Interreg
Danube Region

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Plan-C

# Development of a joint plan to boost circularity in the Machine industry

Deliverable D.2.3.4

Responsible Partner: CLUSTERO, ICMPP and SORINTEX

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# 1. Introduction to the project Plan-C

**Moving PLastics and mAchine iNdustry towards Circularity (Plan-C) project** is a pioneer initiative in the field of circular economy under the EU Strategy for the Danube Region - Priority Area 8: Competitiveness of enterprises and cluster development - Working Group Circular Economy and Circular Bioeconomy.

The project brings together 14 partners from 9 countries from the Danube Region (Germany, Austria, Czech Republic, Slovakia, Hungary, Serbia, Bosnia and Herzegovina, Romania and Republic of Moldova) to **transform the plastics and machine industry towards a circular economy**.

The project aims to foster transnational cooperation and support SMEs and enterprises in adopting circular principles for plastics and machine industry. Through cooperation among plastics processors, producers and the machine industry, Plan-C seeks to develop innovative solutions that emphasize reuse, recycling, and long-term value retention.

The core objectives of Plan- C include:

- **Co-creating circular plastic solutions through collaboration and design thinking,** resulting in practical prototypes and guidelines for SMEs.
- **Redesigning machinery** for reuse and recycling, covering the entire lifecycle and exploring digital opportunities.
- **Developing a transnational joint strategy and action plan for enhancing circularity in plastics and machine industry** that aligns with EU regulations and national strategies, ensuring long-term impact through policy integration and SME support.

Plan-C aims to address significant barriers such as weak recycling infrastructure, outdated waste systems, and gaps in expertise. By promoting reuse, repair, remanufacturing, and smart recycling, the project aspires to accelerate clean growth in manufacturing sectors and strengthen business competitiveness across the region.

This document serves to analyze the results of the Plan-C project in the field of the machine industry with regard to a transnational strategy. For this purpose, the most important results for a joint plan are briefly presented; for a detailed overview, the comprehensive results are available on the project website (https://interreg-danube.eu/projects/Plan-C).

# 2. Importance of circularity in the Machine Industry

**Key principles of circularity in the machine industry** include eco-design and durability, remanufacturing and refurbishment to extend product lifecycles, and product-as-a-service business models that foster long-term customer relationships and greater resource efficiency.

Adopting these strategies also boosts brand reputation, drives innovation, and helps companies comply with growing Environmental, Social, and Governance (ESG) regulations. Circularity offers economic, sustainability and environmental benefits, as well as operational and strategic advantages.

## 2.1. Economic Benefits

- **Cost Savings:** Circularity can lower operational costs by reducing raw material expenses through recycling, minimizing waste and disposal costs, and extending the productive lifespan of machines.
- **New Revenue Streams:** Manufacturers can generate additional income by selling remanufactured products or offering service-based models, such as leasing or pay-per-use, where the machine's performance is directly linked to the company revenue.
- **Enhanced Resilience:** Utilizing recycled and repurposed materials and extending product lifecycles makes companies less vulnerable to volatile global supply chains, material shortages, and price fluctuations.
- **Competitive Advantage:** Companies embracing circularity can differentiate themselves in the market, gain a competitive edge, and foster innovation in materials, processes, and business models.

## 2.2. Sustainability and Environmental Benefits

- **Reduced Waste and Pollution:** The core aim of circular strategies is to eliminate waste and pollution by keeping products and materials in use for longer, thereby reducing the need for new raw materials.
- **Lower Emissions:** By using more recycled content and designing for durability, circular supply chains significantly reduce carbon emissions and the environmental footprint of machinery.

- **Resource Efficiency**: Circularity promotes resource efficiency by maximizing the value of materials and components through design, reuse, repair, and remanufacturing, creating a closed-loop system.

## 2.3. Operational and Strategic Advantages

- **Innovation:** The shift to circular business models necessitates innovation in product design, manufacturing processes, and material sourcing, leading to higher rates of technological development and improved efficiency.
- **Improved Brand Reputation:** Demonstrating a commitment to sustainability through circular practices enhances a company's brand image and resonates positively with environmentally conscious consumers and stakeholders.
- **Stronger Customer Relationships:** Service-based circular models, which focus on machine performance and longevity, can build closer, long-term relationships with customers.
- **Regulatory Compliance:** Companies are better positioned to meet increasingly stringent environmental regulations and reporting requirements by building greater transparency and traceability into their value chains.

# 3. Identified challenges & needs in the machine industry in the Danube Region

The primary challenges and needs for the plastics machinery sector in the Danube Region include the lack of robust waste management and recycling infrastructure, insufficient integration between industry players, and the need for significant investment in circular economy technologies.

Key needs focus on developing robust circular economy models, enhancing technological capacity for recycling secondary materials, fostering transnational collaboration, implementing eco-design principles for machinery, and leveraging digital tools like AI to improve efficiency and reduce costs.

## 3.1. Key Challenges

- **Inadequate Circular Infrastructure:** Many countries, particularly in the southern and eastern areas of Danube Region, lack the necessary infrastructure for waste management and the efficient processing of secondary plastic materials.
- **Environmental Concerns and Regulations:** The industry faces increasing pressure from environmental issues like plastic pollution and evolving EU Green Deal regulations, which require a transition from a linear to a circular economy model.
- **Technological & Efficiency Gaps:** Existing recycling technologies are often inefficient, prone to contamination, and energy-intensive, making large-scale implementation challenging.
- **Economic and Political Constraints**: Challenges include the high cost of bio-based raw materials, limited funding opportunities, and economic barriers that hinder investment. Moreover, there are fewer political incentives for circular practices in the machine sector compared to other industries.
- **Limited Industry Integration**: The lack of cooperation between plastics manufacturers, recyclers, and end-users, limits the effective transformation of the value chain and slows the adoption of circular principles.
- **Low awareness of the circular economy**: Both machinery manufacturers and users in the plastics industry often lack awareness and understanding of circular economy concepts and their relevance to the machinery sector as a whole.

