D5.4. Co-creation, social aspects and non-technological barriers

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List of Acronyms

AHP	Absorbent Hygiene Products
BOF	Basic Oxygen Furnace
CAR	CARTIF
CCS	Carbon Capture and Storage
CCSU	Carbon Capture, Storage, and Utilization
CCU	Common Cellulose Upcycling (barrier ID prefix)
CEAP	Circular Economy Action Plan
CEN	European Committee for Standardization
CER	Ceramic (barrier ID prefix)
CSO	Civil Society Organization
CSR	Corporate Social Responsibility
D&C	Dissemination and Communication
DC	Demo Case
DMP	Data Management Plan
DPP	Digital Product Passport
EAF	Electric Arc Furnace
EC	European Commission
EoW	End-of-Waste
EU	European Union
FAIR	Findability, Accessibility, Interoperability, and Reusability
FAQ	Frequently Asked Questions
ICV	Instituto de Cerámica y Vidrio (CSIC)

IFOR	I-Foria
ISQ	Instituto de Soldadura e Qualidade
ISO	International Organization for Standardization
KER	KERABEN
LAR	Lithium Aluminosilicate Residue
LC	LAR Common (barrier ID prefix)
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LI	Lithium Iberia
NGO	Non-Governmental Organization
NIMBY	Not In My Backyard
P4Planet	Processes4Planet Partnership
PCC	Precipitated Calcium Carbonate
PNO	PNO Consultants
PSCG	Public Stakeholder Councillor Group
QC	Quality Control
R&D	Research and Development
RBF	Rotating Belt Filter
REV	Revolve
SAP	Super Absorbent Polymers
SC	Steel Common (barrier ID prefix)
SCM	Supplementary Cementitious Material
SMC	SMC Group

SOF	SocialFare
SRM	Secondary Raw Material
TEE	Techno-Economic Assessment
UL	Université de Lorraine
WP	Work Package
WWT	Wastewater Treatment (barrier ID prefix)
WWTP	Wastewater Treatment Plant

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Keywords list

- Co-creation
- Stakeholder Engagement
- Social Barriers
- Non-Technological Barriers
- Circular Economy
- Upcycling
- Secondary Raw Materials (SRMs)
- Lithium Aluminosilicate Residue (LAR)
- Urban Waste Cellulose
- Absorbent Hygiene Products (AHP)
- Wastewater Treatment Plant (WWTP) Cellulose
- Carbon Capture and Storage (CCS)
- Precipitated Calcium Carbonate (PCC)
- Industrial Symbiosis
- Public Perception
- Regulatory Frameworks
- Standardization
- Market Acceptance
- Economic Viability
- Technical Performance
- Construction Materials
- Ceramic Materials.

Disclaimer

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While the authors have made reasonable efforts to ensure the accuracy and completeness of the content, this document provides guidance and requires further population with specific data and context for each demonstration case within the ICARUS project. s

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1. Executive summary

This deliverable, D5.4, addresses Task 5.4 of the ICARUS project, focusing on the identification and mitigation of social and non-technological barriers through co-creation and stakeholder engagement practices across the project's three demo cases. The document begins by establishing a methodological outlook, drawing from academic literature to underscore the importance of stakeholder mapping, barrier identification, and co-creation processes in achieving sustainable industrial transitions. It then provides a detailed analysis for each demo case: Upcycling of Lithium Aluminosilicate Residue (LAR), Upcycling of Urban Waste Cellulose, and Upcycling of Steelmaking Slags.

For each case, foreseeable social and non-technological barriers are mapped, high-priority barriers are identified, and specific co-creation actions and guidelines are proposed. These actions are framed as suggestions, acknowledging that their implementation depends on partner resources, but emphasizing that inaction increases project risks. The strategies aim to minimize the likelihood of occurrence and the magnitude of impact of these barriers by fostering greater acceptance, collaboration, and successful implementation of ICARUS innovations.

The deliverable concludes with aggregated and synergistic co-creation strategies applicable to the entire project, emphasizing the need for continuous dialogue, adaptability, and inclusive participation to ensure the long-term impact and societal relevance of ICARUS outcomes.

