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Deliverable

D8.1 – R3-MYDAS Business Models

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Executive Summary

The R3-MYDAS project represents a transformative effort to redefine the remanufacturing of energy goods by integrating advanced digital technologies, innovative engineering solutions, and circular economy principles. As industries face challenges like waste reduction, product traceability, and end-user trust, R3-MYDAS introduces a comprehensive, multi-actor framework to address these barriers. By combining cutting-edge mechatronics, data-driven tools, and sustainable methodologies, the project sets a new standard for creating environmentally and economically sustainable value chains.

The project's framework targets three critical sectors as use cases: **Oil & Gas crankshafts**, **Electric Vehicle (EV) batteries**, and **Wind turbine gearboxes**. These demo cases showcase the application of cutting-edge technologies, including machine learning for process optimization, graph models for defect detection, and digital twins for real-time monitoring and predictive maintenance. Advanced manufacturing solutions, such as additive manufacturing, laser-cladding, and automated disassembly/reassembly, further enhance the efficiency and quality of remanufactured products. A central innovation of R3-MYDAS is its **Digital Passport-like marketplace**, which ensures full traceability of remanufactured products. By providing detailed information on components and processes, the marketplace fosters transparency and trust across the value chain.

Deliverable **D8.1 "R3-MYDAS Business Models**" includes activities from Task 8.1 "Business modelling" and Task 8.2 "IPR Management and Market Analysis" in WP8 "Exploitation & Trainings". This report outlines a market and technology analysis for demo cases and the existing remanufacturing marketplaces, demonstrating the potentials offered by them to address the challenges imposed to accessibility of remanufactured industrial components. This market analysis paves the ways to define new business models for the **commercialization** and **exploitation** of R3-MYDAS solutions, identifying value opportunities and interaction mechanisms that support platform-based business models. It also explores new remanufacturing value chain scenarios, leveraging insights from the project three demo cases of oil and gas crankshafts, EV batteries, and wind turbines gearboxes to define innovative business concepts. The business scenarios describe the different ways of implementing the demo cases' technical development in which the most adaptable one according to the partners desire and project goals will be showcased within business model approaches. According to that, using structured tools like the Business Model Canvas, in Chapter 4 detail analysis regarding the key stakeholders, the offered circular value propositions, and revenue streams, paving the way for sustainable and impactful industry transformations.

The activities of business modelling in this report will be continued in terms of exploitation strategies, both for individual and joint results, along with a plan to protect the results investigating appropriated IPR. These activities will start from the month 13 of the project, demonstrating pathways to facilitate commercialization of the project results.

Deliverable leader:	Parnia SHAFINEJAD (EITM)
Contributors:	Rohit Lakshmanan (LUT), Luke Treves (LUT)
Reviewers:	Fatima Zorro (EWF), Andrea Capaccioli (DBL)
Approved by:	Athanasios Poulakidas, Georgios Stagakis (NCI)

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Definitions, Acronyms and Abbreviations

Acronym/ Abbreviation	Title
AM	Additive Manufacturing
BM	Business Model
BMC	Business Model Canvas
BMI	Business Model Innovation
BMS	Battery Management System
CA	Consortium Agreement
CAGR	Compound Annual Growth Rate
CE	Circular Economy
CEBM	Circular Economy Business Model
DFB	Data Fusion Bus
DfRm	Design for Remanufacturing
DPP	Digital Product Passport
EC	European Commission
EEE	Electric and Electronic Equipment
EOL	End of Life
ERN	European Remanufacturing Network
ESPR	Eco-design for Sustainable Products Regulation
EV	Electric Vehicle
EU	European Union
EaaS	Equipment as a Service
GDNs	Graph Deviation Networks
GTAW	Gas Tungsten Arc Welding
HSE	Health, Safety and Environment
IPR	Intellectual Property Rights
KERs	Key Exploitable Results
MaaS	Machinery as a Service
ML	Machine Learning
OEMs	Original Equipment Manufacturers
PaaS	Product-as-a-Service
RTOs	Research Technology Organizations
SaaS	Software as a Service
SAW	Submerged Arc Welding
SSH	Social Science and Humanities
SOH	State of the Health

Acronym/ Abbreviation	Title
TFF	Tooth Flank Fracture
TRL	Technology Readiness Level

1 Introduction

1.1 Project Information

The R3-MYDAS project is a novel initiative tackling the complex challenges of shifting to a circular economy through innovative remanufacturing methods. By focusing on resource efficiency, cost reduction, and environmental sustainability, remanufacturing has shown its potential for creating impactful solutions. However, key challenges remain, particularly around improving the traceability and reliability of remanufactured products from an end-user perspective, while also monitoring their environmental and economic impacts.

To address these issues, R3-MYDAS is building a multi-actor framework that brings together cutting-edge digital tools, advanced mechatronic systems, and insights from social sciences and humanities. This framework will be applied to three energy related sectors such as Oil & Gas crankshafts, Electric Vehicle (EV) batteries, and Wind turbine gearboxes. The goal is to address the technology obstacles of these industries by delivering better product quality, minimizing rework, conserving resources, and speeding up anomaly detection through a sustainable and circular value chain.

One of the project's important features is the development of a marketplace that acts as a Digital Passport for remanufactured products and components. This ensures full transparency and traceability across the value chain. R3-MYDAS leverages advanced technologies like machine learning for quality control, graphical models for defect detection, and digital twins for predictive maintenance combining with automated tools for manufacturing and disassembly and guided by ethical frameworks. Thus, this ensures efficient and responsible remanufacturing solutions. The project's demo cases highlight its application in these areas:

- **Oil & Gas crankshafts**: Enhancing efficiency with laser-cladding and additive manufacturing to boost quality and minimize rework.
- **Electric Vehicle batteries**: Improving traceability, safety, and sustainability with AI-driven anomaly detection and predictive maintenance.
- **Wind turbine gearboxes**: Increasing reuse rates, cutting down on material waste, and improving repair processes with advanced coatings and structural optimization.

The R3-MYDAS will generate results that foster shorter programming times, improved defect detection, and substantial material and environmental savings. By fostering collaboration across sectors, the project aims to create reliable, transparent, and scalable circular value chains. Key impacts include as follow:

- **Higher productivity**: A 60% reduction in programming time for remanufacturing processes.
- **Higher quality**: A 20% increase in product quality and a 50% faster anomaly detection rate.
- **Resource efficiency**: Savings of up to 85% in raw materials and a reuse rate of up to 99%.
- **Sustainability gains**: Substantial reductions in lead times, waste, and the overall environmental footprint.

Here is the list of partners participating to the project:

Table 1: The R3-MYDAS consortium.

Number[1]	Name	Country	Short name
1 (CO)	NETCOMPANY-INTRASOFT SA	Luxemburg	NCI
2	EUROPEAN FEDERATION FOR WELDING JOINING AND CUTTING	Belgium	EWF
3	EIT MANUFACTURING SOUTH SRL	Italy	EITM
4	FLENDER FINLAND OY	Finland	FLE-FI
4.1 (AE)	FLENDER GMBH	Germany	FLE
5	AVL LIST GMBH	Austria	AVL
6	TALLERES MECANICOS COMAS SLU	Spain	TMCOMAS
7	SPIN ROBOTICS IVS	Denmark	SPIN
8	ASOCIATION DE INVESTIGACION METALURGICA DEL NOROESTE	Spain	AIMEN
9	LAPPEENRANNAN-LAHDEN TEKNILLINEN YLIOPISTO LUT	Finland	LUT
10	INFORMATION TECHNOLOGY FOR MARKET LEADERSHIP	Greece	ITML
11	DEEP BLUE SRL	Italy	DBL
12	CHAROKOPEIO PANEPISTIMIO	Greece	HUA
13	IKERLAN S. COOP	Spain	Ikerlan
14	ZIKNES TECHNOLOGY SL	Spain	Ziknes
15 (AP)	CSEM CENTRE SUISSE D'ELECTRONIQUE ET DE MICROTECHNIQUE SA - RECHERCHE ET DEVELOPPEMENT	Switzerland	CSEM

[1] CO: Coordinator. AE: Affiliated Entity. AP: Associated Partner.

1.2 Document Scope

This document, Deliverable 8.1 R3-MYDAS Business Models, establishes the baseline for the **exploitation activities**, enabling the definition of business concepts and business model alternatives to be established for R3-MYDAS exploitation. Thus, the focus is to define the business model framework for the commercialization and exploitation of the R3-MYDAS service portfolio. The primary objective is to establish viable and sustainable business concepts that leverage the innovative technologies, methodologies, and solutions developed within the project. The scope of this deliverable is twofold:

Firstly, the document identifies, and analyses **new remanufacturing value chain** opportunities made possible by the R3-MYDAS solutions, with a particular focus on circular economy applications.

Secondly, it defines the **business model for the R3-MYDAS marketplace** and its associated services, to identify value opportunities and enable stakeholder interactions. This includes detailing the enabling business models in remanufacturing sector that capture the value exchanges that facilitated by the platform.

The deliverable also incorporates guidelines and archetypal business models, developed through research contributions from LUT, aimed at supporting ecosystem stability and sustainability. These models are formalized using structured management tools, such as the Business Model Canvas, to illustrate **stakeholder interactions**, **value propositions**, and **revenue generation** mechanisms.

This document (D8.1) outlines the formalized business models for the most promising scenarios, based on three key business cases from the project. These cases, previously untapped at the industrial level, are now enabled by the R3-MYDAS platform and its services. Each business model includes:

- **Market analysis**: Insights into reference markets and emerging technology trends.
- **Stakeholder dynamics**: Understanding stakeholder roles and interaction mechanisms.
- **Value propositions and revenue models**: Definitions to guide final business model selection.

1.3 Document Structure

According to the project goals and WP8 objectives, this deliverable comprises of 5 chapters, each contributing to identification of business models and paving the way for the exploitation strategies of the post project. For this manner, the technical developments within the project are the basis of each conducted analysis. Followings are the detailed information of each chapter.

Chapter 1: Presents an introduction and the aim and objectives of the project outlining involved tasks in WP8 and scopes of this deliverables towards the phases designed to submit it.

Chapter 2: Methodology**;** presents the methodology and approaches in a timely manner toward the end of the project planning strategies for exploiting the project results.

Chapter 3: Technology, Market and Business Model analysis; conducts comprehensive market analysis and technology trends of the current value chains (three demo cases and the marketplaces) as well as conducting a scientific remanufacturing energy goods business model analysis.

Chapter 4: R3-MYDAS Business Models and Services; presents a comprehensive analysis of business model scenarios and designing preliminary business models according to the project progress and partners intentions to maximize the impact of the results.

Chapter 5: Conclusion of remarks and highlights the next steps in business modelling and exploitation activities for the following months.

Chapter 6: A list of used scientific articles.

2 Methodology

2.1 Methodological approach and timeline

This chapter outlines the methodological approach used in the R3-MYDAS exploitation strategy. As illustrated in Figure 1, the approach is structured around four main phases and one transversal phase, emphasizing the critical need for active partner participation and collaboration. The figure highlights the core activities related to the exploitation and commercialization of results within WP8, encompassing Task 8.1 (Business modelling), Task 8.2 (IPR management and market analysis), and Task 8.3 (Market exploitation). This methodology serves as a comprehensive guideline for implementing project activities and preparing subsequent reports as the project progresses toward completion.

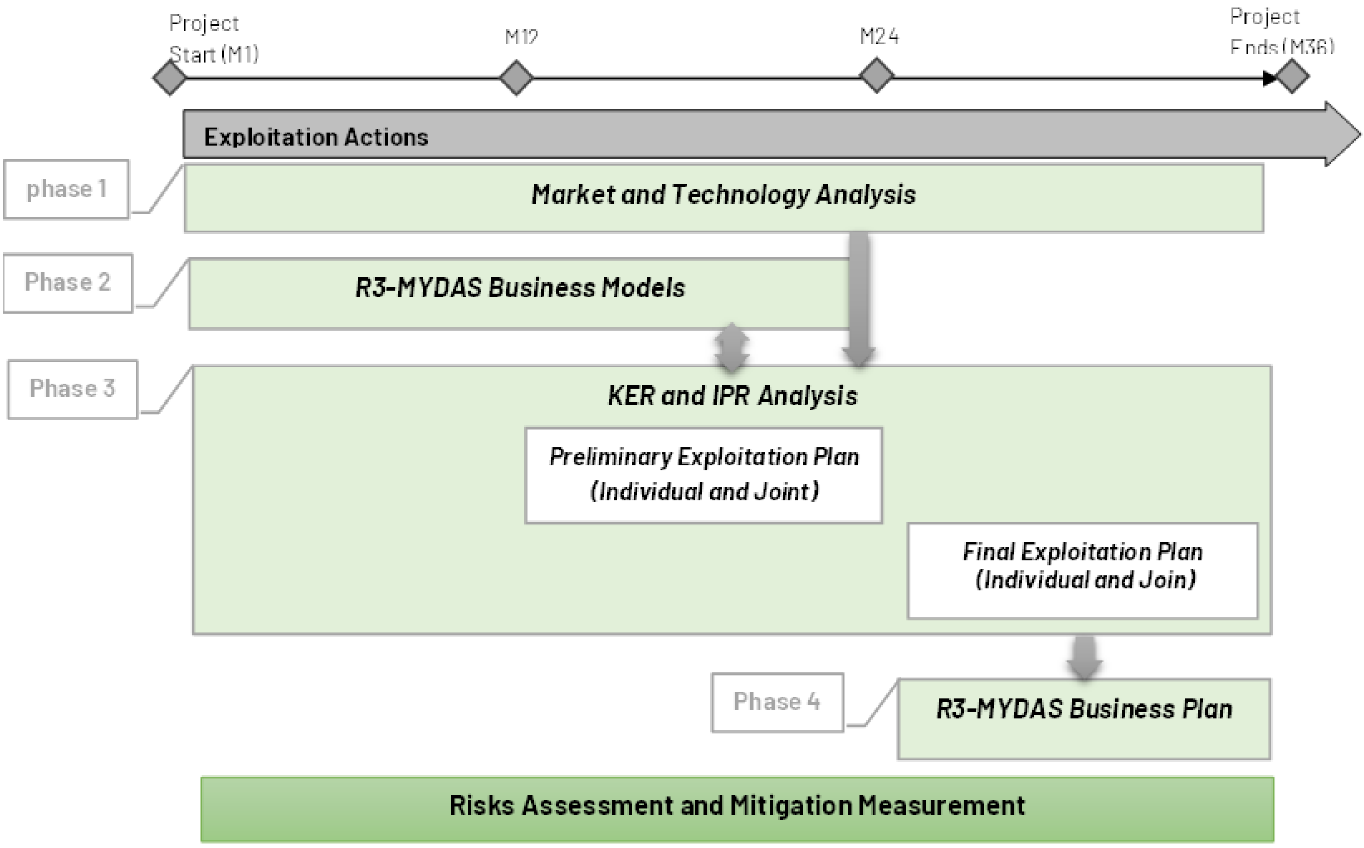

Figure 1: R3-MYDAS exploitation strategy, methodological approach and roadmap.

Phase 1: conducting a comprehensive market and technology analysis

Objectives: The primary objective of this phase is to perform an in-depth market and technology analysis for the project's demo cases. This analysis will establish a foundation for understanding the technological landscape and market potential, aligning with the project's goals.

Activities and connections to other phases: This phase includes a detailed assessment of the current technologies used within the demo cases and their market relevance. Key activities are:

- **Market and technology trends**: Leveraging information from the project Grant Agreement, the analysis examines trends in the energy goods value chain. This includes geographical positioning of each pilot, market sizes, target customers, and state-of-the-art technological advancements.
- **Survey analysis**: Conducting surveys to clarify partner intentions and goals for implementing the technologies developed within the project (questions are reported in Appendix A). Part of the results of such analysis are reported in Section 3.2.6.
- **Strategic tools**: Utilizing methodologies such as SWOT and PESTEL analyses to assess the market positioning of the project's outcomes and solutions.