## 3.2. Key Needs

- **Circular Economy Transformation:** The main need is to transform the entire plastics machine value chain towards circularity, focusing on reuse, maintenance, remanufacturing, and recycling of both products and equipment.
- **Technological Development and Adoption:** There is a strong need for advanced technologies, including those for efficient and high-quality recycling of secondary plastic materials, as well as energy-efficient processing solutions.
- **Eco-design for Machinery**: Manufacturers need to design machines that is robust, long-lasting, repairable and adaptable, in order to align with circular economy principles.
- **Transnational Cooperation:** Enhanced cooperation among countries in the Danube Region is essential to share best practices, knowledge, and resources, to achieve a coordinated transformation.
- **Investment and Digitalization:** Increased investment in circular economy initiatives is needed, along with the adoption of digital tools and AI to improve cost efficiency, optimize processes, and enable new circular business models.

- **Capacity Building and Awareness:** Efforts are needed to strengthen knowledge and capacity within companies to implement circular solutions, encouraging a shift in mindsets and business practices.

While each country faces unique challenges in their transition towards a circular economy, there are significant similarities in the needs that can be leveraged across the region. Common needs include advancing technological capabilities, implementing supportive policies, enhancing public awareness, and fostering cross-sectorial collaboration. Addressing these challenges while capitalizing on shared needs can accelerate progress towards a more sustainable and circular economy across the Danube Region, benefiting both the environment and economic competitiveness.

# 4. Summary of the workshops and key learnings - Guideline for the machine industry

The **outcomes of the design thinking–based workshops** on the potential of circular transformation in the machine industry are synthesized, building on D.2.2.2 (Creation of innovative, circular machine life cycle phases) and incorporating strategic insights from D.2.2.4 (Drafting documents about circularity in the machine industry), including lessons from cross-regional variability and transnational learning. Key learnings derived from the workshop exercises and pilot solutions developed along the full machine life cycle are consolidated and translated into practical guidance for machine-producing companies, demonstrating their contribution to a joint transnational approach to boosting circularity in the machine industry.

## 4.1. Cross-regional synthesis of workshop outcomes

The workshops conducted across Plan-C regions generated a wide range of proposed solutions addressing circularity challenges in the machine industry. Despite a shared understanding of circular economy principles, the maturity and readiness for circular transformation vary significantly across regions, with key differences observed in awareness, access to financing, regulatory clarity, digital readiness, and collaboration culture.
These differences were consistently identified as opportunities for mutual learning rather than barriers. Regions with advanced technical solutions provided reference models, while regions with lower formal maturity contributed valuable insights into pragmatic repair practices, informal reuse, and adaptive maintenance strategies. This diversity strengthened the joint learning process and reinforced the relevance of a flexible, life cycle–based circular framework for the machine industry.

**Key observations:**

- Circular transformation requires not only awareness but also **practical implementation strategies**, with companies often needing support to translate knowledge into action.

- Regional differences present **opportunities for mutual learning**, with more mature regions serving as reference points and less developed regions contributing insights on informal practices and context-sensitive adaptation.

- Effective circular initiatives are strengthened by **cross-sectoral collaboration, access to finance, regulatory coherence, and capacity-building measures**.

**Common circular priorities:**

- Integration of circularity at the design stage through modularity and eco-design approaches.
- Deployment of digital tools for monitoring, predictive maintenance, and process optimization.
- Extension of machine lifetimes through upgrading, retrofitting, refurbishment, and reuse.
- Reduction of energy consumption and recovery of waste heat in energy-intensive machinery.
- Development of service-based and performance-oriented business models, such as leasing and Machine-as-a-Service.
- Strengthening skills, training, and capacity building across all phases of the machine life cycle.

**Illustrative regional examples:**

- Austria and Bosnia and Herzegovina emphasized digital and data-driven solutions, including AI-based optimization and AR/VR diagnostics.

- The Republic of Moldova, Serbia, and Germany focused on modular design, remanufacturing, and material traceability.

- Romania and the Czech Republic highlighted energy efficiency and process optimization measures, such as heat recovery and energy audits.

- Slovakia and Hungary prioritized collaborative innovation approaches and skills development through structured design thinking methodologies.

These examples serve as evidence of the feasibility and scalability of circular solutions across the Danube Region.

**Transnational relevance and applicability:**

Despite contextual differences, common priorities and approaches can be effectively applied transnationally. By leveraging mutual learning and adapting best practices to local conditions, the machine industry can accelerate circular transformation across regions. These insights form a foundation for targeted support measures, policy recommendations, and strategic interventions that foster circularity in diverse industrial and regulatory contexts.

## 4.2. Key learnings along the machine life cycle phases

The joint design thinking approach generated a comprehensive set of circular solutions covering all major phases of the machine life cycle. Across regions, participants emphasized that circularity must be embedded **from the earliest design stages** and supported throughout the life cycle by digital tools, modular architectures, and innovative business models.

### Design and Development

The design phase was identified as the highest leverage point for integrating circularity. Modular architectures enable easier upgrading, repair, and adaptation to changing materials or production requirements. Digital tools, including simulation software, AI-supported programming, and AR/VR environments, allow performance testing prior to physical production, reducing errors, costs, and environmental impacts.

**Key circular strategies:** Design for longevity, eco-design and energy-efficient design, modular design and standardization of parts, digital simulation and virtual prototyping

### Material Sourcing

Sustainable material sourcing was recognized as a critical enabler of circularity across all regions. The use of recycled and recyclable materials reduces dependence on virgin resources while maintaining technical performance standards. Digital traceability tools, including blockchain-based systems, support closed-loop material flows, quality assurance, transparency, and regulatory compliance throughout the machine life cycle.

**Key circular strategies:** Sustainable material sourcing, use of recycled/recyclable materials, closed-loop material systems, digital material traceability

### Manufacturing and Assembly

Workshops highlighted the importance of modular design and data-driven manufacturing processes in enabling remanufacturing and refurbishment. Additive manufacturing supports on-demand production of spare parts, reduces inventory needs, and enables localized manufacturing hubs. Lean manufacturing principles, combined with real-time monitoring, contribute to waste reduction and improved resource efficiency.