2. Introduction

2.1. Background: The ICARUS Project

The ICARUS project is positioned at the forefront of Europe's ambition to achieve a 'twin transition' – a simultaneous shift towards a green and digital future. This transition is critical for delivering a sustainable, fair, and competitive Europe. As outlined in the European Commission's Circular Economy Action Plan (CEAP), a significant focus is placed on transforming industrial production and consumption towards a circular model. This involves eliminating waste and pollution, regenerating the natural environment, and reducing the reliance on primary raw materials. The Processes4Planet (P4Planet) Partnership further supports this vision by aiming to transform process industries towards circularity and climate neutrality by 2050.

ICARUS directly addresses these challenges by focusing on upcycling secondary raw materials (SRMs) from three distinct waste streams within energy-intensive and construction industries. The project aims to develop and demonstrate innovative technologies that ensure these SRMs achieve a quality comparable to primary raw materials, thereby fostering their uptake in the construction sector and improving circular economy principles.

2.2. Task 5.4 Objectives and Scope

Task 5.4, "Co-creation, social aspects and non-technological barriers," within Work Package 5 (Impact Assessment), plays a pivotal role in ensuring the societal acceptance and successful market implementation of the innovations developed within ICARUS. The primary objectives of this task are:

- To map the key stakeholders for each of the three ICARUS demo cases.
- To identify and map foreseeable social and non-technological barriers that could hinder the development, adoption, or scaling of the upcycling technologies and SRMs.
- To assess the co-creation and feedback practices already in place or planned within each demo case.
- To prioritize the identified barriers based on their potential impact and likelihood.
- To propose and develop guidelines for implementing tailored co-creation practices with relevant stakeholders to minimize the occurrence and impact of these barriers.
- To foster an inclusive approach that facilitates the acceptance of the twin transition by making novel technologies accessible and understandable.

The scope of this task encompasses all three demo cases of the ICARUS project, considering the unique social, economic, regulatory, and environmental contexts of each.

2.3. Structure of the Deliverable

This document is structured to provide a comprehensive overview of the methodologies, findings, and recommendations stemming from Task 5.4.

- **Section 3 (Methodological Outlook)**: Provides the theoretical and conceptual foundation for the task, drawing on literature related to stakeholder engagement, barrier analysis, and co-creation methodologies in the context of industrial innovation and sustainability.
- **Section 4 (Process and Actions for Deliverable Development)**: Outlines the specific steps and processes undertaken within the ICARUS project to develop this deliverable, including stakeholder mapping, barrier identification, and the formulation of co-creation strategies.
- **Sections 5, 6, and 7 (Demo Case Analyses)**: Dedicate a chapter to each of the three ICARUS demo cases. Each chapter will describe the specific stakeholders, map the relevant social and non-technological barriers, identify high-priority barriers, and propose tailored co-creation strategies and guidelines.
- **Section 8 (General co-creation strategies for the ICARUS Project)**: Consolidates common co-creation themes from the demo cases, suggests synergistic actions, and integrates overarching project-level enabling practices.
- **Section 9 (Conclusions and Recommendations)**: Summarizes the key findings and provides actionable recommendations for the ICARUS consortium.
- **Section 10 (References)**: Lists the cited literature.

3. Methodological Outlook

The transition towards a circular economy and sustainable industrial practices, as envisioned by the ICARUS project, is not solely dependent on technological advancements. Social acceptance, regulatory alignment, economic viability, and public trust are critical non-technological factors that significantly influence the success of such initiatives. This section outlines the methodological rationale for employing stakeholder mapping, barrier analysis, and co-creation practices as integral components of Task 5.4.

3.1. Understanding the Landscape: Stakeholder Engagement in Industrial Processes

Stakeholder engagement is a cornerstone of responsible innovation and sustainable project management. As Collinge (2020) highlights, stakeholder engagement in construction (and by extension, industrial projects) is a complex process that goes beyond mere corporate social responsibility (CSR), intertwining responsibility, organizational action, and project requirements. Effective engagement helps in understanding diverse perspectives, expectations, and potential concerns, which is crucial for navigating the socio-political landscape of industrial projects (Dobele et al., 2013).