This phase starts from the beginning of the project and continue throughout the whole project in parallel with other phases and in synergy with activities in WP7. The results of this phase serve as inputs for investigating on the business modelling of three demo cases and the marketplace as well as individual and joint exploitation plans.

Timeline: this phase spans the entire project lifecycle, from M1 to M36, to continuously track market and technological developments.

Template: a SWOT analysis tool will be used to identify the critical factors influencing the exploitation plans for the demo cases. This tool ensures a structured and thorough evaluation of market opportunities and challenges.

Table 2: SWOT analysis.

Strengths	**Weaknesses**
•	•
Opportunities	**Treats**
•	•

<u>Phase 2: R3-MYDAS Business Modelling of three demo cases and the marketplace</u>

Objectives: This phase focuses on designing and delivering innovative business models to facilitate the commercialization of the demo case results for consortium partners.

Activities: The business modelling process builds on the analyses conducted in Phase 1 and outlines pathways for leveraging the technologies developed in the project. The activities include:

1. **Scenario development**: Identifying and defining the most promising and adaptable business scenarios for each demo case. This includes specifying aspects like target markets, stakeholders' relations, value propositions, revenue streams, cost structures, and other critical elements.
2. **Circular Business Models**: Developing models that clarify "how" and "why" consortium partners will exploit the outcomes of the demo cases. These models also address how the marketplace will ensure sustainable market growth by facilitating access to remanufactured components and services for identified potential customers.
3. **Inputs from Partners**:
    - Business model analysis by LUT, which explores innovations and novel applications for use cases through both academic and practical studies. This includes ongoing research and fieldwork supported by semi-structured interviews (Section 3.2).
    - Survey distribution (from phase 1) to clarify partner goals and aspirations for promoting new business models.
    - Insights from workshops and semi-structured interviews to define business model criteria for the demo cases and the marketplace (Chapter 4). Details of these surveys and interviews are included in Appendix B.
4. **Workshop Engagement**: Organizing workshops to present and refine business model concepts with consortium partners.
5. **Model Validation**: Developing joint exploitation plans and soliciting partner feedback for validation.

Timeline: Activities in this phase initiated at the start of the project and will continue through M24. The preliminary outcomes are included in this deliverable (D8.1) and updated in D8.3 by M24 to support the development of detailed exploitation plans.

Tools and templates:

- Circular Business Model Canvas (CBMC): This framework has been chosen to design business models aligned with circular economy principles, focusing on reducing material and energy needs in the remanufacturing of crankshafts, EV batteries, and wind turbines.

Phase 3: KERs and IPR analysis for the exploitation plan

Objectives: The primary aim of this phase is to develop strategies and plans for exploiting the project's Key Exploitable Results (KERs) through both individual and joint efforts. Additionally, it seeks to establish an Intellectual Property Rights (IPR) strategy to protect the knowledge generated during the project (foreground) and also background, aligning with the interests of partners and the provisions of the Consortium Agreement (CA).

Activities: This phase involves active collaboration among all consortium partners, who will contribute information on how they intend to exploit project results both individually and collaboratively. The activities include:

1. **Information Gathering**: Partners will provide detailed inputs regarding their plans for exploitation, covering:
    - Names and descriptions of specific results.
    - Type of results and their Technology Readiness Level (TRL) at various project stages.
    - Proposed IPR strategies to safeguard these results.
    - Detailed exploitation plans outlining individual and joint approaches.
2. **Interviews and workshops**: Organized sessions with demo case groups and individual partners to identify and refine exploitation strategies aimed at maximizing the uptake of project results.
3. **Exploitation plan database**: A centralized repository will be created to store exploitation-related information. This database will be updated throughout the project, ensuring it reflects evolving strategies and partner intentions.
4. **Connection with phase 2**: Insights from business modelling activities in Phase 2 will inform the exploitation strategies. Conversely, the finalized exploitation plans will feed into and validate the final business models developed for the project.

Timeline: This phase begins at project inception (M1) and continues until its conclusion (M36). Two key reports will document the progress of exploitation plans:

1. A mid-term report to capture interim strategies and align with project milestones.
2. A final report to detail comprehensive exploitation strategies and outcomes.

Tools and templates:

- A dedicated database will be provided to partners to collect, track, and manage exploitation data for each KER.
- Guidance from the EITM team will support partners in completing the database with relevant IPR assessments and exploitation strategies

Table 3: R3-MYDAS Exploitation Plan data base.

Name of the KER	Description of the KER	Type of the result	TRL M18 and M36 (1-9)	Individual or joint? Which partner?	IPR assessment	Exploitation Strategies	Associated risks to exploitation strategies
KER1							
KER2							
...							

Outcomes of this phase: preliminary exploration plan (D8.3) will be introduced at M24, focusing on Key Exploitable Results (KERs) and IPR assessments aligned with project phases 1, 2, and 3. By M36, a final exploitation strategy (D8.6), including the R3-MYDAS business plan, will be delivered to ensure the long-term impact and market adoption of project outcomes beyond its conclusion.

Phase 4: R3-MYDAS Business Plan

Objectives: The primary goal of this phase is to create and deliver comprehensive business plans to the consortium, ensuring all project outcomes are ready for commercialization and long-term impact.

Activities: In this phase, the following activities are planned:

1. **Business plan development**: Analyse data from individual and joint valorisation plans to define key components such as marketing strategies, sales approaches, target groups, financial plans, and a portfolio of products and services.
2. **Structured dialogues**: Facilitate discussions with consortium members to establish agreements on ownership of demo case results and operational roles for running the marketplace. This includes defining the revenue structure and financial mechanisms to ensure economic benefits for all developers.
3. **Validation and refinement**: Develop initial versions of the business plan and seek partner review and feedback to refine the final document.
4. **Stakeholder engagement:** Organize a workshop to present and promote the business plans to consortium members and external stakeholders, fostering broader collaboration and awareness.
5. **Integration with Phase 3**: Leverage results and insights from Phase 3 to shape final business plans.

Timeline: This phase begins at M24 and continues through the end of the project, ensuring adequate time for development, review, and finalization of the business plans.

Tools and templates: The business plan template will serve as the primary tool for structuring this activity.

Complementary phase: Risk Assessment and Mitigation Actions

Objectives: This phase aims to identify and mitigate risks that could affect the development, implementation, and deployment of the demo cases, marketplace business models, and exploitation plans.

Activities:

1. **Risk identification**: Analyse internal and external factors that may hinder project outcomes, such as emerging competitors, new technologies, regulatory changes, or economic crises.
2. **Exploitation risk assessment**: Evaluate risks and barriers identified in Phase 3 (e.g., KER exploitation strategies) to ensure a proactive approach to challenges.
3. **Mitigation strategies**: Using PESTEL analysis to continuously identify potential threats and establish mitigation measures to address them effectively.

Timeline: This phase runs from the initiation of WP8 tasks and continues through the end of the project, ensuring risks are monitored and addressed throughout the lifecycle.

Tools and templates: PESTEL analysis will guide the identification of threats and support the development of mitigation strategies tailored to both internal and external challenges.

Table 4: PESTEL analysis.

Dimensions	**Actions**
Political	Requirement.... Barriers: .... Measurements:
Economical	Requirement.... Barriers: .... Measurements:
Social	Requirement.... Barriers: .... Measurements:
Technical	Requirement.... Barriers: .... Measurements:
Environmental	Requirement.... Barriers: .... Measurements:
Legal	Requirement.... Barriers: .... Measurements:

3 Technology, Market and Business Models Analysis

This chapter evaluates the current market dynamics and technological advancements that shape the remanufacturing sector in Europe. It emphasizes the specific technologies proposed by the R3-MYDAS project and highlights the growing importance of remanufacturing in industries such as automotive, oil and gas, and renewable energy. This analysis serves as the foundation for the business models designed for the R3-MYDAS demonstration cases.

3.1 Market analysis and technology trends

Manufacturing remains a cornerstone of the European Union's economy, contributing approximately 17% of the region's GDP and supporting millions of jobs. In response to global environmental challenges, the EU has prioritized sustainability through initiatives such as the **European Green Deal**, which aims for climate neutrality by 2050[2].

Despite these commitments, the EU manufacturing sector faces persistent challenges, including resource inefficiency, high energy consumption, and reliance on finite resources. These issues are particularly evident in the **energy goods sector**, where critical materials like lithium, cobalt, and rare earth elements are essential for producing batteries and renewable energy technologies. The extraction of these materials poses environmental and geopolitical risks, especially as much of the supply comes from outside the EU. Additionally, rising labour and material costs, coupled with the need for technological modernization (e.g., transitioning to Industry 4.0), strain the competitiveness of EU manufacturers.

Traditional linear manufacturing models—focused on producing, consuming, and disposing—exacerbate these challenges by generating excessive waste and depleting resources. This has created an urgent need for **sustainable manufacturing solutions** that align with the principles of a circular economy, which prioritize re-use, repair, and recycling.

The role of remanufacturing:

Remanufacturing is a process that returns used products to "like-new" condition, often with performance improvements. Key technological trends include automation of remanufacturing processes, enhanced product lifecycle management, and integration of AI for quality control. For example, the remanufacturing of Electric and Electronic Equipment (EEE) has benefited from automation in steps such as cleaning, disassembly, and reassembly, leading to increased efficiency. In addition, Design for Remanufacture

[2] European Green Deal - https://ec.europa.eu/green-deal

(DfRem) embedding remanufacturing principles into initial product designs, characterized by industry leaders like Caterpillar and Xerox. This practice can extend the lifecycle of high-value energy products[3]. Therefore, by embracing remanufacturing, the EU can reduce its dependence on raw materials, lower production costs, and drive its transition to a more sustainable, circular economy and guarantee economic, environmental and social benefits to its European citizens[4].

3.1.1 Demo Case 1: Oil & Gas sector crankshafts

3.1.1.1 Market overview and requirements

The demand for crankshafts in the Oil & Gas industry is closely linked to the global Oil & Gas exploration and production activities, which is the biggest industry in the world. In terms of the Oil & Gas industry specifically, this market is expected to grow, mainly due to the increasing demand for energy, along with the increasing exploration and production activities in the offshore and onshore areas[5]. The Oil & Gas industry is heavily reliant on high-performance machinery, and crankshafts are critical components that endure significant tension.

The market for crankshaft remanufacturing is driven by the need to extend the operational life of equipment while minimizing downtime and reducing costs. In the EU, remanufacturing of such high-value components aligns with the broader goals of reducing material waste and lowering carbon emissions in industrial processes. In 2022, the global remanufacturing market was valued at around €45 billion, with a significant portion stemming from the remanufacturing of large industrial components like crankshafts. In the EU alone, the automotive and oil & gas remanufacturing sectors generate approximately €8-10 billion annually.[6]

For the oil and gas sector, key market requirements for crankshaft remanufacturing include the ability to reduce equipment downtime, improve durability, and ensure the reliability of remanufactured components. Additionally, companies are increasingly seeking solutions that integrate advanced digital and automated technologies to streamline maintenance operations and reduce the cost of ownership.

3.1.1.2 Laser cladding technology and trends overview

The key technology used in this demo is laser cladding, a cutting-edge process that restore worn or damaged components by applying a fresh layer of material. This technique is particularly valuable for crankshafts, which are vital engine parts, especially in demanding industries like Oil & Gas. Crankshafts endure intense stress during operation, leading to significant wear and damage over time. While traditional repair methods like thermal spraying and arc welding have been used in the past, they often

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[3] European Remanufacturing Network Reports https://www.remanufacturing.eu/reports
[4] Ellen MacArthur Foundation Remanufacturing - https://ellenmacarthurfoundation.org
[5] Remanufacturing Market Study
[6] https://www.marketresearchfuture.com/reports/crankshaft-oil-market-26355

cause issues like high thermal stress, which can weaken the surface and reduce durability.

The challenges with traditional repair methods

Historically, the remanufacturing of crankshaft surfaces has relied on processes like gas tungsten arc welding (GTAW) and submerged arc welding (SAW). In these methods, a new layer is applied by melting and bonding the surface material with additional cladding, often in wire or powder form. These techniques, however, produce high thermal stress, which can lead to issues like cracking and porosity in the repaired surface. For instance, GTAW involves high temperatures that can weaken the repaired areas due to inconsistent cooling, leading to reduced mechanical quality and a need for extensive post-processing. In addition, plating processes, another traditional method for crankshaft restoration, have become less favourable due to environmental concerns. The high energy and material requirements, combined with chemical waste, have made these older methods increasingly unsustainable. This shift has led industries to seek alternatives that offer both quality and environmental benefits [REF-18].

Laser-cladding as a modern solution

Laser cladding has emerged as an advanced alternative to conventional methods, addressing the limitations of thermal spraying and arc welding with a more controlled, precise approach. This technique uses a high-power laser to fuse new material onto the crankshaft surface, creating a strong bond without excessive heat. Unlike traditional welding, laser cladding produces a smaller heat-affected zone, which reduces the likelihood of stress-induced defects like cracks and porosity. This precision results in a more durable surface, minimizing the need for additional post-processing, which saves both time and cost.[7]

Moreover, laser cladding produces a uniform, fine-grain structure in the deposited material. This microstructure improves the surface's wear resistance and overall durability, making it ideal for high-stress components such as crankshafts. Laser cladding's compatibility with various metallic powders also allows manufacturers to customize coatings based on specific performance needs, whether for corrosion resistance, impact tolerance, or structural strength[8] [9].

R3-MYDAS advancements in laser-cladding technologies

The R3-MYDAS project introduces notable advancements laser cladding technology, revolutionizing crankshaft remanufacturing. By integrating digital tools like 3D scanning, robotic automation, and process planning software, the project automates and optimizes repairs with remarkable precision. For example, AIMEN, using ZIKNES's Z-

[7] https://www.coherentmarketinsights.com/market-insight/europe-automotive-parts-remanufacturing-market-3311/market-size-and-trends
[8] Laser Cladding - an overview | ScienceDirect Topics
[9] https://clepa.eu/mediaroom/european-remanufacturing-study-market/

Core Robot software, creates detailed repair paths based on 3D scans, reducing programming time and ensuring faster, more accurate results.

Reverse engineering further customizes repairs by matching cladding layers to the exact contours of damaged crankshafts, restoring them to like-new performance with improved durability. Real-time quality control ensures repairs meet strict industry standards.

Overall, R3-MYDAS showcases how laser cladding can deliver efficient, cost-effective, and environmentally sustainable solutions, setting a new benchmark for advanced remanufacturing. SWOT analysis

Table 5: SWOT analysis of Demo case 1 - Crankshaft remanufacturing.

Strengths	**Weaknesses**
• Delivers high-precision repairs for worn crankshafts, ensuring top-quality results. • Saves significant time and money with the automated laser cladding process. • Reduces material waste and extends the lifespan of critical components, aligning with sustainability goals.	• Requires a high initial investment in advanced digital and automation technologies. • Demands skilled personnel to operate and maintain the complex systems effectively. • The technical complexity increases the risk of system failures if rapid troubleshooting is not seamlessly managed.
Opportunities	**Threats**
• Growing demand in the oil and gas industry for remanufactured components creates a reliable market. • Potentials to expand applications to other industries requiring high-performance machinery. • Global emphasis on sustainability and stricter environmental regulations will favour remanufacturing solutions. • Strategic partnerships along the value chain can drive innovation and meet evolving market needs.	• Variability in oil and gas market demand could reduce the need for remanufactured parts. • Rapid advancements in technology might make current solutions obsolete. • Intense competition in laser-cladding and automation technology could challenge market positioning.

According to the results of the first survey (Appendix A) which aims to assess the project main contributions in developing a circular value chain on three demo cases (oil and gas crankshafts, EV batteries and wind turbine gearboxes), the success rate of remanufacturing process in this demo case from partners point of view reported in figure below. Using a Likert scale question (from 1 to 5), it shows that the success rate of remanufacturing processes in this demo case will be medium to high.