**Key circular strategies include:** Modular manufacturing architectures, additive manufacturing and on-demand production, lean manufacturing, remanufacturing-ready production processes.

### Distribution and Logistics

Logistics optimization plays a significant role in reducing environmental impacts associated with machine production and delivery. Reusable and returnable packaging systems, supported by digital tracking technologies, enable closed-loop logistics and reduce packaging waste. Route optimization, localized production, and low-emission transport solutions further reduce carbon footprints while improving operational efficiency.

**Key circular strategies:** Reusable/returnable packaging systems, closed-loop logistics, efficient transportation and route optimization, local production and distribution

## Use Phase and Maintenance

Predictive maintenance supported by IoT sensors, AI, and data analytics emerged as one of the most impactful circular solutions identified during the workshops. Real-time monitoring enables early fault detection, reduces downtime, and extends machine lifetimes. Modular design simplifies maintenance and upgrading, while retrofitting existing machines improves energy efficiency. Service-based models, such as leasing and subscription schemes, further incentivize durability and reuse.

**Key circular strategies:** Predictive/preventive maintenance, upgrading and retrofitting, performance monitoring, shared ownership and service-based business models

## End-of-life Management

Participants consistently emphasized the importance of designing machines for easy disassembly and material recovery. Modular construction and clear material identification facilitate reuse, recycling, and remanufacturing. Digital tools, including AR/VR-assisted disassembly and reverse logistics systems, support efficient end-of-life processing. Product-as-a-Service models strengthen manufacturer responsibility for end-of-life outcomes and increase recovery rates.

**Key circular strategies:** Reverse logistics, Product-as-a-Service, recycling and material recovery, design for disassembly

## Refurbishment and Reuse

The refurbishment phase was identified as a major opportunity for extending machine lifetimes and developing secondary markets. Reverse supply chains enable systematic collection, inspection, and reintegration of refurbished components. Modular machine architectures allow selective replacement of parts, restoring machines to near-new condition with significantly reduced material input.

**Key circular strategies:** Component reuse, refurbishment and upgrading programs, reverse supply chains for components, marketplaces for refurbished machines

## Waste Management

Effective waste management focuses on maximizing material recovery and minimizing landfill disposal. Advanced sorting and recycling technologies enable the transformation of waste streams into high-quality secondary materials that can be reintegrated into production processes. For non-critical components, the use of biodegradable or compostable materials further reduces environmental impacts.

**Key circular strategies:** Material recovery facilities, zero waste to landfill approaches, advanced sorting and recycling technologies, biodegradable/compostable components.

## 4.3. Guidelines for the Machine Producing Industry

Based on the consolidated workshop learnings and strategic insights from D.2.2.4, the following guidelines support machine producers in implementing circular solutions:

- Integrate circularity principles at the design stage through modularity, digital simulation, and eco-design.
- Prioritize recycled and traceable materials and establish partnerships for closed-loop flows.
- Adopt data-driven manufacturing and predictive maintenance to extend lifespans and reduce resource use.
- Develop reverse logistics and refurbishment pathways as core business functions.
- Explore service-oriented business models (e.g., Machine-as-a-Service) to retain control over product lifecycles and improve circular performance.
- Invest in training and capacity building, fostering a culture of experimentation and collaboration.

## 4.4. Toward an integrated transnational strategy

The outcomes of the workshops provide a solid foundation for developing a joint transnational plan to boost circularity in the machine industry across the Danube Region. The convergence of priorities across countries indicates that circular solutions are transferable and scalable when supported by coordinated policies, digital infrastructure, and cross-sector collaboration.

**Key elements** include:

- Harmonized modular design principles.
- Material traceability systems and closed-loop networks.
- Refurbishment and reverse logistics solutions.
- Digital maintenance and monitoring systems.

These shared priorities facilitate innovation, capacity building, and the alignment of circular business models, reinforcing the transition toward a more circular, resilient and sustainable machine industry in the Danube Region.

# 5. Summary of Business Models for circularity in the Machine Industry

Across the **nine countries**, the **identified business models** illustrate multiple pathways toward circularity, reflecting diverse industrial strengths and different levels of technological maturity.

Overall, the business models for circularity in the machine industry lead to the following conclusions:

- **Circularity is implemented across all phases of the machine and plastics lifecycle.** The models cover a wide range of approaches—from circular design (Serbia, Romania) and use-phase services (Austria) to refurbishment (Bosnia & Herzegovina, Moldova), energy-efficient operation (Czech Republic), and end-of-life recycling (Germany, Slovakia).
- **Modularity and repairability appear as a dominant theme**. Five countries explicitly apply modular concepts (Austria, Romania, Serbia, Hungary via 3D printing, Moldova), indicating a regional trend toward longer-lasting machines that can be easily upgraded or repaired.
- **Digitalization accelerates circularity**. Cloud platforms, measure databases, and on-demand customization show how digital tools facilitate resource-efficient decision-making and improved lifecycle management.
- **Closed -loop thinking is rapidly expanding.** Several models (Germany, Austria, Slovakia, Bosnia & Herzegovina) keep materials and components in circulation through recycling, refurbishing, or component reuse
- **Economic and environmental benefits are consistently aligned.** Each model demonstrates that circularity can reduce costs, extend product lifetime, and lower emissions—while also creating new business opportunities (services, customized materials, training).
- **The models are transferable across borders and industries.** The circular business models developed for the machine industry can be adopted by companies across the Danube Region, supporting cross-national innovation and knowledge diffusion.

## 5.1. Synthesized Best Practices across all Nine Models

By analyzing common patterns, the business models for circularity in the machine industry reveal a set of best practices that can guide companies in the Danube Region toward effective circular transformation.