In the context of ICARUS, which involves novel upcycling processes and the introduction of SRMs into established markets, identifying and engaging a broad spectrum of stakeholders is paramount. These stakeholders include:

- **Industrial Partners:** (e.g., lithium extractors, steelmakers, waste treatment facilities, ceramic and cement producers, construction companies) who are directly involved in the production, processing, and use of SRMs.
- **Regulatory Bodies and Policymakers:** Who define the legal and normative frameworks for waste management, SRM quality, and product standards.
- **End-Users and Consumers:** (e.g., construction sector clients, the general public) whose acceptance and trust in SRM-based products are vital for market uptake.
- **Local Communities:** Residing near industrial sites, who may have concerns about environmental impacts, health, and socio-economic changes.
- **Research and Academia:** Contributing to knowledge, innovation, and independent assessment.
- **Non-Governmental Organizations (NGOs) and Civil Society:** Advocating for environmental protection, public health, and social equity.
- **Investors and Financial Institutions:** Whose support is crucial for scaling up innovations.

Mapping these stakeholders and understanding their interests, influence, and interrelationships (Rowley, 1997, as cited in Dobele et al., 2013) is the first step in developing effective engagement strategies and proactively addressing potential barriers.

Pauna et al. (2023) emphasize the critical role of engaging governmental stakeholders in ensuring the sustainability of industrial engineering projects, as they oversee regulatory frameworks and societal interests. Broadening stakeholder engagement, as advocated by Schoenung & Olivetti (2023) for the sustainable development of materials, is essential for incorporating diverse knowledge and values into decision-making.

3.2. Identifying Challenges: The Role of Mapping Social and Non-Technological Barriers

Social and non-technological barriers can significantly impede the progress of innovative projects, even those with strong technological merit. These barriers can be diverse, ranging from public opposition and lack of trust to unfavorable regulatory environments, market inertia, and insufficient infrastructure.

The ICARUS project proposal (Task 5.4) explicitly recognizes the need to map these barriers. This involves:

- **Systematic Identification:** Utilizing methods such as literature reviews, expert consultations, stakeholder interviews, and workshops to identify potential barriers relevant to each demo case.

- **Categorization:** Grouping barriers into relevant categories (e.g., social/cultural, economic/market, regulatory/policy, institutional/organizational, informational/awareness).

- **Prioritization:** Assessing the likelihood and potential impact of each barrier to focus resources on the most critical challenges.

This proactive mapping allows the ICARUS project to anticipate potential roadblocks and develop targeted mitigation strategies, rather than reacting to problems as they arise. This aligns with principles of risk management and sustainable project planning, where understanding the socio-technical system is crucial for success.

3.3. The Power of Collaboration: Co-creation as a Strategy for Barrier Mitigation and Innovation

Co-creation, defined as the active, creative, and social process of producing new value (products, services, solutions, knowledge) together with stakeholders (Prahalad & Ramaswamy, 2004a, as cited in Jones, 2018), is a powerful approach for addressing non-technological barriers and fostering innovation. It moves beyond traditional consultation by involving stakeholders as active partners in the design, development, and implementation phases.

The literature underscores several benefits of co-creation relevant to ICARUS:

- **Enhanced Acceptance and Trust:** Involving stakeholders in the development process can increase their understanding, ownership, and trust in the resulting innovations (Durugbo & Pawar, 2014). This is particularly important for products derived from waste materials, where public perception can be a significant barrier.

- **Improved Problem-Solving:** Diverse perspectives brought in through co-creation can lead to more robust and contextually appropriate solutions to complex challenges (Jones, 2018).

- **Barrier Identification and Mitigation:** Co-creation workshops and dialogues can serve as platforms to collaboratively identify potential barriers and co-design strategies to overcome them (Bonamigo et al., 2020).

- **Value Co-creation:** By understanding user needs and preferences more deeply, co-creation can lead to products and services that offer greater value to end-users and are better aligned with market demands (Zhang & Chen, 2008, as cited in Durugbo & Pawar, 2014).

- **Facilitating Systemic Change:** Co-creation can help navigate the complexities of socio-technical transitions by building shared understanding and aligning the actions of different actors within a system (Jones, 2018).

The ICARUS project, through Task 5.4, will leverage various co-creation methods, such as stakeholder workshops, participatory design sessions, feedback platforms, and collaborative scenario building, tailored to the specific needs of each demo case an d the barriers identified.

3.4. Integrating Feedback: Ensuring Relevance and Acceptance through Iterative Engagement

Stakeholder engagement and co-creation are not one-off activities but iterative processes that require continuous feedback loops and adaptation. As highlighted by Lane and Devin (2018, cited in Collinge, 2020), viewing stakeholder engagement as a process with distinct stages allows for "checks and balance points," increasing the chance for problem identification and rectification.