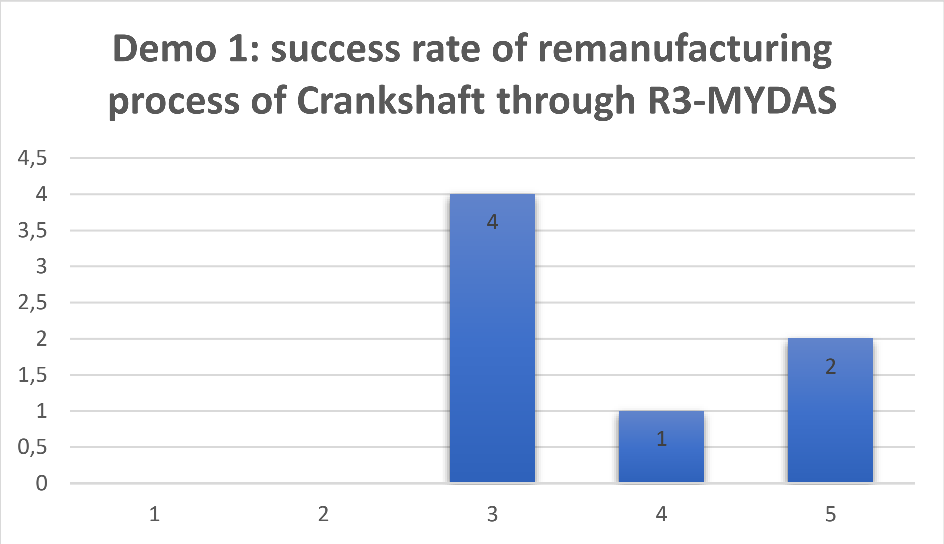

Figure 2: Success rate of crankshaft remanufacturing (survey result).

3.1.2 Demo Case 2: Batteries in electric automative sector

3.1.2.1 Market overview and requirements

The EV market in Europe is experiencing rapid growth, driven by the transition to sustainable energy and decarbonization goals. In Austria, EV sales are projected to reach €3.4 billion in revenue by 2024, with a forecasted Compound Annual Growth Rate (CAGR) of 14.25% until 2028, pushing market volume to nearly €5.8 billion by 2028. Similarly, the Netherlands' EV market is expected to generate € 8 billion in 2024, growing at a CAGR of 13.13%, with an anticipated market size of €13 billion by 2028. As Europe's EV fleet expands, so does the volume of End-of-Life (EoL) batteries, creating environmental challenges due to the complex disposal of used lithium-ion batteries, which contain valuable but limited resources like lithium, cobalt, and nickel[10].

As this market in Europe has witnessed a 40% increase in sales in 2023, it puts more pressure on the supply chain to manage EoL batteries effectively. The ability to remanufacture batteries efficiently and cost-effectively is essential for meeting the market's needs, particularly as Original Equipment Manufacturers (OEMs) and Tier-1 suppliers look to reduce their environmental impact and comply with EU regulations on battery recycling. The EU EoL EV batteries market requires solutions that enhance the

[10] https://www.remanufacturing.eu/

visibility of battery health during remanufacturing, thus reducing failure rates and improving the overall lifecycle of EV components[11].

For remanufactured batteries, the energy requirement is reduced by 224 MJ/kWh, and CO_2 emissions are lowered by 15.6 kg CO_2 equivalent per kWh compared to new battery production. This results in approximately a 20% reduction in both energy consumption and greenhouse gas emissions, based on standard manufacturing values of 1126 MJ/kWh and 72.9 kg CO_2 equivalent per kWh. The remanufacturing of EV batteries not only addresses environmental concerns but also offers significant cost savings, with remanufactured batteries often costing 30-50% less than new ones [REF-07] which make remanufacturing of batteries even more economically favourable. According to a study, factoring in costs and potential resale prices, remanufacturers could see a net benefit of around €60 per kWh [REF-09]. Beside all these benefits and interests, there are still some technicality issues in remanufacturing processes and steps which require higher attentional and investments in the EU to reach to the other advanced countries like the United States and China that are pioneer in battery fields.

3.1.2.2 Battery disassembly & reassembly technologies and trends overview

Conventional EV battery disassembly has been performed manually, where operators remove cells, wiring, and other components. Manual disassembly provides flexibility in handling various battery designs but is highly labour-intensive, inconsistent, and costly. The diversity of EV battery designs across manufacturers makes the process even more complex, requiring technicians to adapt to varying component configurations, connector types, and assembly structures. Manual anomaly detection methods, which use rule-based systems to identify issues, can overlook subtler signs of cell degradation or other faults. This increases the risk of potential failures in remanufactured batteries and impacts the efficiency of the overall process.

Technical advancements for managing EoL EV batteries

To tackle these challenges, advancements in robotics and Machine Learning (ML) have transformed battery disassembly and fault detection. Semi-autonomous robots with machine vision now adapt to variations in battery structures, ensuring safer and more efficient disassembly. Collaborative robots, or cobots, work alongside technicians to precisely remove components like wiring and connectors, reducing the risk of damaging delicate battery cells.

ML-driven anomaly detection has revolutionized diagnostics by analysing vast datasets of battery performance indicators such as voltage and temperature. These models identify early signs of cell degradation or faults that traditional methods might overlook.

[11] https://www.coherentmarketinsights.com/market-insight/europe-automotive-parts-remanufacturing-market-3311/market-size-and-trends

Advanced tools like Graph Deviation Networks (GDNs) treat each battery cell as a network node, enabling sophisticated analyses to detect anomalies based on inter-cell relationships. This approach uncovers subtle patterns that signal potential issues before they escalate, enhancing overall efficiency and reliability.

R3-MYDAS novelties in technical solutions

The R3-MYDAS project advances these capabilities by introducing a collaborative screwdriver (SD35) designed to automate key disassembly tasks, especially in managing pressure-sensitive battery parts. The SD35 minimizes risks of damage, ensuring safe handling of delicate components during both disassembly and reassembly phases.

Additionally, R3-MYDAS incorporates an innovative GDN-based anomaly detection system, which establishes a network representation of the battery pack and its individual cells. The system continuously monitors each cell and detects deviations from normal behaviour, ensuring that only high-quality cells are retained during the reassembly phase by optimizing the Battery Management System (BMS) and cooling. This precision increases battery reliability and extends its useful life in subsequent applications. Furthermore, the project's Data Fusion Bus (DFB) centralizes battery data, allowing technicians to aggregate and analyse performance indicators across various stages of the remanufacturing process, from disassembly to reassembly.

3.1.2.3 SWOT analysis

Table 6: SWOT analysis of demo case 2 - EV battery remanufacturing.

Strengths	**Weaknesses**
• Reduced energy consumption and emissions by reusing battery materials, supporting EU sustainability goals. • Advanced robotics and anomaly detection enhance safety, reliability, and process consistency. • Extends battery life, lowering costs for consumers and enhancing EV affordability.	• High initial costs of implementing advanced automation and ML systems. • Variability in battery designs across brands complicates standardization efforts. • Limited expertise in integrating new robotic systems into existing processes.
Opportunities	**Threats**
• Expanding EV adoption creates long-term growth opportunities for remanufacturing in the circular economy. • Potential for applying remanufactured batteries in other industries, such as energy storage solutions.	• Rapid advancements in battery chemistries may necessitate continuous technological updates. • Changing regulations and trade policies could impact battery disposal and remanufacturing practices.

• Enhanced regulatory support for sustainable practices and lifecycle management of EV batteries. • Standardized processes developed through R3-MYDAS can simplify remanufacturing and reduce costs. • Strategic partnerships with industry leaders can facilitate easier adoption of new technologies and processes.	• Competing recycling methods could reduce the appeal of remanufacturing. • Material shortages and logistical challenges may arise from geopolitical tensions and market fluctuations.

To complement the SWOT analysis, the results of survey (Appendix A) shows that partners consider a high success rate for the technology development to facilitate the remanufacturing of EV batteries in this demo case as shown in the figure below.

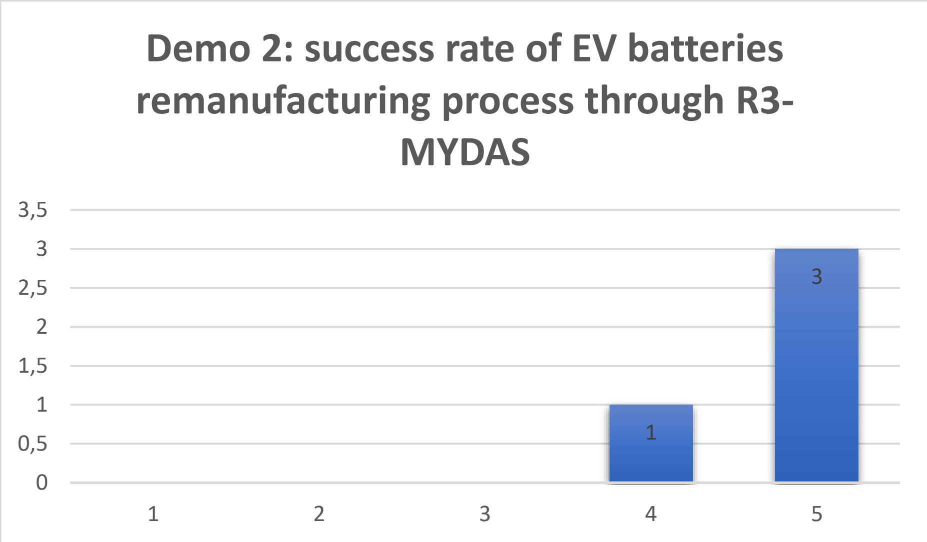

Figure 3: Success rate of EV batteries remanufacturing (survey result).

3.1.3 Demo Case 3: Gearboxes in wind turbine sectors

3.1.3.1 Market overview and requirements

The market for wind turbine gearboxes is growing rapidly as wind power continues to expand across Europe, especially in Germany, Spain, and Finland. In 2022, the global wind turbine gearbox market was valued at €18.92 billion, and foresee to reach €28.74 billion by 2028, growing at a CAGR of 7.4%s wind sector, with nearly 29,000 onshore turbines and a combined offshore and onshore capacity of over 69,000 MW[12], remains one of the Europe's largest, making gearbox remanufacturing a high-priority segment due to the high maintenance costs associated with these components[13] [14]. In Spain, wind

[12] Wind Turbine Gearbox Market | Size, Growth | 2024 to 2032
[13] Statistics Germany | BWE e.V.
[14] Finland_2022-1.pdf

power also plays a major role, with installed capacities of 22,000 and 5,678 MW, respectively. Spain's National Energy and Climate Plan aims to increase wind capacity to over 50 GW by 2030, signalling substance for sustainable maintenance solutions[15].

Given the operational needs of wind turbines, gearboxes are one of the most maintenance intensive components due to their exposure to fluctuating loads and environmental stresses. Repair and replacement costs can be substantial, with onshore gearbox repairs estimated between €150,000–€250,000 and offshore replacements costing as much as €500,000 due to logistical complexities. The high failure rate of wind turbine gearboxes, compounded by expensive downtime, emphasizes the importance of remanufacturing as a cost-effective alternative to traditional replacements. Regarding the expected European market for wind turbine gearboxes, more operators seek remanufactured components that are cheaper and have a smaller environmental footprint compared to new one.

3.1.3.2 Additive-Manufacturing technology and trends overview

Current technologies and limitations

Conventional methods for remanufacturing wind turbine gearboxes have primarily focused on the regrinding of worn surfaces and replacing damaged parts with standard components. These techniques, while widely used, have limitations: they often fail to address underlying weaknesses that caused the initial failure, leading to recurring maintenance needs. Additionally, conventional surface hardening processes, like carburizing, are time-consuming and can result in inconsistent hardness across gear surfaces, leaving gearboxes prone to premature wear under high load conditions.

Bearings within gearboxes are also a frequent complex load patterns and exposure to harsh environments. Traditional practices often replace functional bearings as a precaution, contributing to increased operational costs. Furthermore, the absence of standardized remanufacturing protocols for wind turbine components results in varied quality and durability across remanufactured parts, impacting overall turbine performance and reliability[16].

R3-MYDAS technology advancements

R3-MYDAS leverages advanced remanufacturing techniques like AM and targeted induction hardening. Induction hardening enhances wear resistance with localized heat treatment, avoiding damage to surrounding areas, while AM reduces material waste by up to 30% and extends component lifespans by 20%.

The project advances AM through laser-based additive repairs that restore or improve damaged gears, introducing updated materials and coatings to address issues like Tooth Flank Fracture (TFF) and interior fatigue. Additionally, a TFF engineering tool identifies gear surface weaknesses and proposes tailored mitigation strategies, while journal

[15] Spain | IEA Wind TCP
[16] Wind gearbox repair analysis | Engineer Live

bearings with wear-resistant materials improve durability in wind turbine gearboxes. These innovations enhance reliability and longevity, addressing critical challenges in the renewable energy sector.

3.1.3.3 SWOT analysis

Table 7: SWOT analysis of demo case 3 - Wind turbine gearboxes remanufacturing.

Strengths	Weaknesses
• Enhanced gearbox durability with advanced hardening and coating processes, reducing maintenance costs. • Remanufactured components offer cost savings compared to full replacements, supporting wind industry sustainability goals. • Increased turbine uptime due to lower failure rates, leading to more stable energy production.	• Initial costs of implementing advanced technologies like additive manufacturing and induction hardening. • Variability in gear design and materials complicates standardization of remanufacturing processes. • Limited industry experience with certain advanced technologies (e.g., AM for high-stress components).
Opportunities	**Threats**
• Growing wind energy sector in Europe provides long-term demand for remanufactured gearboxes. • Potential to expand remanufacturing to other turbine components, creating a comprehensive circular economy model for wind energy. • Improved regulatory support for sustainable practices in the energy sector and subsidies for remanufacturing.	• Rapid evolution in turbine design may require frequent technology upgrades in remanufacturing. • Fluctuating regulations and standards for component reuse and remanufacturing in the wind industry. • Competition from newer, more efficient wind turbines that may reduce demand for component remanufacturing in aging turbines.

To complement the SWOT analysis, the results of survey (Appendix A) shows that partners consider a medium to high success rate for the technology development in this demo case as shown in the figure below.

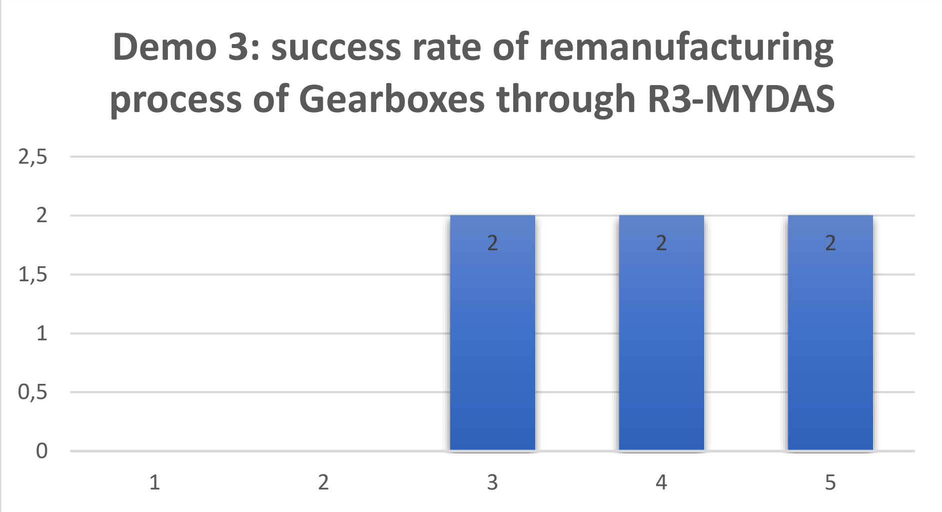

Figure 4: Success rate of gearboxes manufacturing (survey result).