## 1. Design-phase best practices

- **Modularity first:** Use interchangeable, standardized parts to simplify repair and upgrade (Austria, Romania, Serbia, and Moldova).
- **Design for disassembly**: Ensure components can be separated for reuse or recycling (Serbia, Austria).
- **Durability as a design goal:** Choose long-lasting materials that reduce replacement frequency (Austria, Moldova).

## 2. Lifecycle extension practices

- **Refurbishment and reconditioning of equipment:** Give machines multiple lifecycles (Bosnia & Herzegovina, Moldova).
- **Preventive and predictive maintenance:** Reduce downtime, increase machine lifetime (Austria, Romania).
- **Reintroduction of used equipment into the market:** Avoid unnecessary production of new machinery (Moldova, Bosnia & Herzegovina).

## 3. Resource and materials best practices

- **Closed-loop recycling:** Reintroduce post-consumer materials into production (Germany, Slovakia).
- **Use renewable materials:** PLA-based solutions reduce environmental impact versus petroleum-based plastics (Hungary).
- **Efficient use of materials via additive manufacturing:** Minimizes waste and supports localized repair (Hungary).

## 4. Digital and knowledge-based best practices

- **Cloud-based design tools:** Enhance circular design decisions with environmental impact data (Serbia).
- **Databases and guidelines for energy-efficient operations: Support** industry-wide adoption of efficient technology and ECO -design (Czech Republic).

- **Data-driven service models:** Monitor usage, optimize maintenance, and improve longevity (Austria).

### 5. Business model innovation practices

- **Shift from product to service:** Selling performance instead of ownership incentivizes long-term durability (Austria).

- **Value from waste:** Transforming waste streams into high-quality raw materials (Germany, Slovakia).

- **On-demand customization:** Tailoring materials or components reduces overproduction and improves efficiency (Hungary).

## 5.2. Recommendations for Scaling These Models across the Danube Region

Based on the business models for circularity in the machine industry, the following strategic recommendations can help scale and replicate these business models region-wide.

### Strengthen cross-border knowledge transfer

- **Create a regional online platform** to share modular design libraries, best practices, and energy-saving guidelines (linked to Serbia and Czech Republic models).

- **Host regional training programs** for refurbishment, recycling, and modular product design.

### Support SMEs in adopting modular and circular design

- **Provide subsidies or tax incentives** for companies implementing modular machine design (Austria, Romania, and Serbia).

- **Encourage suppliers to standardize components**, enabling easier repair and longer machine lifecycles.

### Expand digital infrastructure for circularity

- **Invest in cloud platforms and assessment tools** that allow companies to simulate environmental impact (Serbia).

- **Develop open-access databases** for energy-efficient technologies and circular design guidelines (Czech Republic).

## Build regional recycling and refurbishment hubs

- **Replicate closed-loop recycling systems** similar to those in Germany and Slovakia to increase regional availability of recycled materials.
- **Establish repair and refurbishment centers** modelled on DKR's robot lifecycle service.

## Incentivize renewable and alternative materials

- **Promote the use of low-impact materials**, including bio-based alternatives (Hungary).
- **Support research and innovation** in bio-based or recyclable materials to replace high-impact metals and plastics.

## Promote Product-as-a-Service across more industries

- **Leverage Austria's model** as a reference for machinery sectors such as compressors or automation equipment.
- **Encourage companies to retain machine ownership** to ensure maintenance, upgrade pathways, and end-of-life recovery.

## Integrate circularity into national and regional policy frameworks

- **Introduce requirements for modularity, recyclability, or lifecycle reporting** in industrial machinery.
- **Provide financial mechanisms**, such as:
  - Green innovation vouchers
  - Circular economy investment funds
  - Low-interest loans for refurbishing or recycling technologies

## Build customer and market awareness

- **Promote the benefits of refurbished and certified used equipment**.
- **Encourage public procurement** to prioritize circular machinery.

# 6. Transnational strategy for enhancing circularity in the machine industry in the Danube Region

The transnational strategy proposal presents a comprehensive approach to foster the transformation of the machine industry towards a circular economy. It is based on the findings of Plan-C activities and addresses key aspects such as industry challenges and needs, machine life cycle phases, and relevant business models, as summarised above. For more detailed information, the full results are available in the project documents on the Plan-C website (https://interreg-danube.eu/projects/Plan-C). Following this approach, five strategic pillars and relevant key topics have been identified for the Plan-C partner regions.

## 6.1. Innovation/Technology/Capacity building

### Slovakia

- The Slovak engineering industry has a **strong manufacturing tradition**, but the transition to a circular economy is progressing slowly.
- **Digitalization, automation, and Industry 4.0 technologies** for recycling, repair, or remanufacturing are not yet widely adopted.
- There is a **shortage of experts in circular processes**, eco-design, and advanced materials.

### Hungary

- Companies face **challenges working with recycled and bio-based materials**, which behave differently compared to virgin plastics; machine design must account for this.
- Designs must integrate **inline quality-control systems** for processing alternative feedstocks.
- **Testing modular solutions** can extend equipment lifespan and increase adaptability.

### Bosnia and Herzegovina

- **Refurbishment, remanufacturing, and repair as innovation drivers**: DKR's lifecycle model demonstrates that Bosnian SMEs can extend machine life through systematic refurbishment, diagnostics, and component renewal—practices largely absent in most BiH industries.

- **Lack of technical skills**: A2.1 mapping shows low awareness and weak capacity in circular economy principles, predictive maintenance, eco-design, and lifecycle management, highlighting the need for structured SME training programmes.
- **Outdated technologies**: Many companies operate energy-inefficient, aging machines; adopting modern, energy-efficient technologies can significantly reduce waste.
- **Potential in green materials and bioplastics**: The Bioplastic Toys example shows how renewable materials and 3D printing can inspire sustainable product development and new pathways in machine design.

## Czech Republic

- **Ecodesign**: modularity, upgradeability, standardised parts, sustainable raw materials, energy and water savings, design for circularity.
- **Digitalization:** Industry 4.0 integration, predictive services, active sensor systems.
- **Human resources development**: training in digitalization, eco-design, and environmentally oriented thinking.
- **Circular business model development**.
- **Overcoming manufacturer hesitation** toward reuse and refurbishment of machinery.