The methodological approach for Task 5.4 will therefore emphasize:

- **Early and Continuous Engagement:** Involving stakeholders from the early stages of the demo cases and maintaining dialogue throughout the project lifecycle.

- **Diverse Engagement Mechanisms:** Employing a mix of methods to suit different stakeholder groups and engagement objectives (e.g., informational meetings, consultative workshops, collaborative design sessions).

- **Transparent Communication:** Providing clear, accessible, and honest information about the project, its progress, potential impacts, and how stakeholder input is being used.

- **Feedback Integration:** Establishing clear mechanisms for collecting, analyzing, and integrating stakeholder feedback into project decisions and activities.

- **Monitoring and Evaluation:** Regularly assessing the effectiveness of engagement and co-creation activities and adapting strategies as needed.

By adopting this comprehensive and iterative methodological outlook, Task 5.4 aims to effectively identify, understand, and address the social and non-technological barriers facing the ICARUS demo cases, thereby enhancing their potential for success and contributing to a more sustainable and circular industrial future.

4. Process and Actions for Deliverable Development

This chapter outlines the structured approach and specific actions undertaken within the ICARUS project to develop Deliverable 5.4, "Co-creation, social aspects and non-technological barriers." The process was designed to be systematic, collaborative, and informed by both existing literature and direct input from project partners involved in the three demonstration cases.

4.1. Defining the Scope and Objectives of Task 5.4

The initial step involved a thorough review of the ICARUS Grant Agreement, specifically the description of Work Package 5 (Impact Assessment) and Task 5.4. This ensured a clear understanding of the mandated objectives:

- Mapping key stakeholders for each demo case.
- Identifying and mapping foreseeable social and non-technological barriers.
- Assessing existing co-creation and feedback practices.
- Prioritizing identified barriers.
- Proposing guidelines for tailored co-creation practices.

The scope was confirmed to cover all three demo cases, acknowledging their unique contexts. This foundational understanding guided all subsequent activities.

4.2. Stakeholder Mapping Process

A systematic process was implemented for mapping stakeholders relevant to each of the three ICARUS demo cases. This involved:

- **Initial Identification by Demo case partners:** Partners leading each demo case (LI, K-UTEC, UL, ICV, KER, ACC for DC1; ACCIONA Agua, IFOR, SMC, ACCIONA for DC2; ArcelorMittal, CALES DE LLIERCA, ACCIONA, KERABEN, CSIC-ICV, CARTIF for DC3) provided initial lists of known and anticipated stakeholders based on their expertise and existing networks.
- **Categorization Framework:** A common framework for categorizing stakeholders was adopted, including groups such as Industry & Commercial, Research & Academia, Regulatory & Policy, Civil Society & NGOs, Financial & Investment, Local & Regional Authorities, and General Public/End Consumers. This ensured consistency across demo cases.

- **Iterative Refinement:** The initial lists were refined through internal discussions within the ICARUS consortium, particularly with WP5 and SOF (as leader of T5.4). This involved considering stakeholders across the entire value chain and those who might be indirectly affected or influential.

- **Data Collection:** Templates (shared spreadsheets) were developed and utilized to systematically capture stakeholders for each demo case. You can find examples in the annex chapter (11)

- **Documentation:** The identified stakeholders for each demo case were documented, forming the basis for the descriptions in Sections 4.1, 5.1, and 6.1 of this deliverable.

4.3. Identification and Mapping of Social and Non-Technological Barriers

The identification and mapping of social and non-technological barriers followed a multi-pronged approach:

- **Literature Review:** A review of academic and grey literature was conducted (as evidenced in Section 2 and Section 9) to identify common barriers associated with industrial innovation, circular economy transitions, waste valorization, and specific technologies relevant to the demo cases (e.g., CCS, use of residues in construction).

- **Expert Input from Demo Partners:** Demo case leaders and technical partners provided insights into foreseeable non-technological barriers based on their experience with the specific materials, processes, and target markets.

- **Structured Data Collection:** Templates (shared spreadsheet) were developed and utilized to systematically capture potential barriers for each demo case, including common barriers and those specific to different applications of the SRMs. These templates prompted consideration of barrier type, subtype, description, foreseeable impact, affected stakeholders, and initial priority level. You can find examples in the annex chapter (11)

- **Consolidation and Categorization:** The collected data on barriers was consolidated in 3 co-creation workshops and categorized (e.g., Social/Cultural, Regulatory/Policy, Economic/Market, Technical/Operational, Environmental, Informational) to allow for structured analysis and presentation in Sections 4.2, 5.2, and 6.2.

