do not [92].

Measurement creates discipline. Transparency creates trust. Large buyers are systematising this: through CDP's Supply Chain programme, more than 250 major purchasing organisations now request environmental data from over 47,000 suppliers worldwide, pushing standardised reporting deep into value chains [93]. These data are not collected for show. CDP finds that companies disclosing after an investor or buyer request reduce their direct emissions by 7-10% on average within two years, demonstrating how measurement plus accountability drives real change [94].

Investors increasingly expect this level of clarity. Recent global surveys indicate that around 80–89% of institutional investors now use ESG or sustainability information in their decisions, and a large majority want detailed, comparable data rather than high-level narratives [95]. At the same time, talent markets are shifting: 62% of Europeans say it is important that prospective employers prioritise sustainability, and among young people aged 20–29 this rises to 76% [96]. In other words, verified sustainability metrics help attract capital, customers and employees at the same time. Every data point becomes a building block of credibility—and credibility becomes a competitive advantage.

Continuous learning then emerges as the cultural anchor of this stage. The company reviews its indicators, compares performance over time, and adjusts its processes accordingly. Lessons from audits and KPIs flow back into product development and process design. Over time, circularity stops being a static label and becomes something dynamic, iterative and alive: a managed cycle of measuring, learning and redesigning that keeps the business aligned with tightening regulations, shifting markets and rising stakeholder expectations.

4.6. The Regenerative Enterprise: Leadership through Example

A regenerative company is not defined by where it ends up, but by who it chooses to be. It no longer aims merely to reduce harm; it uses its capabilities to create net-positive impact. Its machines last longer, its relationships deepen, its waste becomes input, its employees innovate, and its region is tangibly better off because it is there. European case studies in remanufacturing show what this looks like in practice: remanufactured components can cut carbon emissions by 70–80% and save up to 80% of energy and 85% of materials compared with producing new parts, while keeping performance at "as-new" level[97]. Companies that design equipment for multi-decade lifetimes and plan for multiple remanufacturing cycles are, in effect, engineering long-term environmental and economic value into every product they ship.

These firms increasingly become magnets. On the talent side, nearly two-thirds of Europeans (62%) say it is important that prospective employers prioritise sustainability, and among young people aged 20-29, that share rises to 76%, with 22% calling it a top priority [79]. Globally, 70% of Gen Z and Millennials consider environmental sustainability an important factor in choosing an employer, and these generations are expected to make up around 74% of the global workforce by 2030 [98]. Regenerative enterprises therefore enjoy a structural advantage in attracting and retaining skilled people. On the finance side, meta-analyses of hundreds of studies find that strong environmental and sustainability performance is most often associated with neutral-to-positive financial performance, with many reviews reporting a predominantly positive relationship between corporate environmental performance and profitability or market valuation. Capital markets are reinforcing this trend: the outstanding volume of sustainable debt securities in the euro area has more than doubled in three years [99], and the global sustainable-loan market reached about €907 billion in 2024, up 17% on the previous year, with green and sustainability-linked loans among the fastest-growing segments [100]. In other words, companies that combine credible climate and circular strategies with solid financials are first in line for the cheapest capital.

In Central Europe, such leaders are already emerging—machinery producers that design for lifetimes of several decades, remanufacturers that achieve emission cuts of 70–80% compared to new production [101], and regional clusters that keep significant shares of their material loops within short distances through local recycling and reuse partnerships. Their example shows that circularity is no longer an experimental add-on; it is increasingly the benchmark for industrial excellence.

A regenerative enterprise does not merely adapt to change; it helps create the conditions for a different kind of economy. By proving that long-lived products, closed loops, motivated people and strong financial performance can reinforce one another, these companies turn circularity from a compliance obligation into a source of strategic advantage—and from a future vision into a present identity.

A company that completes this cycle discovers that circularity is not an endpoint but a competitive identity. Its value no longer comes only from efficient production, but from its ability to regenerate resources, strengthen relationships, and continually renew ideas. Such companies become magnets for skilled workers, trusted partners for loyal clients, and preferred candidates for long-term investment. They embody the future of European industry — adaptive in uncertainty, responsible in resource use, and collaborative in shaping shared prosperity.

Across Central Europe, this future is already emerging. A Polish manufacturer transforming machining waste into certified secondary raw material; an Austrian equipment producer designing machines for perpetual repair and modular upgrades; a Hungarian SME cluster offering shared maintenance and service platforms — each example shows that circularity is not an abstract ambition but a practical discipline embedded in daily operations. These companies are demonstrating that regeneration can be engineered, managed, and scaled.

For mechanical SMEs, the roadmap forward is clear: begin with curiosity, build a coherent vision, redesign production, reinvent the business model, and measure relentlessly to learn. Each stage reinforces the next, forming a continuous spiral of improvement and renewal. When thousands of companies move through this journey, Central Europe will not only preserve its industrial heritage — it will redefine it. The region can become Europe's most dynamic hub of regenerative manufacturing, where precision engineering meets long-term purpose, and where innovation restores rather than consumes.