## Serbia

- **Modernisation of manufacturing processes** to improve resource efficiency.
- **Development and adoption of digital tools** (IoT, AI, predictive maintenance) to support circular practices.
- **Capacity-building programmes** for implementing eco-design and circular innovation.

## Germany

- Adoption of **advanced digital tools** (predictive maintenance, digital twins) to optimize resource use in machine manufacturing.
- **Strengthening national skills** in refurbishment, remanufacturing, and life-extension of industrial machinery.
- **Development of modular machine architectures** enabling component exchange, upgrades, and circular lifecycle management

## Romania

- **Integration of Industry 4.0 technologies** (real-time monitoring, predictive maintenance, IoT) to reduce energy consumption and optimise processes.
- Strengthening internal capacity for **modular design, eco-design, and component standardisation**—building on the EURODAC Automation model.
- **Capacity-building programmes** for SMEs on remanufacturing, component reuse, and rapid prototyping.
- **Investments in energy-efficient technologies** and **equipment upgrades** to reduce emissions and operational costs.

## Austria

- **Manufacturer scepticism toward major changes** remains a barrier.
- **Challenges related to scaling innovative circular solutions**.
- **Circular lifecycle management** through:
    - Modular machine design platforms
    - Standardized components enabling easy upgrades
- **Predictive maintenance & digitalisation / industry 4.0:** using IoT and AI, leveraging sensor data and algorithms for proactive machine servicing.
- **Circular and resilient material sourcing**
- Development of **circular business models**.

## Republic of Moldova

- Integration of **predictive maintenance technologies and IoT** sensors to monitor machine health, extend equipment lifespan, and prevent failures.
- Adoption of **additive manufacturing (3D printing)** to produce lightweight, on-demand spare parts, reducing material waste and storage needs.
- **Strengthening technical capacity** through vocational training in welding, repair, and maintenance of plastic processing machinery.
- **Promoting R&D in modular machine design** to enable easy disassembly, repair, and upgrading, shifting away from linear "make–use–dispose" approaches.

# 6.2. Regulation/Policy/Infrastructure

## Slovakia

- **Circular economy principles** are included **in national plans**, but specific guidance for mechanical engineering is missing.
- High-value mechanical engineering products require **clear standards for reuse, remanufacturing, and take-back schemes.**
- **Infrastructure for sorting, reverse logistics, and processing** of metal and composite components remains insufficient.

## Hungary

- **Financial incentives**—such as EU or national grants, tax benefits, or subsidised pilot projects—can reduce investment risks and accelerate the development of circular machinery and equipment capable of processing circular materials.
- **Stronger requirements for mandatory recycled content** in plastic products would make recycling more economically viable.
- A **more efficient separation and collection system** for municipal recycling is needed.

## Bosnia and Herzegovina

- **Regulatory inconsistency and weak enforcement:** Although BiH has relevant laws (e.g., Waste Management Law, WEEE regulation), implementation capacity is limited, resulting in fragmented circular practices.
- **Lack of standards and certification for refurbished machinery**: The DKR case highlights the absence of testing, certification, and warranty frameworks for reused machine components, creating market uncertainty.
- **Insufficient waste-management and recycling infrastructure:** Many regions lack adequate technological systems, forcing companies like Aida Commerce to fill critical service gaps, demonstrating the need for systemic infrastructure investment.
- **No financial incentives for circular economy adoption:** A2.1 findings show that SMEs lack access to grants, subsidies, or tax reductions supporting circular practices, slowing the transition.

## Czech Republic

- Standardisation **efforts for eco-design, take-back systems, refurbishment, and reuse** are needed in the machinery sector.
- **EU circular strategies require advanced technologies** whose availability may be limited due to development and funding barriers.
- **Political and financial support** is essential for business models focused on circular practices.
- **Infrastructure for collection, take-back, refurbishment, and recycling** of machine parts must be strengthened both nationally and internationally.
- **Development of international education and training infrastructure** is needed to train multidisciplinary experts considering environmental aspects.

## Serbia

- **Alignment with EU industrial and circular economy legislation** is necessary to ensure regional consistency.
- **Incentives** should be developed **for repair, remanufacturing, and end-of-life recovery** of machinery.
- **Investments** are required in **infrastructure for collection**, reuse, and recycling of machine components.

## Germany

- **Harmonised standards** across the Danube Region are needed for durability, reparability, and component traceability in machinery.
- **Regional infrastructure** must be expanded for collection, sorting, and recycling of machine parts, including metals, electronics, and technical plastics.
- **Policy support** is required for remanufactured components and circular service models (leasing, performance-based models).

## Romania

- Development of **regulatory frameworks** supporting the reuse and recycling of technical components, including specific rules for technological waste management.
- Introduction of **financial incentives and schemes** to help SMEs upgrade equipment, digitalise production, and adopt circular technologies.
- **Expansion of national and regional infrastructure** for collecting, sorting, refurbishing, and reintegrating used machine parts and industrial waste.
- Alignment with EU circular economy objectives through **minimum eco-design standards** for the machinery used in plastics processing.

## Austria

- Greater **predictability of upcoming regulations** is needed to support industry planning.
- Some manufacturers show **reluctance to comply with policy intentions**, slowing circular adoption.
- **Technologies required** to meet regulatory goals are often unavailable or too costly.
- **Funding and incentives** are needed to support circular manufacturing and innovation, leveraging relevant national strategies (e.g., The Austrian Circular Economy Strategy (Kreislaufwirtschaftsstrategie), #upperVISION2030, Austrian RTI strategy (FTI-Strategie 2030)).