4.4. Assessment of Existing Co-creation and Feedback Practices

As per the task description, an assessment of co-creation and feedback practices already in place or planned within each demo case was undertaken.

- **Expert Input from Demo Partners:** Demo case leaders and technical partners provided insights into foreseeable existing co-creation and feedback practices based on their experience with the specific materials, processes, and target markets.

- **Structured Data Collection:** Templates (shared spreadsheet) were developed and utilized to systematically capture potential existing practices for each demo case.

- **Findings:** This information was used to ensure that the co-creation strategies proposed in this deliverable build upon, rather than duplicate, existing efforts, and to identify gaps where new co-creative approaches are needed.

4.5. Prioritization of Barriers

Once barriers were mapped, a prioritization process was necessary to focus co-creation efforts.

Methodology. The prioritization process is based on two key criteria:

- Potential Impact: the extent to which a given barrier could negatively affect the implementation, scalability, or social acceptance of the upcycling solutions developed within the ICARUS project.
- Likelihood of Occurrence: the estimated probability that the barrier will materialize during the project's implementation or future exploitation phases.
- Each barrier was assessed qualitatively against these two dimensions. This enabled the identification of high-priority barriers — those with both a high potential impact and a high likelihood of occurrence — which were selected as the main focus for co-creation activities with stakeholders. This approach ensures that collaborative efforts are directed towards overcoming the most relevant and potentially disruptive challenges.

Outcome. The high-priority barriers for each demo case are presented in Sections 4.3, 5.3, and 6.3.

4.6. Development of Co-creation Strategies and Guidelines

The core of this deliverable is the development of co-creation strategies. This involved:

- **Linking Barriers to Co-creation Principles:** For each high-priority barrier, relevant co-creation principles and methodologies from the literature (see Section 2) were considered as potential solutions.
- **Tailoring Strategies to Demo Cases:** Generic co-creation approaches were tailored to the specific context, stakeholders, and high-priority barriers of each demo case.
- **Integrating Existing Project Activities:** Where possible, suggested co-creation actions were designed to enhance or provide a specific co-creative methodology for implementing activities already planned within other ICARUS WPs (e.g., WP3 for communication, WP10 for standardization, WP15 for validation).
- **Formulating Actionable Suggestions:** The strategies were framed as specific, actionable suggestions for demo leaders and the consortium, as presented in Sections 4.4, 5.4, 6.4, and Chapter 7.
- **Emphasis on Collaboration:** A consistent emphasis was placed on involving diverse stakeholders as active partners in the co-creation process.

4.7. Internal Collaboration and Review within ICARUS

The development of this deliverable was a collaborative effort within the ICARUS consortium.

- **Process:** The mapping of social impacts, barriers, and stakeholders was carried out through a series of iterative discussions and exchanges with the leaders of the three Demonstration Cases. These interactions took place both in person (during consortium meetings and dedicated workshops) and remotely (via online meetings and bilateral sessions). The contributions of the demo leaders were crucial for identifying case-specific dynamics, value chain characteristics, and context-dependent challenges.

- **Refinement:** The deliverable was refined based on internal feedback to ensure accuracy, relevance, and alignment with the overall project objectives and ongoing activities.

5. Demo Case 1: Upcycling Lithium Aluminosilicate Residue (LAR)

5.1. Overview of Demo Case 1 and Key Stakeholder Groups

Demo Case 1 focuses on the upcycling of Lithium Aluminosilicate Residue (LAR), a waste stream generated from the extraction and processing of lithium from spodumene and lepidolite minerals. The objective is to transform this currently non-valorized residue into Secondary Raw Materials (SRMs) for various applications in the construction and ceramic sectors. The targeted applications include:

- **Ceramic Tiles:** As a total or partial replacement for feldspars.
- **Cement and Concrete:** Utilizing potential binding and pozzolanic properties.
- **Road Applications:** As treated LAR for asphalt filler or in cement-treated layers.
- **Hydraulic Backfilling:** In mining operations.