5. Synergies and Policy Alignment

The strategy presented in this report is not an isolated regional initiative, but part of the European Union's broader transition towards a climate-neutral, resource-efficient and circular economy. At EU level, circularity has shifted from a niche sustainability topic to a core pillar of industrial and climate policy. The roadmap developed for Central Europe's mechanical companies mirrors this evolution: it translates high-level EU objectives into concrete steps that SMEs can apply in their factories, supply chains and business models.

At the highest level, the European Green Deal sets the overarching vision: a climate-neutral EU by 2050, with economic growth increasingly decoupled from resource use and environmental degradation. The Green Deal explicitly calls for a "clean and circular economy" and mobilises all policy levers—regulation, investment, innovation and industrial strategy—to achieve it [102].For mechanical SMEs in Central Europe, this is not an abstract backdrop; it defines the structural conditions under which they must now remain competitive. The steps outlined in this strategy—from material-flow awareness and eco-design to remanufacturing, service-based models and regenerative practices—are precisely the mechanisms through which companies internalise Green Deal principles: reducing waste intensity, extending product lifetimes and strengthening resilience against raw-material and energy shocks.

The Circular Economy Action Plan (CEAP) 2020 deepens this alignment by providing a dedicated policy framework for circularity. CEAP is described by the Commission as a "cornerstone" of the Green Deal and aims to make sustainable products the norm in the EU, focus on sectors that use the most resources with high potential for circularity, empower consumers and ensure less waste [103]. It pays particular attention to high-impact value chains such as electronics, ICT, batteries, vehicles, plastics, textiles, construction and food, all of which rely heavily on machinery and equipment. The company roadmap in this report—redesigning components, enabling modular upgrades, improving disassembly, integrating remanufacturing, and monitoring circular key performance indicators (KPIs)—operationalises exactly the CEAP agenda of durable, repairable, recyclable and resource-efficient products throughout their life cycle. In that sense, the transformation steps proposed for mechanical SMEs are not parallel to CEAP; they are a practical implementation layer.

This alignment becomes even more explicit with the Ecodesign for Sustainable Products Regulation (ESPR), adopted in 2024. ESPR significantly broadens the EU product framework: it allows the Commission to set binding performance and information requirements for almost all physical goods on the EU market, with a focus on durability, repairability, recyclability, resource efficiency and the presence of hazardous substances [104]. It also introduces the Digital Product Passport, which will provide product-level environmental information (e.g. composition, repair options, recycled content, carbon footprint) across multiple value chains [104]. For mechanical companies, this means that design choices, modularity strategies, documentation practices and life-cycle data systems are no longer optional—they are becoming preconditions for market access. Companies following the redesign and data-oriented steps in this strategy are therefore not merely “early movers”; they are aligning with the regulatory baseline of the coming decade.

The strategy is also consistent with the updated European Industrial Strategy and the SME Strategy for a Sustainable and Digital Europe. The industrial strategy emphasises strengthening the resilience of strategic value chains, supporting Europe’s “open strategic autonomy”, and accelerating the twin green and digital transitions, including through the concept of industrial ecosystems [106]. The SME Strategy recognises SMEs as central to this transition and calls for measures that help them become more competitive, resilient and sustainable, including better access to finance, reduced regulatory burden, and support for green and digital innovation. Central Europe’s mechanical SMEs—highly export-oriented, strongly interconnected across borders and vulnerable to critical-raw-material and energy shocks—sit at the heart of these policy priorities. The emphasis in this report on cross-border collaboration, industrial symbiosis, regional clusters and shared innovation platforms directly reinforces the ecosystem approach promoted by these EU frameworks.

National strategies across Central Europe further validate this trajectory.

- Germany’s National Circular Economy Strategy (Nationale Kreislaufwirtschaftsstrategie) aims to bundle circular-economy and resource-efficiency goals from all relevant strategies, explicitly linking circularity to raw-material security, resilience of supply chains and competitiveness [107].
- Austria’s Circular Economy Strategy, adopted by the federal government in December 2022, defines a national framework for transforming the economy into a circular one, with cross-sector intervention areas including product design, circular business models and industrial cooperation [108].
- Slovenia’s “Roadmap towards the Circular Economy” (2018) positions circular economy as a strategic development priority and identifies priority sectors including the manufacturing industry, industrial symbiosis and secondary raw materials [109].
- Czechia is developing “Circular Czechia 2040”, a national strategic framework designed to accelerate the circular transition, strengthen competitiveness and reduce environmental pressure, building on existing circular-economy actions and profiles [110].
- Hungary is finalising a National Circular Economy Strategy, prepared by the Ministry of Energy and informed by an OECD review that identifies priority areas such as better management of biomass, food, plastics and the material-intensive construction sector [111].

Despite differences in timing and scope, these national frameworks converge on key priorities: improving product design and durability, mobilising SMEs, modernising industrial processes, professionalising waste and material management, and strengthening regional and cross-border cooperation. What they often lack, however, is a detailed, company-level implementation pathway. The transformation sequence proposed in this report—from awareness, vision and technological change to business-model innovation, measurement and regenerative leadership—fills exactly this operational gap.

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