## Republic of Moldova

- **Mandatory recycled-content requirements** for plastic products would create a stable market for recycled materials and encourage investment in machines capable of processing them.
- **Development and funding of reverse logistics and collection systems** for end-of-life machinery and plastic waste are essential to closing material loops.
- **Strengthening and enforcing the Extended Producer Responsibility** (EPR) scheme for packaging is necessary to ensure proper financing for plastic waste collection and recycling.
- **Financial incentives and grants** — modelled after programmes such as ODA's "SME Greening Program" — should support machine manufacturers and plastics processors in adopting energy-efficient and circular technologies.

## 6.3. Collaboration and knowledge exchange

### Slovakia

- Existing **networks between companies, universities, and research organizations** were not systematically focused on the circular economy in mechanical engineering.
- Slovakia's **involvement in international projects** (Horizon Europe, EIT Manufacturing) was moderately active, although the potential was higher.

### Hungary

- **Integrating knowledge** from predictive diagnostics, contamination monitoring, and energy tracking further optimized the processing of recyclates, improving efficiency, reducing downtime, and extending equipment lifespan.
- **Direct collaboration with plastics processors** helped define technical requirements for handling recycled materials efficiently, including inline quality control and contamination monitoring systems.
- **Collaborative R&D projects** involving academia and industry demonstrated the business value of modularity, predictive maintenance, and energy-efficient systems, motivating manufacturers to integrate these features from the design stage.

### Bosnia and Herzegovina

- **Collaboration** between machine users, recyclers, refurbishers, and policy actors remained **fragmented**; companies often operated in isolation, reducing the ability to create circular loops for materials, components, and machines.
- **Strong potential** existed **for regional circular economy clusters** by combining expertise from recyclers (C.I.B.O.S., MZ Company), refurbishers (DKR), and waste managers (Aida Commerce) to build regional hubs for CE innovation.
- Good practices showed the **importance of stakeholder cooperation**: Aida Commerce successfully integrated multiple actors (government, community, industry) in waste-stream management and refurbishment processes.
- However, **formalized knowledge-transfer programs were still lacking**; existing workshops and trainings were not embedded into long-term, systematic platforms for circular economy exchange between SMEs, universities, and institutions.

### Czech Republic

- **A stronger connection was needed between research institutions** (including universities) **and industry**, at a multidisciplinary level, guided by circular economy experts.
- The creation of **industrial associations for knowledge and good-practice exchange**, including international ones, was identified as a key priority (digitalisation also played an enabling role).
- **Expanding the knowledge** base of mechanical engineering experts in eco-design, environmental management tools, and circular economy principles was necessary.

- **Close cooperation between industry and policymakers**, including timely access to information on upcoming regulations, supported proactive development of circular solutions

## Serbia

- Stronger **collaboration between R&D institutions, universities, and machine-industry companies** was required.
- **Cross-sectoral cooperation** supported component reuse and the development of industrial symbiosis models.
- **Transnational knowledge exchange** facilitated the dissemination of best practices and innovative circular solutions

## Germany

- **Stronger cooperation** was needed **between machine manufacturers, toolmakers, engineering service providers, and recycling firms** in the Northern Black Forest region.
- **Cross-border knowledge exchange** on remanufacturing processes, spare-parts management, and design-for-disassembly further supported circularity.
- **Cluster-driven collaboration** (e.g., INNONET and regional industrial networks) helped SMEs adopt circular technologies and methods.

## Romania

- **Transnational networks for sharing best practices** (e.g., modular design, design for disassembly, refurbishment models) were strengthened.
- **Partnerships between companies, research institutes, and technology providers** supported the development of integrated circular solutions.
- **Digital platforms** facilitated collaboration, material-flow monitoring, component reuse, and life-cycle assessment.
- **Joint training programmes** among Plan-C partners improved technical and managerial capacities across the Danube Region.

## Austria

- **Cross-industry partnerships** fostered circular innovation by enhancing cooperation between manufacturers, recyclers, and technology providers.
- **Transnational knowledge-sharing platforms** enabled the exchange of best practices across the Danube Region and broader EU networks.
- **Joint research and development initiatives** involving universities and clusters accelerated the adoption of sustainable technologies.
- **Clusters and platforms** played a central role in supporting continuous knowledge exchange.

## Republic of Moldova

- **Public-private partnerships** supported the co-development and demonstration of circular solutions involving farmers, recyclers, and environmental agencies.

- The **establishment of transnational industrial clusters and networks** for the machine and plastics sectors addressed a key gap in Moldova by enabling the exchange of best practices, technologies, and circular business models.
- **Knowledge transfer between research institutions** (e.g., universities) and SMEs promoted eco-design and circular economy principles in machine manufacturing.
- **Cross-border matchmaking platforms** connected machine manufacturers with plastics processors to co-create circular solutions tailored to regional needs

## 6.4. Awareness/Societal/Education

### Slovakia

- **Awareness of the ecological and economic benefits** of circular production remained low in the engineering sector.
- **Public discussions** on the circular economy were fragmented and insufficiently focused on industrial companies.
- **Technological solutions** supporting waste reduction and product life-cycle extension were not widely promoted or popularized.

### Hungary

- **Communal recycling systems** required better separation practices, which could be improved through machinery equipped with artificial vision technologies.
- The idea of a "**Vinted for machinery**"—a safe, insured platform for buying second-hand parts or equipment—represented an important opportunity to increase acceptance of reused components.
- **Stronger enforcement mechanisms** were needed to ensure compliance with circularity-related regulations.

### Bosnia and Herzegovina

- **Low acceptance of refurbished machinery and reused components**: A2.1 shows users often distrust second-hand machines; however, DKR demonstrates that refurbished robots can match new-machine performance—an important awareness message. (D2.3.1)
- **Limited general understanding of circular economy principles**: Machine manufacturers and users show low knowledge about circular economy beyond basic recycling, requiring broad awareness actions.
- **Positive influence of "green pioneers"**: Bioplastic Toys demonstrates how consumer-level awareness impacts business choices and reinforces trust in sustainable solutions.
- **Need for awareness campaigns** on repairability, durability, and lifecycle extension: Public and business perceptions must shift towards valuing lifetime extension over equipment replacement.

### Czech Republic

- The **circular economy is still not perceived as a competitive advantage or strategic benefit** in the mechanical engineering sector.