3.1.4 The marketplace for remanufacturing services and components

Digital platforms are increasingly recognized as enablers of circular economy practices by facilitating the exchange, repair, and remanufacturing of products and components. Circular marketplaces are recognized as online platforms, like traditional Product-as-a-Service (PaaS) marketplaces focusing on the usage-based services, connecting different stakeholders along a product's lifecycle with each other to exchange goods and services, to increase resource utilisation and exchange on a large scale[17]. These marketplaces not only serve as second-hand markets, offering remanufactured or upgraded industrial goods, but also help extend product lifetimes and reduce reliance on raw materials, addressing a critical need for sustainability [REF-03].

The EU remanufacturing covers high value-added sectors such as automotive, aerospace, industrial machinery, and electronics. This deemed to even a higher overall market needs of the remanufacturing platforms. Each of these industries depends on remanufacturing to reduce production costs and/or adhere to strict environmental regulations while meeting the growing demands by consumers for greener products. Within the automotive sector, there is extensive demand for both remanufactured engines and transmissions, while in the aerospace industry, remanufacturing is focused on high-value components requiring traceability at an advanced level. In the electronics sector, the challenge of e-waste has been increasing, hence allowing digital platforms to provide the possibility for refurbishment and resale options for electronic components [REF-08].

[17] How circular marketplaces transform material usage | Impact Hub Berlin

A key driver for the digital platforms in general in the EU is certainly the regulatory framework introduced by the European Green Deal[18] and by the Circular Economy Action Plan[19]. The Digital Product Passport (DPP), introduced under the Eco-design for Sustainable Products Regulation (ESPR)[20], has further forced the adoption of digital solutions by directing detailed lifecycle data for products, making these platforms indispensable for manufacturers aiming to comply with such regulations.

The EU has been actively promoting the remanufacturing of industrial components through various projects and initiatives, intending to foster a circular economy and enhance sustainability in the manufacturing sector. Several EU-funded projects have been developed or are in the process of developing marketplaces and platforms to facilitate the buying and selling of remanufactured products and services. Among them, the **European Remanufacturing Network** (ERN)[21], funded under the Horizon 2020 program, was established to support remanufacturing activities across Europe. ERN provides resources such as directories, e-learning modules, and case studies to the businesses to facilitate the remanufacturing practices' adoption. Indeed, this is not the only feature, ERN have been considering like a hub for networking and sharing knowledge in promoting the remanufacturing operations and encourage new businesses to foster remanufacturing in the European market. Projects and initiatives, such as DigiPrime, CREDIT, and RESTORE funded by the EU, ensure that the growing concentration is on digital innovation in the remanufacturing value chain. DigiPrime works on a platform that can allow cross-industry business models of remanufacturing, considering data-sharing-related problems among stakeholders. CREDIT uses AI in enhancing remanufacturing processes across industries like automotive and aerospace, while RESTORE works on the digitalization of the ecosystem enabled by advanced manufacturing technologies.

Despite this growth, there are several important challenges that must be overcome for the digital platform market in remanufacturing area. Key barriers include:

- There is **limited standardization across different industries**, and thus the exchange of data between platforms or the interoperability of platforms is hard to realize;
- The **high cost of implementation** makes SMEs, although the dominant portion of manufacturing enterprises within the EU, they are still reluctant to adopt advanced platforms;

[18] European Green Deal - European Commission. https://ec.europa.eu/green-deal
[19] Circular Economy Action Plan - European Commission. https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
[20] Eco-design for Sustainable Products Regulation (ESPR) - European Commission. https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/ecodesign-sustainable-products-regulation_en
[21] https://www.remanufacturing.eu/

- **Complex regulatory frameworks** dealing with areas such as data security and privacy are especially a challenge for both developers and users of such platforms.

However, the market offers also substantial opportunities, by **integration of blockchain** in digital platforms and marketplaces. This will lead to solve the traceability issues by providing secure, **immutable records of product lifecycles** and thereby build trust in remanufactured products. Predictive analytics powered by AI can further optimize remanufacturing operations to reduce downtime and enhance efficiency. Digital platforms, which can provide detailed insights into the origin of the products, their environmental impact, and the quality of remanufacturing secured by certifications, will foster consumer trust and loyalty and create a competitive advantage for businesses [REF-02].

The R3-MYDAS marketplace aims to foster the European industrial equipment sector by providing a marketplace for stakeholders to buy and sell remanufactured products and services. In fact, the R3-MYDAS marketplace fosters CE by integrating **reverse logistics** and **digitalization** which are the two main features in the CBMs context [REF-16]. By integrating blockchain technology for traceability and aligning with the European Parliament's DPP recommendations, R3-MYDAS seeks to enhance transparency and consumer empowerment. By providing detailed product information through DPPs and blockchain integration, consumers can make informed purchasing decisions. This transparency fosters trust and encourages the adoption of remanufactured products and services developed through the R3-MYDAS demo cases.

According to the survey analysis (see Appendix A), partners consider a very high success rate for the marketplace services and showcasing of remanufacture components as reported below.

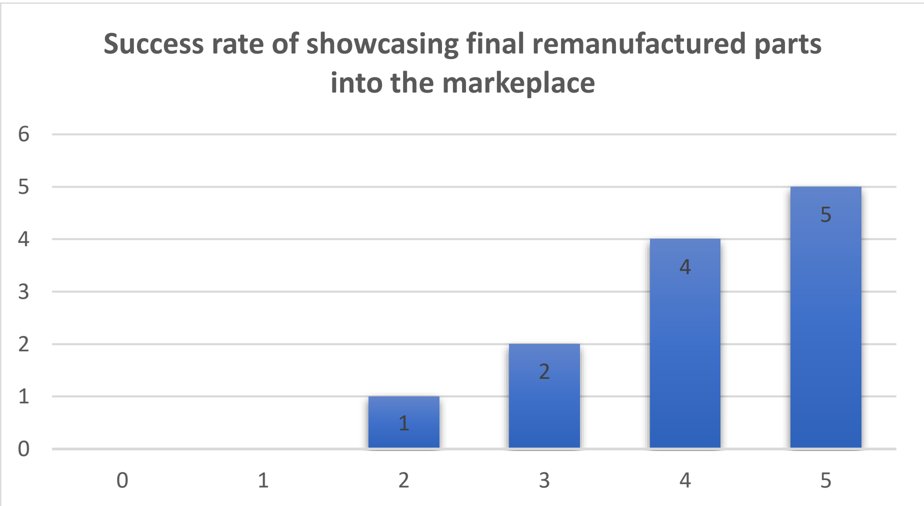

Figure 5: Success rate for the marketplace showcasing the components (survey result).

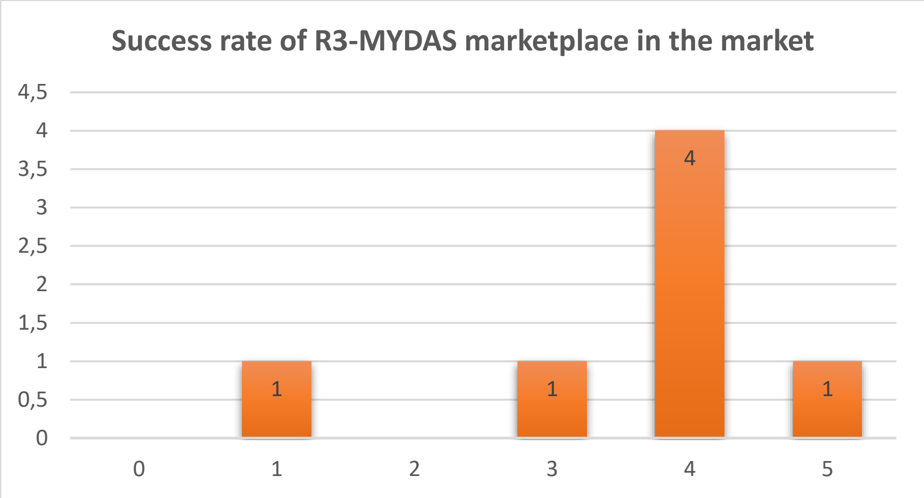

Figure 6: Success rate of R3-MYDAS marketplace in the market (survey result).

The figure above shows a good perception regarding the success rate of marketplace among the existing one in the market offering remanufacturing services. Even though, for some partner the functionality is a concern, in which by progress of the project this will become clear.

3.2 Circular economy business models for remanufacturing of energy goods

3.2.1 Introduction on the adopted approach

To complement the analysis of EITM in the business model analysis, LUT aims to conduct qualitative research stemming from key academic theories. For this research, a multiple case study design by Eisenhardt and Graebner in 2007 has been utilized to investigate business model innovation for the demo case leaders and their complementors, as well as the platform developer (NCI) for the context of remanufacturing of energy goods. Since there is a growing need for knowledge about the phenomenon, an inductive approach shall be taken to develop theoretical insights from empirical observations.

The data collection comprises of two main types of research: desk and field research. For desk research, a literature review has been performed to identify the key concepts related to the research context. Specific keywords were used to academic databases such as Scopus and Google Scholar. There is typically a lack of academic research on business model design and innovation in the research context, and instead. The conceptual background consists of literature on business models, business model innovation and business model design. The basics of business models, how companies can create, deliver and capture value, and furthermore on the contexts of sustainability, technological innovation and circularity shall be considered. Furthermore, the interview guide has been developed considering the business model as an activity system, where firms leverage interdependent activities to create value. This "design" as an activity system emphasises the interconnectedness of various components including resources, activities, and partnerships, enabling firms to innovate and adapt in changing markets.

For the field research, data will be collected through in-depth semi-structured interviews as the main source of data collection from the related partners. Field research is essential as state-of-the-art information is available within the companies, and an investigation of the phenomena through direct interviews with the participants. Beside the interviews conducted by EITM for developing the R3-MYDAS business models, LUT will set an interview with semi-structured and open-ended questions to additionally obtain data and information from the participants. Its aim is to reinforce the academic investigations with an applied-science approach for innovative business models in industrial remanufacturing. Given that, for this report a literature review focusing on the different business models are summarized across the following sub-sections.

3.2.2 Foundational theories in business models and business model innovation

In a study by [REF-19], it is emphasized that business models are configurations of activities that connect a firm's internal resources with external opportunities. By focusing on **value creation** and **delivery**, their activity-system perspective provides a basis for understanding how companies could structure their offerings to retain and reintroduce value to the market. This is further elaborated by [REF-17], who argues that business models should enable companies to innovatively response to the technology upgrades and market conditions. Remanufacturing requires adapting innovative and sustainable oriented business models to incorporate **product life extension** as a core strategy. [REF-05] were among the early proponents of business model innovation (BMI) for value capture, defining BMI as a pathway for companies to create new sources of revenue by adjusting their value propositions, revenue structures, and delivery mechanisms. This has specific relevance to remanufacturing, where new models are often needed to accommodate take-back schemes, refurbishment processes, and alternative pricing methods, such as performance-based pricing in industrial sectors.

3.2.3 Sustainable and circular business models

Circular Business Models (CBMs) focuses on eliminating wastes and maximizing the continuous use of resources by adopting innovative technologies, organizational processes and practices. Unlike the linear models, which follow "take-make-dispose" approach that generates waste and depletes resources, CBMs aim to create sustainable systems. This shift is crucial for achieving industrial decarbonisation and addressing environmental challenges.

[REF-04] emphasizes the importance of aligning economic objectives with environmental and social goals. Their work on sustainable business models introduced archetypes for sustainable innovation, including "**closing the loop**" and "**extending product value**," which are directly applicable to remanufacturing. For example, their case study on Ricoh's GreenLine remanufacturing program shows how extending product life cycles through refurbishment could effectively address market demand for high-quality, sustainable products. This archetype aligns with the needs of remanufacturers in the EV battery and wind energy sectors, where extending product life is essential to reduce waste and resource use.

According to a similar study by [REF-12] CBMs stands apart from traditional models by emphasizing on resource circularity. Their research highlights remanufacturing as a critical aspect of CBMs, enabling the recovery of value through repeated cycles of **repair**, **refurbishment**, and **upgrading**. Successful case studies of companies like Caterpillar and Xerox illustrate how these principals can be implemented at large scale. Caterpillar, for example, applies circular practices in the heavy equipment sector, while Xerox does so in the printing industry. Both companies rely on robust take-back systems and service-based revenue models, demonstrating how circularity can be both practical and profitable.

3.2.4 Business model applications in remanufacturing

Remanufacturing plays an important role in advancing the circular economy across various industrial sectors, offering innovative business opportunities. By extending the lifespans of products and reducing the reliance on virgin materials, remanufacturing archives both economic and environmental benefits, directly contributing to the sustainability growth. The R3-MYDAS project, is an example for this potential by focusing on remanufacturing of energy-related goods, showcasing how circularity principles can be applied to complex industrial products. However, transitioning to remanufacturing-based business models presents challenges, requiring innovative solutions for creating circular values like reverse logistics, managing stakeholder's relationships, and optimizing resource use. To address these complexities and systematically analyse and refine remanufacturing strategies in the project three demo cases, **the Circular Business Model Canvas (CBMC)** has been chosen as the guiding framework that perfectly discover the sustainability and economic benefits of remanufacturing practices following the approached highlighted by [REF-08].

Concrete examples from remanufacturing literature illustrate diverse approaches to circular business models across different industrial sectors. For instance, [REF-13] delve into remanufacturing in the automotive industries, focusing on components like crankshafts, where the **cost-effectiveness** of remanufacturing depends on achieving high recovery rates and maintaining the precision during refurbishment process. A notable case study in their work is Volvo Trucks' remanufacturing program, which highlights the critical roles of **closed-loop supply chains.** These supply chains efficiently manage end-of-life components, enabling their refurbishment and reintroduction to the market at a significantly reduced cost compared to producing new parts. These examples how CBMs can deliver economic and environmental benefits in a real-world industrial context.

In the context of EV batteries, research by [REF-06] highlights that the remanufacturing process requires advanced infrastructure and technical expertise to effectively test and repurpose battery modules. The study identifies viable business models that emphasize on the potential of remanufacture batteries for other application uses. These includes **second-life applications**, such as stationary energy storage systems, and the **sale of refurbished batteries** at reduced prices to cater to budget-conscious markets. In this sector, remanufacturing is not only an environmental imperative but also a business opportunity. Since the residual value of used batteries, can generate economic benefits to companies by creating new revenue streams while addressing sustainability goals [REF-08].

For wind turbine gearboxes, study by [REF-01] illustrates the benefits of remanufacturing in terms of reduced costs and minimized downtime. Remanufacturing of gearboxes involves high levels of technical complexity due to the need to restore components under strict performance standards. The business model here often relies on **long-term service contracts**, whereby manufacturers offer remanufactured gearboxes as part of maintenance packages, ensuring reliability while minimizing resource reliance. This provides a circular model tailored to high-capital industrial equipment where durability and performance are critical to successfully satisfy the customer's need.

3.2.5 Circular business models and circular business model canvas – Industry cases

Given the challenges and specialized requirements of remanufacturing, the Circular Business Model Canvas (CBMC) by [REF-11] serves as a suitable framework for assessing these models. Unlike the traditional BMC by [REF-15] which focuses on value creation and revenue generation without considering sustainability, the CBMC includes essential dimensions focusing on circular economy strategies like **resource flow optimization, product recovery process**, and **environmental impacts**. By embedding circularity into the design of business model, the CBMC becomes particularly valuable for industries where product life extension and closed-loop systems are core to their operations.

For example, [REF-10] applied the CBMC implemented to evaluate Bosch automotive remanufacturing operations, which are focused on take-back and refurbishment strategies. Their analysis shows how Bosch leveraged the CBMC to streamline resource efficiency and adopt to market needs for cost-effective replacement parts. Additionally, [REF-14] explored the application of the CBMC in high-tech industries, demonstrating its adoptability to sector-specific needs. Their research highlights the framework's flexibility in addressing unique circular strategies, including the development of tailored value propositions, innovative customer engagement methods, and sustainable revenue models.