- **Sharing good-practice examples** through electronic platforms or industrial associations helped increase awareness among experts.
- A **broader societal mindset shift** is necessary, and the education system—including but not limited to universities—played a critical role in supporting this changed.

# Serbia

- **Awareness** needed to be increased **among manufacturers** regarding long-term cost savings from circular business models.
- **Educational programs** for engineers and technicians supporting the adoption of circularity principles.
- **Public campaigns** promoting demand for durable, repairable, and circularly designed machines.

# Germany

- **Increasing awareness** among regional machine manufacturers about the competitiveness gains of circularity (reduced material costs, lower downtime, supply chain resilience)
- **Workforce training** in repair, diagnostics, remanufacturing and sustainable engineering practices
- **Communication of success stories** from innovative machine producers in the Northern Black Forest as role models for the Danube Region

# Romania

- **Increasing awareness** about the economic benefits of circularity (lower maintenance costs, extended product lifetime, reduced dependence on imports).
- **Market awareness campaigns** to improve acceptance of refurbished machinery and reused components.
- **Promoting circular economy concepts** among the workforce: green skills, energy efficiency, and responsible machine operation.
- **Encouraging organizational cultures** focused on "repair, reuse, remanufacture".

# Austria

- **Public campaigns on circular economy benefits** for raising awareness among consumers and businesses about resource efficiency.
- **Community engagement for sustainable practices**, involving local stakeholders in recycling and reuse initiatives.
- **Educational programs for behavioural change**, promoting sustainability through schools, vocational training, and industry workshops.

# Republic of Moldova

- Launching **educational campaigns** targeting farmers and agricultural producers on the economic and environmental benefits of recycling agricultural plastic waste.

- **Promoting the socio-economic benefits of circular models**, such as job creation in refurbishment, remanufacturing, and recycling sectors, to gain public and governmental support.
- **Raising awareness about brand value and market competitiveness** gained through adopting sustainable and circular practices, enhancing the image of agricultural and industrial products.

# 6.5. Ecological design and sustainable product development

## Slovakia

- **Eco-design** in the engineering sector is **only sporadic**; most companies use a traditional linear approach.
- The materials used are **predominantly standard metals**; recycled or alternative materials are used minimally.
- **Few products are designed to be easily repairable or modular**.

## Hungary

- **Develop machinery and machine lines** that can integrate with on-site plastic recycling systems, enabling closed-loop production
- **Financial sustainability** must **be coupled with environmental sustainability**
- Machinery has to be **adapted to operate on renewable energy**.

## Bosnia and Herzegovina

- **Low adoption of eco-design in machine engineering:** A2.1 shows minimal use of design-for-disassembly, modularity, repairability, or recycled material integration in BiH machinery.
- **DKR as a practical model for design for longevity:** Their approach prioritizes component standardization, easy disassembly, and premium-material sourcing, key principles of circular engineering. (D2.3.1)
- **Inconsistent availability of sustainable materials:** High-quality recycled materials are limited, inconsistent, or expensive, which constrains eco-design implementation in BiH.
- **Innovation potential in biobased materials:** Bioplastic Toys' successful use of PLA shows that sustainable materials can be introduced into manufacturing systems when supported by proper design and technology.
- **Need for training eco-design experts:** Regional industry lacks the skills to integrate eco-design into machine development; targeted education programs are necessary.

## Czech Republic

- **Machinery needed to be designed for longevity and repairability**, supported by modularity and standardization of parts and materials.

- Ensuring the **possibility of renovation, refurbishment, or reuse of parts** at the end of the machine's life cycle was essential.
- **Sustainable manufacturing required technologies** that minimized energy, water, and auxiliary material consumption.
- **Waste-prevention principles** had to be embedded in production, including the use of advanced raw materials, recycled materials, green chemicals, and environmentally friendly auxiliaries

## Serbia

- Designing **machines with modularity** and principles that facilitated **easy disassembly**.
- **Selecting sustainable materials** and reducing dependency on critical raw materials
- **Development of business models** focused on product-as-a-service, repair, and remanufacturing

## Germany

- **Early integration of ecological design principles:** modularity, standardized materials, easy disassembly and clear component labelling
- **Use of recycled metals and high-quality technical recycles** where performance requirements allow
- **Implementation of lifecycle assessments and digital product passports** to track components and optimize end-of-life pathways

## Romania

- **Promotion of modular design and component standardization** to support repair, replacement, and upgrading of machinery (as demonstrated by EURODAC).
- **Integration of eco-design principles in early development stages**: reduced resource use, minimal production losses, easy disassembly, and longer product life.
- **Increased use of recycled materials** where technically feasible, supporting a closed-loop material system.
- Development of **solutions for remanufacturing, retrofitting, and upgrading** existing machinery to extend service life and reduce the need for new equipment.

## Austria

- Design for longevity and modularity, creating durable products with interchangeable components to extend lifecycle.
- Use of recycled and renewable materials, integrating sustainable resources into manufacturing processes.
- Design for sustainability: Eco-design principles for energy efficiency, minimizing environmental impact through optimized design and low-energy operation.
- Compliance with environmental regulations

## Republic of Moldova

- Implementing **Design for Longevity and Disassembly (DfD)** principles in machine manufacturing to facilitate repair, refurbishment, and material recovery at end-of-life.
- **Prioritizing the use of recycled and recyclable materials** in machine components and promoting standardization of parts to simplify maintenance and reduce the need for virgin materials.
- **Developing and promoting Product-as-a-Service (PaaS)** and leasing models for machinery, where manufacturers retain ownership and responsibility for maintenance, upgrade, and end-of-life management.
- **Adopting lean manufacturing principles and reusable packaging** throughout the production and distribution process to minimize waste and environmental impact.

# 7. How Plan-C could help to transform the Danube Region into a more circular area?

Plan-C provides the strategic backbone to shift the Danube Region from fragmented circular initiatives toward a coherent, competitive, and resilient circular industrial ecosystem.