The relevant industrial sectors to this project – automotive, renewable energy, and heavy machinery – present various business cases for remanufacturing. In the automotive industry, remanufacturing allows **cost-effective repairs**, like the case of Volvo and Bosch, where reconditioned components meet rigorous quality standards at lower prices. In renewable energy, EV battery remanufacturing enables companies to create second-life applications, such as grid storage solutions, providing an alternative revenue stream while addressing battery disposal challenges. Wind turbine gearbox remanufacturing supports **uptime and equipment durability**, crucial factors in industries where reliability affects overall profitability.

Each of these cases demonstrates how remanufacturing can be profitable and environmentally responsible, justifying the selection of the CBMC as a tool to explore business model dimensions relevant to circularity. Therefore, the CBMC emphasizes **value creation through life extension** and **resource recovery**, critical for remanufacturers who rely on closed-loop supply chains and take-back systems. Additionally, its focus on **stakeholder engagement** is aligned with the multi-stakeholder nature of industrial remanufacturing, where collaborations with suppliers, service providers, and customers are essential to maintain the closed-loop system.

According to the conducted literature and industrial articles analysis, the circular business model canvas provides a comprehensive framework that captures the unique challenges and opportunities within the remanufacturing sector. Therefore, it aligns with the R3-MYDAS business models development for the different demo cases. Its modular approach allows companies to systematically analyse value propositions, resource flows, and customer relationships from a circular perspective, which is essential for firms engaged in remanufacturing. For companies in the crankshaft, EV battery, and wind turbine gearbox sectors, the CBMC provides an adaptable, theoretically robust framework that aligns with both the economic and environmental objectives of remanufacturing. By structuring business models around circularity, the CBMC enables companies to evaluate their strategies for sustainable growth, ultimately making it the most suitable tool for analysing business models in this context.

3.2.6 Simulating factors for adopting Circular Business Models – survey results

To define the preliminary business models, it was necessary to clarify partners needs and evaluate their knowledge concerning the circular economy factors to facilitate circular value chain. Therefore, the developed survey (see Appendix A for more details regarding the questions) shared among all the consortium partners provided a comprehensive understanding of project partner's needs and their position within each project technical use case development as well as their expectation toward the business modelling activities focusing on the novel solutions. From this survey, 13 responses were submitted from partners, including partners with critical role in each demo cases. Beside this section, in the market and technical analysis different previous sections we have used the results of such survey.

The figure below, shows the stimulating factors (conducted from performing desk research and asking AI like ChatGPT regarding circular economy benefit for industries) for three demo cases to adopt the circular business model.

The question is: From your perspective, what expectations or incentives drive the adoption of new circular business models in demonstration cases within the project? (You can select from the following examples or provide more:

- *Lower cost of production,*
- *lower price,*
- *accessing to broader market of remanufactured products,*
- *increase the value chain actors' engagement,*
- *increase the visibility*
- *receiving further funds,*
- *expand the revenue stream,*
- *improve sustainability measurements, others...*

As the results represent for each demo case there are different factors ruling the needs. For instance, demo 1 oil and gas, expanding the revenue model by adopting advanced technologies plays an important role. While for demo case 2, lower costs of production and improvement of sustainability measurements are more critical like in the demo case 3, wind turbine. However, increasing the value chain engagement in demo case 3 has been considered as a second important stimulating factor to adopt circular economy business models.

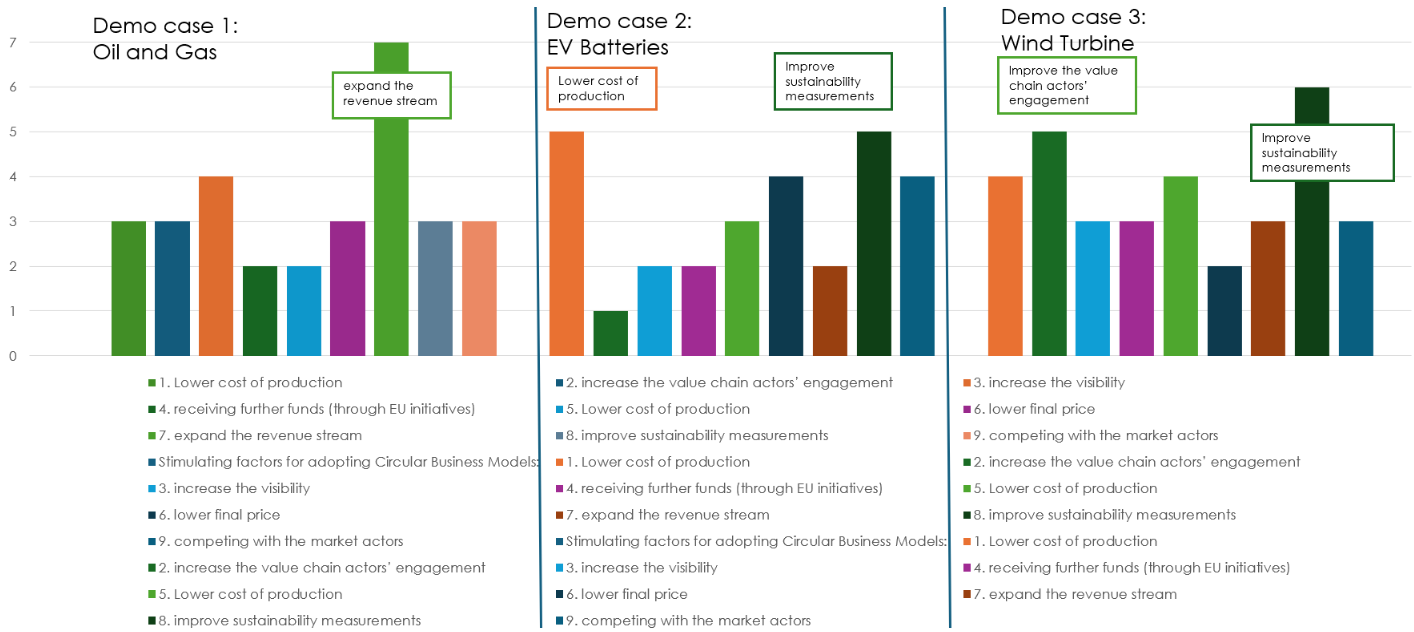

Figure 7:Stimulating factors for adopting circular business models - demo cases.

This is also valid for the marketplace however, the most important factor for the marketplace is increasing the visibility and accessibility with broader users. Other important selected factors are improving the sustainability which is one of the R3-MYDAS marketplace aims along with increasing the value chain actors' engagement. Which subsequently it will also cause a higher revenue.

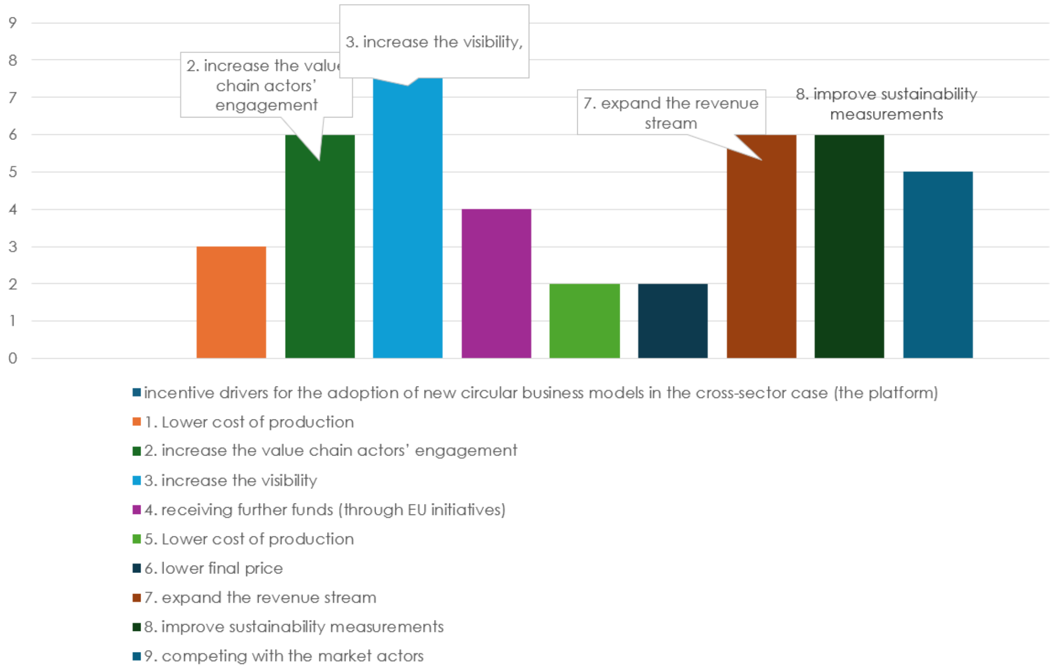

Figure 8: Stimulating factors for adopting circular business models – the marketplace.

In order not making the report complicated and long in terms of pages, we have decided not to report specifically the whole analysis of the survey showing in graphs and tables, however, its results helped us to conduct the business modelling.

4 R3-MYDAS Business Models and Service Results

This chapter presents the newly formulated business models for the most promising business scenarios in the R3-MYDAS demo cases and the marketplace. Currently underutilized at an industrial level, these business models will become actionable through the R3-MYDAS platform and its associated services. Each business model aligns with Circular Economy (CE) principals emphasizing sustainable remanufacturing value chains. The models include detailed descriptions of involved stakeholders, their interaction mechanisms, the value-propositions, and revenue models developed through a structured management framework.

The following sub-sections provide an in-depth analysis of the defined business models and scenarios for each demo case as well as the R3-MYDAS marketplace. The analysis draws on insights from preliminary questionnaire (see Appendix A) to describe the aim and position of each partner within the technical developments. The results of this survey are included in the previous sections following by each relevance topic. This activity is then followed by a workshop and a series of interviews (see Appendix B) with consortium partners, those who play pivotal roles in the development of the demo cases and the marketplace.

The first workshop was organized during the second General Assembly in Finland, where partners actively discussed potential business model scenarios for each demo case and marketplace functionalities. During the workshop, a CBMC template (shown in Figure 9) was introduced and discussed to be selected as the guidance framework. This CBMC template, selected from the scientific and market investigation and research (Section 3.2) done by LUT and EITM aimed at emphasizing the environmental and social impacts within the circular value chains of the three demo cases.

The workshop outcomes provided a foundation for business model building blocks and setting the stage for further analysis and development of scenarios. Subsequently, follow-up virtual interviews were conducted with partners to gather additional inputs. Partners responded to specific questions related to the CBMC referring and complementing the workshop data.

The combined results of the workshop and virtual interviews form the preliminary business models presented in this report. These models represent the initial steps toward an actionable framework, which will be further refined in Deliverable 8.3 by month 24 of the project, along with the detailed exploitation plans. Therefore, the results of each developed business models are presented as the following.

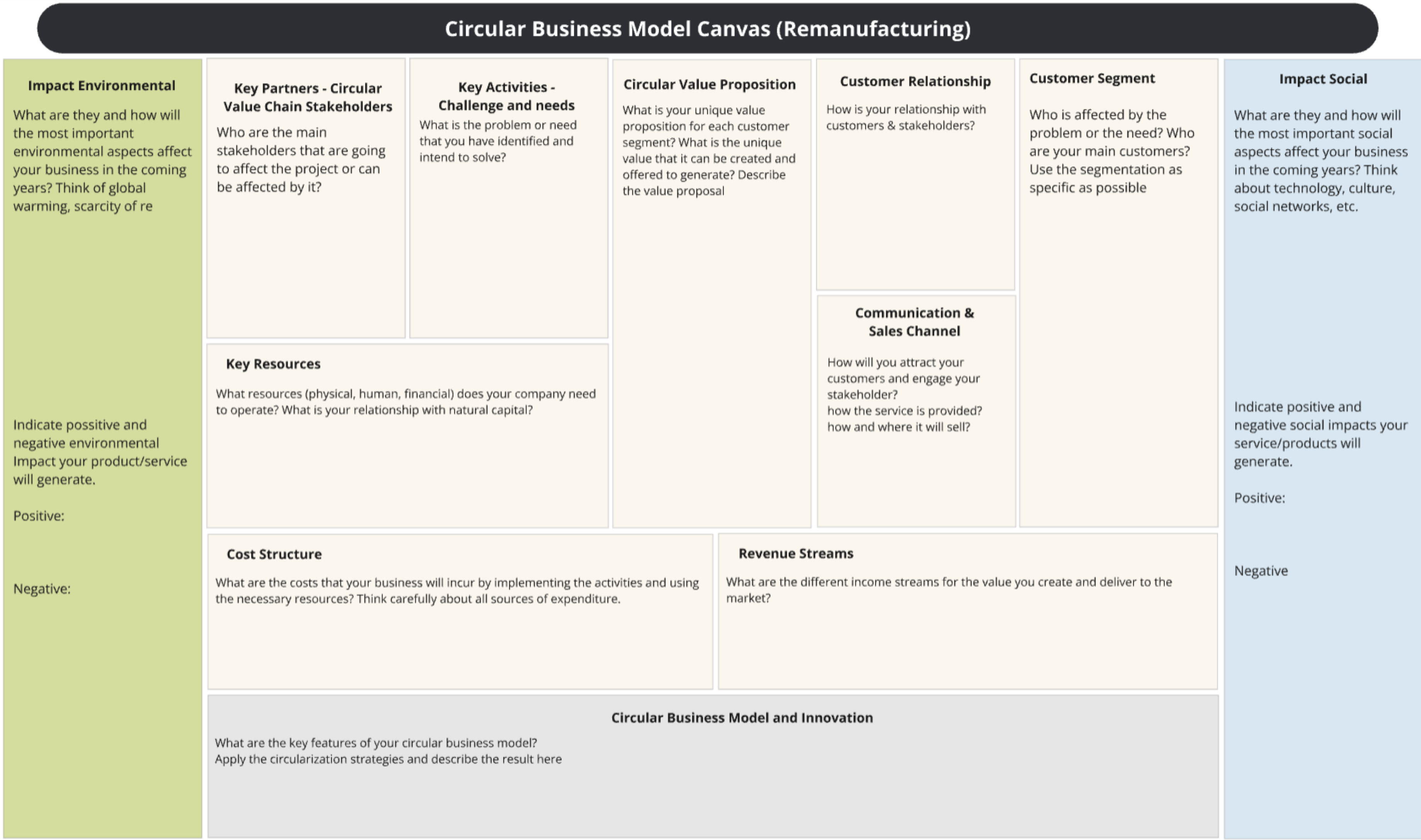

Figure 9: Circular Economy Business Model Canvas template.

4.1 Demo Case 1: Circular value chain for remanufacturing/renovation of Oil&Gas crankshafts

TMCOMAS is the owner of this demo and has a role of remanufacturer of crankshafts, AIMEN and ZIKNES companies are collaborating partners. The core objective is to leverage advanced and automated laser-cladding technology, transforming the remanufacturing process by introducing digital-based 3D path planning for laser coating processes through robot collaboration developed by AIMEN and programmed by ZIKNES. This development enables TMCOMAS to evolve its current business, which has relied on strong customer relationships within the oil and gas sector, where it provides high-quality, timely repair services.

The integration of automated laser cladding into TMCOMAS's operations allows the company not only to enhance its current service offerings but also to broaden its market reach. The new system optimizes efficiency and flexibility, making it feasible to offer tailored remanufacturing services beyond the oil and gas sector. Given that, four types of business scenarios are studied, each representing various market potentials and needs, the selected one is based on the interventions made by each involved partner in this demo case.

4.1.1 Scenarios for crankshaft remanufacturing business models

In the primary stage, three business model scenarios were considered according to the demo case technical developments and partner's business needs and interests. These scenarios aim to determine how involved partners in this demo case can effectively deploy new laser cladding technologies in a way to support scalability, accessibility and environmental benefits. Here are overviews of each scenario:

Scenario 1: Integrated Manufacturing and Remanufacturing Hub (centralized)

This approach involves setting up a centralized facility that combines both the manufacturing of new crankshafts and the remanufacturing of end-of-life crankshafts through laser cladding. This model aims to unify production and remanufacturing in a single hub, potentially lowering logistical and operational costs.

Although cost-effective in terms of operations, this model may face limitations in scalability and customer reach, especially for companies with a wide geographic spread that require local access to services.

Scenario 2: Direct Remanufacturing Service Provider (Distributed Remanufacturing Network)

This scenario focuses on providing remanufacturing services directly to heavy machinery industries like Oil&Gas through a distributed network. It allows for localized remanufacturing of end-of-life crankshafts, with the advantage of digital-based process control to ensure consistency and quality across locations.

This scenario was selected by the partners as a viable option. It also aligns well with TMCOMAS's goal of expanding its customer base while maintaining service quality. The distributed model enhances accessibility, especially for industries demanding proximity to repair services. This structure also enables flexibility to respond quickly to customer needs across different sectors especially heavy industries demanding crankshafts.

Scenario 3: Technology Licensing and Training Provider (In-house)

This model mainly concentrates on the automation and technicality of laser-cladding that partners like AIMEN and ZIKNES are developing to be integrated into TMCOMAS remanufacturing processes. Therefore, they would focus on developing and licensing digital tools specifically for laser cladding. The company would provide training and support for clients implementing these tools in their own remanufacturing operations.

While this option generates revenue from licensing, it lacks the direct service engagement with customers by TMCOMAS, potentially reducing the brand's impact on the end-user experience.

Scenario 4: Digital Process Optimization and Consulting Services (In-house)

This approach involves offering customized consulting services that optimize laser cladding processes for other organizations. These services would focus on improving efficiency, reducing costs, and enhancing quality in remanufacturing.

Similar to scenario 3, this model lacks direct engagement with the final remanufactured product and does not directly showcase the value of TMCOMAS's advanced cladding technology.

4.1.2 Circular business model for direct remanufacturing service provider

Direct remanufacturing service provider through distributed remanufacturing network was selected based on the partners agreement and technical development, offering advanced repairing services. In the R3-MYDAS project, TMCOMAS will leverage these new advancements to broaden its service offerings and optimize existing operations. Traditionally serving as a supplier for OEMs and end users, TMCOMAS maintains strong, direct relationships with clients to deliver high-quality crankshaft repair and remanufacturing services. With the R3-MYDAS project's technological developments, TMCOMAS can enhance its market presence by advancing repair capabilities through digital automation, centralizing offerings on the R3-MYDAS marketplace developing by NCI and expanding consultancy services.

Furthermore, the adoption of a distributed model enables TMCOMAS to extend services like a "Machinery-as-a-Service" (MaaS) or "Equipment-as-a-Service" (EaaS) solution, targeting smaller businesses that lack in-house remanufacturing capabilities. This can be enlarged to other services such as consultancy and tailored solutions along with workforce training through their academy to small businesses beyond the repair services. This diversified model, mixing service provision with training and consultancy, adds value across different client segments. By doing so, TMCOMAS not only enhances its service offerings but also align with circular economy principles by fostering resource efficient manufacturing across a broader market.

In this demo case, ZIKNES as an industry partners, will benefit from this arrangement by providing tailored software robot system and after-sale support for TMCOMAS, ensuring ongoing service and operational continuity for clients utilizing the advanced robotic software developed through R3-MYDAS. Additionally, the long-lasting relationship with AIMEN, a research and development partner, will enable TMCOMAS to stay current on laser-cladding technologies advancements. This collaboration/partnership brings ongoing access to evolving technologies, enabling TMCOMAS to maintain cutting-edge service quality. On top of that, R3-MYDAS marketplace will notably generate added value to the business of crankshafts remanufacturing through a trustworthy and transparent system by offering digital transition in this value chain. This circular business model for crankshaft remanufacturing reflects the project's chosen business scenario and will adapt as the partners progress, ensuring continuous improvements and alignment with market demands until the end of the project.

Customer segment

- Primary clients: Original Equipment Manufacturer (OEMs) and suppliers, oil and gas companies, marine, automative, petrochemicals, and heavy machinery industries needing high quality remanufacturing services for crankshafts.
- Secondary clients: smaller businesses lacking in-house remanufacturing services like some of equipment maintenance and repair service providers, recycling and waste management companies to collect and retrieve the non-repaired or deficit parts.
- Workforce training clients: Companies interested in training their workforce on remanufacturing best practices and the latest in laser-cladding technology

Circular value proposition

- Enhanced component lifecycle: High-quality laser cladding for remanufacturing, extending crankshaft and component lifespan, meeting performance and environmental standards.
- Localized and accessible services: Through a distributed service model, clients have easier, regional access to remanufacturing solutions, reducing downtime and logistical costs.
- Resource efficiency and cost savings: Lower costs compared to new parts manufacturing, promoting circular economy practices with significant waste and carbon emission reduction.

- Consulting and training services: Customized consulting and training for companies looking to optimize or internalize remanufacturing, supporting industry upskilling.

Customer relationship

- Long-term collaboration: Fostered partnerships with larger organizations, providing consistent service while maintaining high standards through automation and process standardization, supporting personalized and tailored made offers and services for customers based on their needs.
- Dedicated customer support: Continuous support during and after the remanufacturing process, addressing specific technical needs and ensuring customer satisfaction.
- Educational outreach: Training and consulting services for companies interested in remanufacturing skills, building deeper relationships through knowledge sharing, involving and networking through R&D funded projects.

Communication and sales channels

- Distributed remanufacturing hubs: Regional service centres for direct access to remanufacturing services, reducing logistical time and costs.
- Online platform: R3-MYDAS marketplace for scheduling, and tracking, making the remanufacturing process more accessible and transparent for clients.
- Consulting and training programs: In-person and digital workshops and courses for workforce training on remanufacturing and laser cladding.
- Communication channels: Direct sales, direct emails to promote new offerings to the existing customers, offering promotions and added-value services through social media and industrial conference.

Key partners – (Circular value chain stakeholders)

- Technology developers and providers: Providers of digital laser cladding and robotics solutions like ZIKNES are essential for process standardization and efficiency.
- Supply chain partners: Material suppliers, and end-of-life management companies in case of crankshaft components.
- Research Institutions: Collaborators like AIMEN who drive innovation and support ongoing development, ensuring access to advanced technologies.
- Logistics and regional support partners: Local entities that assist in setting up and managing regional hubs, enhancing service reach and localization.
- Associations and standardization bodies: Oil and gas industry associations, Health, Safety and Environment (HSE) agencies, standardization bodies (API)
- End-customers to provide remanufacturing programs.

Key activities – (Challenges and needs)

- Remanufacturing operations: Utilizing advanced laser cladding techniques to repair and refurbish crankshafts and high-value components.

- Digital tool development and optimization: Continuous R&D for digital path planning and laser cladding automation, keeping technology efficient and up to date, standardization of automation processes.
- Consulting and training: Providing tailored consulting services and training to organizations and smaller businesses, enhancing industry-wide expertise in remanufacturing.
- Participation to EU funded programs to keep updated and exchanging the knowledge.

Key resources

- Laser cladding equipment and software: Core equipment and digital tools enabling efficient, precise remanufacturing processes.
- Other physical sources: Facilities and premises
- Skilled workforce: Trained personnel proficient in advanced remanufacturing and digital process management.
- Distributed service infrastructure: Regional service hubs equipped for localized remanufacturing, making services accessible and responsive.

Cost structure

- Equipment and technology maintenance: Upkeep of laser cladding machinery, software licensing, and R&D for continuous improvement.
- Labor and training: Costs associated with skilled labour, training programs, and workforce development.
- Operational and logistical expenses: Expenses for maintaining distributed service hubs, logistics, and fees to use the digital marketplace.
- Variable costs: Energy consumptions, marking and sales campaign.

Revenue stream

- Direct service fees: Income from remanufacturing services, charged per project or as a recurring service for regular clients.
- Subscription models (MaaS/EaaS): Revenue from "Machinery-as-a-Service" or "Equipment-as-a-Service" offerings, providing flexible payment options for small-to-medium businesses.
- Consulting and training fees: Fees from customized consulting and training services, supporting clients in adopting best practices in remanufacturing and laser cladding technology

Environmental impacts

- Reduction in material consumption, waste, and emissions by prolonging component lifecycles, aligning with the EU's circular economy goals.

Social impacts

- Promotes local job creation and workforce upskilling, especially through accessible remanufacturing hubs and training programs, fostering sustainability in the regional economy.

4.2 Demo Case 2: Circular value chain for remanufacturing of EV Batteries

In this demo case, AVL as the leader of the demo will provide engineering and diagnostic services to OEMs and Tier-1 suppliers, offering advanced anomaly detection and monitoring through ITML data analytics and support. SPIN specializes in the design and supply of hardware for the automated disassembly and reassembly of EV battery packs, targeting battery dismantling centres and remanufacturing facilities. The SPIN dismantling battery packs technologies will be optimized by integration of camera inspection technology developed by CSEM.

The identified business model scenarios for the EV batteries demo case emphasize on the relationship among the supply chain actors in the battery value chain. Given that in the battery value chain actors are playing distinct roles, implementing circular business models in this sector will strength the synergies and collaboration between different stakeholders and reduce uncertainties and ambiguity imposed from the battery performance along its lifetime. The following different business scenarios are described representing various pathways, considering that the marketplace integration will emphasize and narrow the distinction between these players to offer complementary services at once in the future.

4.2.1 Scenarios for EV battery remanufacturing business models

Based on the current market requirements and demo partners' desire, we have offered three business model scenarios. Bellow, each identified scenario is presented and a circular business model is delivered for the selected model.

Scenario 1: Hybrid business model with integration of the marketplace

In this scenario each partner operates within their specific area and maintain the distinct business models. The partners collaborate but offer their services and products separately, ensuring that each maintains control over their segment of the supply chain. Given AVL and SPIN's roles across different points in the supply chain, a joint CBM would hide the current unique value each partner brings to the project. Instead, distinct business models better capture their core services and customer engagement models, they would contribute to an overarching ecosystem where their technologies and services reinforce each other. This model respects the automotive sector's preference for traditional business models while allowing partners to adapt over time. If Software-as-a-Service (SaaS) faces an exponential growth, and the marketplace can pivot to include subscription-based services, opening doors to recurring revenue.

Scenario 2: Integrated SaaS platform with engineering and hardware solutions

This scenario consolidates AVL's diagnostics and SPIN Robotics' disassembly hardware within a Software-as-a-Service (SaaS) model on the R3-MYDAS marketplace, with access to all partners' solutions through a single platform. This business model scenario lays the groundwork for scaling into SaaS as customer acceptance grows, particularly with increased familiarity with cloud-based tools. It could evolve towards subscriptions, allowing continuous access to updated analytics and diagnostics services. Customers can source diagnostics, hardware, and analytics solutions in a modular format, combining AVL's predictive diagnostics and SPIN's robotic systems for a comprehensive remanufacturing solution.

Scenario 3: Dedicated service provider with engineering and hardware bundles

This scenario offers a bundled solution to meet remanufacturing needs of large OEMs or battery recycling facilities. Through this scenario, a spin-off will be founded potentially from AVL and SPIN joint solutions that targets large OEMs and battery recycling and offering them end-to-end services through large- scale project-based contracts with an option for an on-site service engineering support. In this scenario, customers gain access to both partners solutions in a bundled package catering to clients with high volume battery remanufacturing needs. Given that, this model is ideal for high-value clients but lacks the flexibility needed for scaling across a wider customer base. Over time, it could be adapted to offer smaller, modular services to appeal to a more diverse customer set.

4.2.2 Circular business model for hybrid scenario with marketplace integration

The Hybrid service business model with marketplace integration was selected as the optimal scenario, providing flexibility and alignment with partner capabilities while addressing current and future market needs. This business model scenario addresses immediate market demands while supporting future growth. The R3-MYDAS marketplace offers a consistent entry point, encouraging partner collaboration without compromising each partner's distinct market role. With this business model scenario, AVL engineering services such as anomaly detection and State-of-the-Health (SOH) optimized solution integrated with data analytics from ITML can be offered through the R3-MYDAS marketplace to the OEMs. This offering will generate added value across the whole battery supply chain. This solution is at its highest importance especially for the OEMs and Tier-1 suppliers to early detect the battery misbehaviour and ensure an accurate repair process to extend the lifecycle of the batteries.

SPIN hardware solutions will also benefit from increased visibility to a broader customer through the marketplace, enhancing reach across different market segments (automotive, battery recycling, and remanufacturing sectors). This approach fosters adaptability, enabling AVL and SPIN transition decision to subscription models in the future as customer needs with SaaS increases, ensuring a scalable, future-proof solution for EV battery remanufacturing. The integration with marketplace will allow customers to choose the AVL, and SPIN services separately or as a combined solutions based on their needs without bundling services upfront.

The following circular business model building blocks are conducted based on the separate business models of SPIN and AVL while the value proposition remains unique, emphasizing the benefit generated from the interconnections.

Customer segment

- Primary clients:
  For AVL: EV manufacturers (OEMs), Tier-1 suppliers, battery remanufacturer and recyclers.
  For SPIN: Dismantlers to use robots for dismantling the battery pack and cell, and battery recyclers,
- Secondary clients:
  For AVL: battery maintenance and service providers, energy storage provider/manufacturers
  For SPIN: compliance scheme companies.

Circular value proposition

- AVL's advanced anomaly detection and predictive diagnostics extend battery lifecycle and reduce downtime. Higher accuracy of data on SOH battery which relies on the operation phase in vehicles and in refurbishment centre.
- SPIN's automated robotics systems streamline battery disassembly optimized by inspection camera developed by CSEM, reducing labour costs and lowering the operation costs, increasing safety, and reduced hazardous and emissions.
- R3-MYDAS marketplace provides a unified platform for customers to source comprehensive remanufacturing solutions and access to the diagnostic engineering and disassembly services. Allows access to AVL's diagnostics and SPIN's robotics separately or as an integrated solution, streamlining the customer experience.

Customer relationship

- Personalized engagement for engineering service delivery
- Building long term relationship, collaborative development by working closely with customers
- High quality support to response customer service and technical needs
- Incentives for loyal customers and distributors like promotions or access to premium features

Communication and sales channels

- Communication through website, webinars and conferences, and email campaign supporting both traditional direct sales with customers in the circulation and reaching to new customers through marketplace offering advanced technologies both for battery supporting system and automated dismantling especially when the battery volumes are high (futuristic scenario).
- Consulting sales: for offering tailored solutions AVL and SPIN will provide consulting services to sale complex services.

Key partners – (Circular value chain stakeholders)

The partners are comprised of the group of project partners and other relevant and potential organizations. These key partners cover both AVL and SPIN business models, which some of them are considered in the customer segmentation due to communalities among the actors.

- Engineering service providers (AVL)
- Robotic and hardware providers especially in automation disassembly (SPIN)
- Data analytics, marketplace providers and cloud services (NCI, ITML)
- Camera inspection for robot screwdriving to optimize the disassembly process (CSEM)
- Standardization organizations and regulatory bodies
- Research Technology Organizations (RTOs) and academic organizations
- EV manufacturers companies
- Recycling companies
- Energy storage provider companies

Key activities – (Needs and challenges)

- AVL: Development and refinement of anomaly detection for battery SOH and predictive diagnostics. Provision of engineering services, with potential SaaS expansion for analytics.
- SPIN: Robotics system development for battery pack disassembly. Hardware distribution and post-sale support for dismantlers and recyclers.
- Marketplace Activities: Managing and optimizing the R3-MYDAS platform, enabling streamlined access for customers. Integration of SaaS options, fostering an adaptable platform as customer demands shift.

Key resources

- Technical expertise: AVL's expertise in diagnostics and ITML's analytics capabilities.
- Robotic technology: SPIN's advanced robotic hardware and automation solutions.
- Digital infrastructure: R3-MYDAS marketplace platform, including cloud-based software for seamless customer interaction.