Insights from all partner countries show that circularity in the machine and plastics-processing sectors requires systemic transformation across design, business models, skills, collaboration, policy, and infrastructure. By coordinating action in these areas, Plan-C acts as a catalyst for long-term economic, technological, and environmental progress.

## 1. Designing Machines for Multiple Lifecycles

Partners consistently emphasize that circularity must begin at the design stage. Eco-design principles—modularity, reparability, upgradability, and durability—enable machines to operate efficiently over extended lifetimes. Digital tools such as predictive maintenance and IoT increase lifetime performance, while designs optimized for recycled feedstock strengthen the plastics circularity chain. Plan-C can harmonize these design principles across the region and accelerate adoption among manufacturers.

## 2. Enabling Circular Business Models

Insights from countries such as Austria and Moldova underline the need to shift from traditional one-time machine sales to models based on long-term lifecycle management. Product-as-a-Service, leasing schemes, refurbishment programs, and performance-based contracts align profitability with machine longevity. These models stimulate regional value creation by generating new jobs in maintenance, diagnostics, remanufacturing, and refurbishment while reducing dependency on imported equipment. Plan-C can support the diffusion of these models and provide guidance for practical implementation.

## 3. Building Integrated Circular Industry Ecosystems

Circular economy transformation requires coordinated cooperation between machine manufacturers, recycling firms, engineering experts, research institutes, clusters, and policymakers. Examples from Hungary and Bosnia and Herzegovina demonstrate strong potential for cross-sectoral collaboration, especially in modular solutions, refurbishment loops, and recyclate-ready technologies. Plan-C can formalize such networks, strengthen cross-border collaboration, and support the creation of shared refurbishment hubs and circular supply chains across the Danube Region.

## 4. Strengthening Skills, Trust, and Awareness

A lack of awareness and trust—especially regarding refurbished machines—remains a major barrier. Plan-C an address this by promoting quality standards for remanufactured machines, supporting the development of training programs, and sharing best practices such as those demonstrated by EURODAC and DKR. Building skills in eco-design, diagnostics, circular business models, and maintenance is essential for developing a workforce capable of supporting the circular transition.

## 5. Aligning Policies, Finance, and Infrastructure

Many circular technologies are already available but face barriers due to insufficient financial incentives, regulatory uncertainty, and inadequate infrastructure. Plan-C can help align national regulations with EU circular economy objectives, advocate for funding mechanisms supporting eco-design, refurbishment, and digitalization, and promote the development of reverse logistics, component reuse systems, and refurbishment infrastructure. This alignment is crucial for scaling circular solutions across the entire region.

## 6. Boosting Regional Resilience and Competitiveness

Circular transformation enhances resource and energy independence, which is critical for a region exposed to supply volatility. Circular machine systems reduce raw material dependence, stabilize production costs, and increase energy and material efficiency. By fostering strong local capacities for manufacturing, repair, and remanufacturing, the Danube Region becomes more resilient, technologically advanced, and globally competitive. Plan-C provides the shared vision and framework necessary to achieve this transformation.

***Plan-C thus not only supports the adoption of circular practices but also fosters a shared regional identity as a leader in sustainable and resilient industrial development.***

# Conclusions

The **Plan-C initiative** presents a vital and timely strategic framework for **catalyzing the transition toward a circular economy within the machine and plastics industries of the Danube Region**. The comprehensive analysis, derived from regional/national workshops and trans-regional exchange, stakeholder mapping, and country-specific assessments, reveals a clear imperative: the linear "take-make-dispose" model is no longer economically viable, environmentally sustainable, or strategically resilient for the region's industrial future. The transition to circularity is not merely an ecological aspiration but a fundamental economic and competitive necessity.

Achieving this transformation **demands a systemic and synchronized approach across multiple dimensions**. First, **innovation must be purpose-driven**, focusing on the development and adoption of technologies that enable circularity from the outset. This includes designing machinery for modularity, disassembly, and longevity, integrating digital tools like IoT and AI for predictive maintenance and resource optimization, and advancing processing technologies capable of handling complex recycled feedstocks. Concurrently, capacity building is essential to cultivate a skilled workforce proficient in eco-design, advanced repair, remanufacturing, and circular systems management, ensuring the human capital exists to implement and sustain these innovations.

Second, an enabling environment requires **coherent policy and robust infrastructure**. National and regional regulations must evolve to support circular practices through clear standards for durability, reparability, and recycled content, coupled with financial incentives that de-risk investment in green technologies. Parallel development of physical infrastructure—including collection systems, reverse logistics, and specialized hubs for refurbishment and high-quality recycling—is critical to close the material loops and create viable markets for secondary raw materials.

Third, the inherent complexity of the value chain underscores that **collaboration is the cornerstone of success**. Isolated efforts by individual companies or sectors will yield limited impact. The future lies in strengthened transnational and cross-sectoral partnerships—between machine manufacturers and plastics processors, between industry and academia, and between the public and private sectors. Building formal networks, clusters, and knowledge-exchange platforms will accelerate the diffusion of best practices, foster industrial symbiosis, and co-create solutions tailored to regional needs.

Finally, **societal and market awareness** must be elevated to create both pull and push factors for change. Educating consumers, businesses, and policymakers on the long-term economic, environmental, and social benefits of circular models is crucial to build demand for refurbished equipment, create acceptance for products with recycled content, and foster a cultural shift toward valuing resource efficiency and lifecycle performance over initial purchase price.

In conclusion, the **Plan-C project provides the essential blueprint and collaborative platform to navigate this multifaceted transition**. By strategically integrating innovation, policy, collaboration, and education, the Danube Region can move beyond fragmented pilot projects toward a coherent, competitive, and resilient circular industrial ecosystem. This transformation will not only mitigate environmental impact and enhance resource security but also unlock new avenues for economic growth, job creation, and technological leadership. The journey toward circularity is a collective endeavor, and through the concerted efforts championed by Plan-C, the Danube Region is poised to emerge as a model of sustainable industrial development in Europe.