- Data management: Real-time data analytics through ITML's DFB, enhancing predictive accuracy and customer insights.
- Patent and trademarks
- R&D resources
- Facilities

Cost structures

- R&D investment: Continuous investment in robotics and anomaly detection R&D for ongoing innovation.
- Platform maintenance: Marketplace maintenance and updates to support SaaS models and user interface.
- Sales and marketing: Direct sales team costs, marketing to raise marketplace and product visibility.
- Customer support and training: Service costs to onboard, train, and support customers using advanced robotics and diagnostic tools.

Revenue stream

- Direct sales: Initial revenue through direct sales of SPIN's robotic systems and AVL's engineering consulting.
- Marketplace transaction fees: Commission fees on services accessed via the marketplace, providing revenue to R3-MYDAS platform developers.
- Licensing fees: License fees for advanced analytics and anomaly detection software, as SPIN explores recurring revenue models.
- Subscription fees: SaaS subscriptions for AVL and ITML's diagnostics and analytics offerings as market maturity increases.

Environmental impact

- Lower resource consumption and emissions through extended battery lifespan and recycling as well as enhancing workplace safety.
- Marketplace model supports efficient reuse of battery components, promoting a circular economy.

Social impact

- New roles in EV battery remanufacturing and diagnostics.
- Training opportunities for advanced diagnostic and robotics skills.
- Contributing to industry-wide sustainability and circular economy goals, creating shared societal value.

4.3 Demo Case 3: Circular value chain for remanufacturing of wind turbine gearboxes

In this demo case, Flender (FLE) as the manufacturer of gearboxes plays the owner role which offers a repairing and remanufacturing services to its client in wind turbine energy sector. Since the remanufacturing of the gearboxes deemed operational limitations in which, due to safety reasons, the whole part will be replaced to mitigate any future failures. The technological advancement in this demo case will respond to these current limitation and consumptive remanufacturing processes of gearboxes. Implementing AM or recoating techniques, engineering tools and mitigation method along with failure predictive analysis improve the remanufacturing processes and minimize future failure rate by either using the remanufactured part in a new designed component or in the original product guaranteed a higher strength and resistance.

FLE as the industrial partners who produce gearboxes is adopting these new technologies to securely repair the worn-out components of gearboxes, where LUT with its scientific expertise in digital twins and improvement-based simulation methods will pave the way for further advancements in this field, and Ikerlan with its knowledge will develop structural reliability models for helical geometries and improved induction hardening simulation tool. CSEM with their expertise and knowledge in scientific field and quality predictive will help to advance the technologies for gearboxes remanufacturing as well as designing new components that are more suitable for repairing with lower impacts. On top of this technological development, like other demo cases, the R3-MYDAS marketplace will increase the visibility of these advancement and generate additional value for the remanufacturing of gearboxes for wind turbines industry actors.

4.3.1 Scenarios for gearboxes remanufacturing business models

Scenario 1: Remanufacturing services in a centralized hub

This model provides FLE end-to-end remanufacturing services for gearboxes on a centralized hub. In this scenario continuous monitoring with integration of enhanced predictive maintenance tools will ensure on time responses on remanufacturing and repairing needs. FLE can also offer some of its remanufacturing processes through EaaS model to the customers who do not have in-house huge machineries, so they can rent a unit section receiving FLE knowledge to operate their businesses. The R3-MYDAS marketplace will facilitate these service access allowing customers to book accurate remanufacturing services to optimize their production and reduce the down time operations.

This scenario is the selected one, in which allow FLE customers experiencing an advanced and reliable services ensuring an extended life of gearboxes.

Scenario 2: On-site remanufacturing services

This scenario introduces mobile units for on-site remanufacturing, where a direct intervention in the FLE customers premises. These units are equipped with predictive maintenance tools that monitor gearbox health and enable real time scheduling for maintenance or remanufacturing. Like previous scenario R3-MYDAS marketplace will facilitate the access and acquisition of the gearboxes' repair advanced services offered by FLE. This scenario is not a good choice since the investment and operation costs of a mobile unit at the moment do not have an economic justification for FLE as the probable operator.

Scenario 3: Predictive maintenance services

Through this scenario, the predictive maintenance tools with simulation programs are at the centre of the service provision and can be offered to the customers requiring on-time prediction of the forthcoming defects to prevent grave damages. For this service, an Intellectual Property Rights among the FLE and CSEM and Ikerlan will safeguard the patent of this novelty and FLE can offer it through the marketplace on a subscription model.

Even though this scenario sets an effective relation to strengthen the innovation developed, it requires further investigation and development of various results which at the moment cannot be perceived as a viable solution.

4.3.2 Circular business model for predictive maintenance and remanufacturing services in a centralized hub

As mentioned above, this scenario emphasizes the importance of AM practices as a novel solution to improve reusing of failed components in wind energy industry through advanced remanufacturing processes. To deliver this technology by FLE, it is important that the induced services and knowledge from Ikerlan, LUT and CSEM assure that developed mitigation methods (called mitigation root) is effectively operative to repair damaged parts. Therefore, it will become directly applicable into new production to extend the lifetime of gearboxes as well as being adoptable to other industrial needs of gearboxes beside the wind turbines. The follow details each building blocks of CBM for the optimized repairing/remanufacturing services:

Customer segment

- Primary customers: Wind turbine farms and operators, Maintenance and service companies, and OEMs
- Secondary customers: Renewable energy investors, Engineering service providers, and other OEMs looking for standalone predictive maintenance and diagnostics.

Circular value proposition

- Fast and low costs of repair with minimum used material in a consistent end-to-end remanufacturing process
- Increased reliability and durability of gearboxes through advanced technologies
- Avoid gearboxes total failure level by Condition monitoring
- Adopting advanced technologies: using AM laser welding to improve component performance
- Provide high quality reman components

- Predicted maintenance tools allow early detection of failure risks and minimizing the unplanned downtime.
- Reduced wastes and circular economy integration
- Big portfolio of remanufacturing parts

Customer relationship

- Offering personalized support and tailored solutions through a subscription-based access to predictive maintenance tools.
- Establishing ongoing maintenance contracts and supports based on customer specific needs.
- Collaborative meetings and feedback mechanisms

Communication and sales channels

- Communication channel:
  - Website, social media, and email campaign to existing customers
  - Industry webinars, forums and industrial exhibitions in the sector.
  - Technical communication with leading customers
- Distribution:
  - Direct sales and contract based: personalized engagement with client's service location
  - Through R3-MYDAS marketplace: Customers can browse and select service packages, book remanufacturing sessions, monitor service progress, and access Digital Product Passports.
  - Third party network engagement: interacting with partners network to create the awareness.

Key partners – (Circular value chain stakeholders)

- Equipment suppliers (especially AM equipment)
- Wind turbine OEMs
- Material suppliers
- Wind turbine site operators
- Maintenance companies to offer comprehensive maintenance packages
- Certification and industry bodies
- Research institutes
- Insurance companies seeking to reduce risks associated to the turbine failure.

Key activities – (Needs and challenges)

- Using advanced tools to analyse gearbox failure and determine repair
- Implementing technologies like AM
- Conducting tests to ensure remanufactured gearboxes meet industry standards
- Utilizing digital twins and simulation software to predict failure behaviour and design new methods to optimize the process
- Data analytics to improve efficiency of the process

Key resources

- Technical resources: Induction hardening machines, AM laser welding
- Specialized simulations modelling; digital twins and fatigue model
- Skilled technicians and engineers
- R&D team for advanced knowledge of material science
- Patents and property knowledge
- Equipped facilities with updated technologies
- Skilled third-party suppliers

Cost structures

- Capital expenditure: Investments in advanced remanufacturing equipment and in predictive maintenance, diagnostics and material treatment.
- Skilled technicians, engineers and support staff
- Operational costs: expenses for the operations like energy consumption, transportation costs for moving components, and maintenance costs
- Marketing and sales
- Ongoing costs for the digital marketplace.

Revenue stream

- Service fee: Price per unit of service remanufacturing and repair offered
- Selling remanufactured components to other industries
- Subscription or loyalty-based mode: long term agreement with customers based on the high volume of remanufacturing needs
- Supplementary services: upgrading to the higher performance, providing predictive diagnostic based on subscription.

Environmental impact

- Resource efficiency: The centralized hub model reduces waste by remanufacturing components instead of replacing them, contributing to material savings and lower carbon emissions.
- Reduced downtime and waste: Predictive maintenance minimizes unexpected failures, allowing optimal use of materials and reducing the need for premature replacements

Social impact

- Job creation: requiring skilled personnel in manufacturing area
- Secure job environment

4.4 The R3-MYDAS Marketplace

The R3-MYDAS marketplace has two main functionalities to promote **remanufactured components** and to offer **remanufacturing resources and services**. The R3-MYDAS will use the MARKET4.0[22] marketplace, developed by NCI, sophisticated functionalities like matchmaking and bidding to facilitate supports for remanufacturing tools and materials, remanufacturing infrastructure-as-a-service and other services for remanufacturers.

The R3-MYDAS marketplace, has its unique characteristics that aims to extend and optimize the functionalities offered by MARKET 4.0 platform. The first functionality of the marketplace is more relevant to demo cases that will offer remanufactured products, like demo 2 - EV batteries – AVL will be enabled to promote the remanufactured batteries for the second life applications as well as diagnosis services to the OEMs. While the second feature has a service-oriented purpose by attracting higher customers. For example, demo case 1 – crankshaft - TMCOMAS has its own customers, while reaching to a wider customer range will be an added value for them. They can offer these advanced technologies for repairing the crankshafts not only to gas and oil industries but also to other crankshafts' dependent industries. Demo case 3 – gearboxes – FLE who possesses repairing and remanufacturing processes using advanced technologies, would offer its testing facility (in a renting mechanisms) as a part of this process to the end-users and this service offering can be accessible through the marketplace.

The R3-MYDAS marketplace will respond to the increasing needs of remanufacturing services and components in the EU. Currently there are few marketplaces in the EU that are offering the remanufacturing components. However, in the EU we are still behind the technical and operational advancements to support the market demand on the remanufacturing services. The marketplace aims to enhance the remanufacturing services by offering following services as its distinguished character:

- **Data space** which establishes the federation of services and negotiations between stakeholders. It allows creation of the synergies and trustworthiness between remanufacturing stakeholders, by setting agreements with each other to collaborate on the remanufacturing practices.
- **Blockchain technology** to guarantee the traceability of remanufactured components across the remanufacturing supply chains. All the data regarding the showcased components like state of the health, quality checks, certifications and characteristics are accessible through the marketplace to the registered and verified users. The accessibility to data will be based on the confidentiality levels and agreements that stakeholders made in the data space.
- **Digital Product Passport-like** log offering transparent information on the remanufacturing history of the products.

There are distinct roles in the marketplace among the stakeholders like sellers who sell their products or remanufacturing services. The consortium partners will act as the

[22] The Market 4.0 marketplace (https://platform.market40.eu) is live and supported by other follow-up projects (DOME4.0, ALICIA).

initial sellers and advisors. Buyers, who buy services and products buy paying a fee based on the future revenue models of the marketplace for accessing to the remanufacturing communities and trustworthy services. A hybrid role will be an option in which a stakeholder can act as a buyer and a seller role at the same time. This will support the collaboration for example among the remanufacturer stakeholders in the marketplace. There will be also advisors and expert's role in the marketplace by accessing to data space and creating collaboration with remanufacturer experts to foster the adoption of remanufacturing practices and create synergies among the stakeholders in the other industries. According to the roles and relationships among different stakeholders in the marketplace, the following scenarios will pave the way for further discussion around the marketplace implementation in the EU remanufacturing sector.

4.4.1 Scenarios for the business model of the marketplace

This part explores possible business model scenarios based on the marketplace functionalities, stakeholder relations, revenue streams and various ownership structures. Each scenario outlines how and by which company or companies the marketplace might be operated. However, the final choice among the different scenarios remains open and requires further in-depth research focusing on market demands, stakeholders' acceptance and the development of marketplace itself.

In the end, using the business model canvas, various elements of the marketplace are highlighted in the busine model building blocks (shown in Figure 9) facilitating the future decision-making processes by illustrating its functionalities and possible relations.

Scenario 1: Co-ownership among groups of remanufacturers

This model involves a group of remanufacturers, in which the priority will be with the consortium partners who are involved in demo cases' developments by owning and operating the marketplace. NCI role as the developer of the marketplace would be two-fold, whether to be among the shareholders and act as the technical provider or don't take the ownership responsibility and provides only the technical supports as a service provider.

Scenario2: A new company operated by external marketplace providers

This scenario relays on a new company managing marketplaces and platforms to buy the R3-MYDAS marketplace. In this case, NCI still would have two options; first is to remain as a shareholder and provide its services and based on this receive fees. The other option would be that NCI as the technical developer of the marketplace sell it to this third party on a price.

In both scenarios, consortium partners can act as buyer, seller and also advisor to the marketplace. However, at the moment a final decision to choose one of the scenarios has not been made and further investigation is needed to clearly define the marketplace features since the activities regarding the marketplace started from June-July 2024.

4.4.2 Circular business models for the marketplace

At this stage of the project considering that a specific business model scenario is still missing, we have proposed a generic business model for the marketplace using BMC, various building blocks of the marketplace business models are highlighted bellow:

Customer segment

- Remanufacturers and remanufacturing service providers
- Engineering service companies
- Manufacturers needing remanufacturing tools or components.
- Consultants and technology solution providers
- Buyers of the remanufactured components like OEMs.

Value proposition

- Provides a marketplace for connecting the different stakeholders in the value chain of remanufacturing.
- Ensures transparency through blockchain technology on traceability, supported by Digital Product Passports.
- Facilitates access to remanufacturing tools, infrastructure, and services.
- Encourages collaboration through data-sharing spaces and matchmaking functionalities.
- Promotes sustainability by enhancing resource efficiency and extending the life of products.

Customer relationship

- Contractual basis: based on the registration and user agreements to access to the marketplace services.
- Medium to long term relationships to fostering trust and collaboration among stakeholders.
- Subscription based models: agreements for high volume users of remanufactured services.

Communication and sales channels

- The R3-MYDAS marketplace act as a primary connection hub for stakeholders
- Network of partners and industrial communities
- Marketing campaign and conference meetings

Key partners – (Circular value chain stakeholders)

- EU industrial manufacturers and remanufacturers: especially the demo case partners like TMCOMAS, AVL, FLE, and others.
- End-users: OEMs, maintenance providers, and recyclers
- Technology service providers: vendors offering predictive maintenance services, diagnostic, digital tools, and technical support.

Key activities – (Needs and challenges)

- Development and maintenance of the marketplace.

- Blockchain integration for traceability and implementation of Digital Product Passports.
- Matchmaking and reverse auction functionalities for remanufacturing services.
- Data aggregation and analytics to refine and improve service offerings.
- Collaboration with supply chain partners to onboard remanufacturers and service providers.
- Trading remanufactured components and products

Key resources

- Technology infrastructure: Innovative functionalities in the marketplace platform.
- Expertise: Knowledge of remanufacturing technologies, predictive maintenance tools, and blockchain integration.
- Human resources: Personnel for management, customer service, and marketing efforts.

Cost structures

- Capital expenditure: marketplace development and setups
- Operational costs of running the marketplace
- Maintenance and customer service expenses
- Marketing and sales to expand the customer base and joining new partners.

Revenue stream

- Transaction fees: commission fees from sales or contracts closed via the marketplace for data space and other services.
- Service fee: charges for accessing to remanufacturing services and products
- Subscription or loyalty-based mode: recurring revenues from long-term users such as high-volume remanufacturers.
- Communication and advertising: value creation for stakeholders through promotion of services or products on the platform.

Environmental impact

- Promote resource efficiency by facilitating remanufacturing products and extending the product lifecycles.
- Encourages sustainable practices with transparent traceability and collaborative engagement.

Social impact

- Job creation: support skilled employment in manufacturing and digital platforms management.
- Raise awareness of using remanufacturing products with hight quality close to new one.
- Promote knowledge sharing upskilling within sustainable manufacturing community

5 Conclusion

The R3-MYDAS project represents a major step towards advancing the circular economy, leveraging cutting-edge technologies and collaborative business models to reshape how industries approach sustainability. By focusing on remanufacturing solutions for EV batteries, wind turbine gearboxes, and crankshafts, the project highlights alternatives to the traditional (re)manufacturing and repairing processes for energy goods. Through advanced diagnostic tools, predictive maintenance, and strong multi actor partnerships, R3-MYDAS delivers solutions that reduce waste, conserve resources, and promote sustainable practices across industries.

This report aimed to demonstrate the business model solutions for the industrial remanufacturing technologies developing under the R3-MYDAS project. A methodology approach with timeline has been adopted setting the guidelines to carry out the activities allocated to WP8, especially activities belong to the Task 8.1, 8.2 and 8.3 across the course of project. To this aim, Chapter 3 presented a comprehensive market analysis and technology trends for the three demo cases of crankshafts in oil and gas industries, EV batteries, and wind turbine gearboxes. Then followed by an analysis focusing on the opportunities, threats, weaknesses and strength for the developed technologies within the current market context. The findings derived from the market analysis along with results of a survey and series of interviews have been provided technical strategic insights to create new business models, presented in Chapter 4, addressing industry needs and capitalize on emerging opportunities.

The proposed business model scenarios focus on stakeholder relationships, revenue streams and circular value propositions offered by the main project results that have yet to be fully and widely realized in the market. For crankshafts remanufacturing, a centralized hub advanced with ZIKNES automation robots for laser cladding integration with TMCOMAS's advanced machineries was proposed to create a Machinery-as-a-Service model, offering cost-effective solutions to smaller businesses. In the EV batteries demo, a hybrid service model integrates AVL's engineering expertise on anomaly detection of batteries to OEMs, and SPIN's automation technologies, delivering seamless solutions for its customers to effectively and safely disassemble the batteries. Like in demo case 1 oil and gas crankshafts, in the wind turbine sector, a centralized maintenance hub equipped with FLE's advanced repair tools ensures cost-effective services that extend turbine lifespans and improve reliability. These tailored approaches demonstrate the power of collaboration and technological innovation to solve complex industrial challenges.

The impact of these remanufacturing technologies and services is amplified through the R3-MYDAS marketplace - a digital hub that connects remanufacturers, service providers, and customers. By incorporating blockchain-based traceability, digital product passports, and advanced matchmaking features, the marketplace builds trust, fosters transparency, and streamlines operations. It expands access to remanufacturing resources, promotes sustainable products, and amplifies economic, environmental, and social benefits, thereby maximizing the project's overall value.

This deliverable D8.1, presents the initial exploration of new business models aligned with the Circular Economy principles. However, further analysis is required to refine these models from both a market perspective and the technical development of project partners. This ongoing work will continue in an updated deliverable next year by month 24, providing a more realized form of business models along with analysis regarding the possible strategies to develop exploitation plans for both individual and joint results and proposing suitable IPRs to safeguard these advancements within the project and therefore completing the investigations.

In conclusion, R3-MYDAS offers more than just solutions to today's industrial challenges. Indeed, it sets a new standard for how circular business models and digital platforms can revolutionize remanufacturing. By aligning cutting-edge technologies with real-world needs, it paves the way for a future that is not only more resource-efficient but also deeply sustainable. The project stands as a key contributor to Europe's green transition, helping industries stay competitive while reducing their environmental footprint.

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Appendix A : Business Model Survey

This survey aims to identify partners' roles and responsibilities within the project along with their expectations regarding the technical development. In this regard, the designed survey with three main sections, general information, the current technical advancement and future improvements. The survey was distributed among the whole consortium partners and about 13 responses were received. This helped us to conduct the first analysis for the creation of business models considering both partners expertise and market potential.

Section 1 – General Information

1. What is the name of your company?
2. Please select the category of your company in the project (Select all that apply)
   - Supplier (1st or 2nd Tier)
   - manufacturer
   - intermediary
   - RTO
   - Consultancy
   - University
   - Research Institutes
   - Other...
3. What is the geographical location of your company?
4. What is the size of your company?
5. Please select your role in the R3-MYDAS project (Select all that apply)
   - Demo developer: (please indicate which demo)
     Technology provider in demo case
     Service provider in demo case
     Owner of the demo case
   - Replicator of demo case
   - Research development role
   - Other....
6. Please describe the expertise/contribution/technology your organization contributes to the R3-MYDAS project:
7. Please provide a short description of your current market/service/products target:

(starting from the analysis provided in the Grant Agreement; in case report any useful web link/document that describes the market)

Section 2 – Current Value Chain Situation of Demo Cases

Objective: To understand the technological, circular, and strategic landscape of the current value chains within the project scope.

1. What is your awareness about the circular economy principles integration into manufacturing industries?
2. What strategies are currently employed for treating damaged components? (select all that apply)
   - Take-back schemes
   - Recycling
   - Repairing
   - Remanufacturing
   - Other (please specify): ______________

3. Assess the current circularity practices of other actors in your value chain:
4. Are these strategies influenced more by market demand or internal decisions?
5. What are the main challenges of remanufacturing parts in the current value chain? (first select the relevant demo case to your organization)
    - Oil and gas (Crankshaft)
    - EV batteries
    - Wind Turbin (Gearboxes)
8. What is your general idea about the perceived benefits and drawbacks of the current value chain setup.
9. How do you think about the existing advanced digital/technical solutions within these sectors across the value chain?

Section 3 – Circular Value Chain Specifications

Objective: To capture innovative contributions, collaboration dynamics, and strategic approaches to market entry and IP protection.

1. Innovations and Outcomes
    - List the technologies, services, or products that will be developed and specify how they address current challenges: (technologies/knowledge/services/products)

    - Are there any main challenges imposed on the development of these outcomes?

2. Collaboration in Development
    - Is the development a collaborative effort? (Select all that apply):
        - Solely by your organization
        - In partnership with other organizations (please name them): __________

      Please provide further details about your (organizational) intention of this choice:

    - What can be the main resources that you may need to develop your results during and beyond the course of the project?

        (partnerships with external community, trainings, Skilled persons, financial resources beyond the project, etc)
3. Target Customers/Users/ Owners
    - Define intended potential target customers/users of these innovations (Select all that apply):

        Oil and gas components
        - Current market sectors
        - Other industries (please specify): _____________

        EV batteries
        - Current market sectors
        - Other industries (please specify): _____________

        Wind Turbine gearbox
        - Current market sectors
        - Other industries (please specify): _____________
    - Ownership strategy for the innovations (Select all that apply):
        - Customer-owned
        - Owned by your organization
        - Third-party ownership
        - Other (please specify): ______________

      Please provide further details about your (organizational) intention of this choice:

4. Market Entry factors
    - How would you measure the success rate of the developed remanufacturing processes within each demo cases in the future? (select all that apply)
        - Oil and gas components (Scale from 1 to 5)
        - EV batteries (Scale from 1 to 5)
        - Wind turbine gearbox (Scale from 1 to 5)

    Please provide further information about your rating:
    - How would you measure the success rate of R3-MYDAS Platform in the market? (Scale 1 to 5)

    Please provide further information about your rating:
    - What are the challenges or risk associated to the market entrance of these results?
    - Beside developing innovative remanufacturing processes, do you expect the possibility of final remanufactured products to be entered in the R3-MYDAS marketplace?
        - YES
        - NO
        - Do you see any challenges associated with showcasing of components in the marketplace?
5. Value Chain Actors
    - How much the upstream and downstream actor's circularity actions can impact the adoption of remanufacturing processes and new technologies integrations?
    - If possible, please describe which actor(s) can impose higher impacts.
6. From your perspective, what expectations or incentives drive the adoption of new circular business models in demonstration cases within the project?
   (You can select from the following examples or provide more:

- Lower cost of production,
- lower price,
- accessing to broader market of remanufactured products,
- increase the value chain actors' engagement,
- increase the visibility
- receiving further funds,
- expand the revenue stream,
- improve sustainability measurements, others)

   Oil and gas:

   EV batteries:

   Wind Turbine:

   Marketplace:

7. Would there be any information complexity in collaboration with partners in the value chain for developing these demo cases in R3-MYDAS and beyond?
   Oil and gas:
   EV batteries:
   Wind Turbine:
   Marketplace:
8. Would there be any information complexity in collaboration with external actors in the value chain for developing these demo cases in R3-MYDAS and beyond?
   Oil and gas:
   EV batteries:
   Wind Turbine:
   Marketplace:

Training Needs Specific training needs to effectively implement project outcomes (indicating the area(s) that require following trainings)

Needed skills for transferring the results of demo cases to production phase:

- What is your current skill sets in your area of activity? (multiple answer)
  - Skilled personnel / technicians
  - Advance data analysis and interpretation
  - Software programming and development
  - Product design
  - Process optimization
  - Quality control and assurance
  - XR integration
  - Consulting/ advisory services
  - Networking
  - Others...

  Please provide further explanation regarding your selection(s):

- What are your needed skills in the future? And what do you need for this transitory phase?
  - Advanced manufacturing technologies
  - Emerging software tools and platform for development
  - Sustainable design and eco-friendly production methods
  - Automation and robotic solutions
  - XR integration
  - Tailored technical training specific to the project demo .... Please specify.
  - Specialized higher education (ex. PhD, technical courses,...)
  - Workshops on creativity and innovation in product development
  - Others

  Please provide further explanation regarding your selection(s):

  Do you anticipate any training requirements or areas for improvement within your organization to optimize the adoption of R3-MYDAS results in the future?

Appendix B Business Model Interview Questions

To conduct the series of interviews in each demo case, 2 to 3 representatives participated from technical and management team guaranteeing the accuracy and details of the information.

Demo case 1: Crankshafts in oil and gas industry

1. What are their specific needs and pain points regarding crankshaft wear and maintenance?
2. What is the size and scale of these customers?
3. How do they currently manage worn-out crankshafts?
4. What level of customer service do our customers expect?
5. How can we build long-term relationships with customers? any feedback mechanisms to improve services?
6. How does your solution in the project outperform current alternatives?
7. Time efficiency: How does a 60% reduction in programming time impact the customer's productivity?
8. Through which channels do our customers prefer to be engaged?
9. How will we deliver our remanufacturing service to the customer? Onsite? centralized reman facility?
10. Are there partnerships we can leverage to access customers more effectively?
11. What pricing strategies will we use for our remanufacturing service?
12. How sensitive are our customers to price changes? Are they willing to pay more for higher quality and faster service?
13. Can we offer supplementary services? Maintenance contracts? Extended warranties?
14. Who are our essential technology suppliers or partners?
15. Can you collaborate with customers to tailor solutions?
16. What specialized equipment is essential for laser-cladding process?
17. What proprietary technology or software do we possess?
18. Do you have the skilled personnel required?
19. What funding is necessary to scale the operations?
20. What are the primary costs involved in the operations? Which of them are fixed and which are variable?
21. How will increasing the volume impact the costs?
22. Where you we achieve cost savings without compromising quality?

Demo case 2: EV-Batteries

1. What are the specific needs of these customers regarding EV battery end-of-life management?
2. Are there different segments within these customers based on size, location, or operational focus?
3. Are there other industries or sectors that could benefit from our technologies and solutions?
4. What specific problems are you solving for customers with EV battery remanufacturing solutions?
5. How do these solutions improve upon current technologies and methods?
6. How do you differentiate yourselves from competitors?

7. What type of relationships do your customers expect to establish and maintain with them?
8. What strategies can you employ to retain customers and encourage repeat business? (Service contracts, Performance-based, Loyalty programs…)
9. What feedback mechanism can improve the services?
10. Through which channels do the customers prefer to receive information and engage with us?
11. How can we effectively demonstrate our technology and its benefits to potential customers?
12. How will you deliver the remanufacturing services or products to customers?
13. Are there partnerships you can leverage to enhance your reach and effectiveness?
14. What pricing strategies will we use for our remanufacturing services or products?
    a. Per unit or per batch pricing?
    b. Subscription models for continuous services?
    c. Outcome-based pricing linked to performance metrics?
15. Would you offer supplementary services or products to your customers?
    a. Data analytics and reporting services?
    b. Training and consulting on battery lifecycle management?
    c. Licensing of AI and digital technologies developed?
16. What is the perceived value of your solution to the customers?
17. What value do these partners bring to our business model?
18. Who will supply the necessary materials and components?
    a. Suppliers of robotics and automation equipment?
    b. Providers of battery handling and safety equipment?
19. Can you establish partnerships with customers for co-development or pilot projects
20. What are the essential activities required to deliver our value proposition?
21. How will you optimize and improve the processes over time?
22. What steps will you take to ensure compliance with regulations and standards?
23. How will you continue to innovate and stay ahead of emerging technologies and regulations?
24. What specialized equipment and facilities are essential for delivering your solutions?
25. What risks can impact your business model, and how can you mitigate them?
26. What are the barriers to entry for new competitors? Technological complexity? Regulatory compliance? What are your long-term growth objectives?

Demo case 3: Gearboxes in wind turbines

1. who are the main customers for remanufacture wind turbines?
2. what are the specific needs of these customers regarding the gearbox failure and maintenance?
3. Are there different segments within these customers based on size, location, or operational scale?
4. Are there any other industries or sectors that can get benefit from the R3-MYDAS technologies?
5. What are the decision-making characteristics for these customers when choosing gearbox solutions?
6. What specific problems will be solved for the customers with the new materials, design methods, and remanufacturing technologies?
7. How do R3-MYDAS solutions would improve current technologies and methods?
8. 3)What are the quantifiable benefits (e.g., cost savings, increased availability) that the customers can expect?
9. How this solution can be differentiated from the competitors? what is the unique value compared to other competitors?
10. What type of relationships do the customers expect to establish and maintain with them?
11. What strategies can be employed to retain customers and encourage repeat business?
12. Through which channel do the customers usually prefer to receive information and being engaged?

13. How can you effectively demonstrate the technology and its benefits to potential customers? Case studies? Demonstrations or pilot projects? Technical workshops?
14. How will deliver the remanufacturing services or products to customers? On-site services? Centralized remanufacturing facilities? Partnering with local service providers?
15. Are there partnerships that can leverage to enhance technology reach and effectiveness?
16. How do our customers prefer to pay? Based on long term agreement?
17. Can you offer supplementary services or products? Like Predictive maintenance solutions, Training and consulting services and Upgrades or retrofits for existing gearboxes?
18. What value do stakeholders will bring to this business model?
19. What are the essential activities to secure the value proposition will be delivered?
20. what are needs to optimize and improve the process over time? utilizing data analytics? machine learning integration?
21. what steps are needed to ensure reliability and performance of the Remanufacturing gearboxes are met?
22. how will you continue to innovate and stay ahead of emerging failures and technologies?
23. What specialized equipment and facilities are essential for delivering our solution?
24. What proprietary technologies, patents, or software do you possess?
25. what type of expertise and skilled person do you require?
26. what type of funding and investment is required to scale the solution?
27. What pricing strategies will we use for our remanufacturing services or products? Per unit pricing, Subscription or service contracts or Performance-based pricing (e.g., sharing in cost savings)?

The R3-MYDAS marketplace

1. What are the aims of developing the R3-MYDAS marketplace?
2. Which gaps/issues the marketplace intends to address that other running marketplaces couldn't?
3. What are the added values of such marketplace? Are they internal or external/industry-wide platforms, or both?
4. Which problem the marketplace will solve?
5. Will the market to sell remanufactured/repaired components or only offer services to the end-users?
6. Who will be the main customer/end-users of the platform?
7. Will the innovation used to develop the platform be sold to other parties (out of the consortium) or will be developed and used by the project partners (NCI)?
8. Who will be the main beneficiaries of the R3-MYDAS marketplace?
9. What roles are pre-defined in the marketplace?
10. Who will be the main stakeholders of the marketplace? Will be the one running and operating it?
11. Which are the customer targets for the marketplace? Is it a B2B platform or it will support also B2C?
12. Which market and area is the main target of the platform?
13. Which business model type do you foresee for the marketplace in the future?