Key Stakeholder Groups for Demo Case 1:

The successful implementation and market uptake of LAR-derived SRMs depend on the engagement and collaboration of a diverse range of stakeholders. These can be broadly categorized as follows:

- **Industry and Commercial Stakeholders:** This is a primary group, encompassing the entire value chain. It includes **Lithium Mining and Processing Companies** (e.g., ICARUS partner Lithium Iberia - LI) as the generators of the LAR feedstock. Crucial are the **Technology Providers and Material Processors** (e.g., ICARUS partners K-UTEC, Université de Lorraine - UL, Instituto de Cerámica y Vidrio - ICV) who are developing the LAR treatment, purification, and upcycling technologies. Downstream, **End-User Industries** are vital, such as the **Ceramic Industry** (e.g., ICARUS partner KERABEN) for feldspar replacement, the **Cement and Concrete Industry** (including precast manufacturers and ready-mix companies) for SCMs or aggregates, and **Construction Companies and Road Authorities** (e.g., ICARUS partner ACCIONA) for road applications and hydraulic backfilling. This category also includes **Mining Companies** (other than LI) who might adopt LAR-based backfilling solutions, and **Equipment Manufacturers** for processing and application machinery.

- **Research and Academia:** This group, including ICARUS partners UL and ICV, as well as other universities and research centers, provides essential expertise in material science, geology, chemical engineering, civil engineering, and environmental science. They are key for R&D, independent testing, validation of LAR properties and applications, and developing innovative solutions.

- **Regulatory, Policy, and Standardization Bodies:** These stakeholders define the operational and market landscape. They include **National and EU Environmental Agencies** (responsible for waste classification, End-of-Waste criteria, environmental permits), **Mining Authorities** (regulating extraction and waste management at mine sites), **Construction**

and Material Standards Bodies (e.g., CEN, national standardization organizations like AENOR in Spain) responsible for product safety, performance standards, and building codes. **Policymakers** at local, regional, national, and EU levels also shape the broader legislative context for circular economy and resource management.

- **Civil Society and Non-Governmental Organizations (NGOs):** This category includes **Environmental NGOs** who monitor the environmental impacts of mining, LAR processing, and the use of LAR-derived products. **Local Community Groups and Associations** near mining operations, LAR processing facilities, or significant construction sites using LAR products are critical for social license to operate. **Consumer Associations** may also take an interest in the safety and quality of end-products like ceramic tiles.

- **Financial and Investment Stakeholders: Investors, Banks, and Funding Agencies** (public and private) are crucial for financing the development, scaling-up of LAR processing technologies, and the commercialization of LAR-based products. Their perception of risk and return is a key factor.

- **Local and Regional Authorities:** Beyond specific regulatory roles, **Municipalities and Regional Governments** are key stakeholders in terms of land-use planning, local economic development (job creation), infrastructure development, and representing the interests of their constituents. They are often involved in permitting processes for new industrial facilities.

- **General Public and End Consumers:** While indirect, the **General Public's** perception of safety, sustainability, and the "waste-to-product" concept can influence market acceptance, especially for visible applications like ceramic tiles or public infrastructure. **End Consumers** of buildings or products incorporating LAR-materials are the ultimate arbiters of market success.

Effective engagement across these diverse groups, understanding their specific interests, concerns (e.g., environmental impact, economic benefits, safety, quality), and influence, is essential for navigating the non-technological barriers associated with LAR upcycling.

5.2. Mapped Social and Non-Technological Barriers for LAR Upcycling

This section details the social and non-technological barriers identified for the upcycling of Lithium Aluminosilicate Residue (LAR). These are categorized into common barriers applicable across all LAR applications and barriers specific to its use in ceramics, cement and concrete, road applications, and hydraulic backfilling.

5.2.1. Common Barriers for LAR Upcycling

Table 1 Common Social and Non-Technological Barriers for LAR Upcycling (Demo Case 1)

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority Level
LC001	Social/Cultural	Public Perception	Negative perception of "waste" (LAR) being used in products; concerns about safety and quality of LAR-derived materials.	Market rejection, project delays, reputational damage.	General Public, End-users (Construction, Ceramics), Local Communities, Consumer Associations.	High
LC002	Social/Cultural	Community Acceptance (NIMBY)	Local community opposition to new LAR processing facilities or increased industrial activity due to perceived environmental/health risks.	Permitting delays, social unrest, project cancellation.	Local Communities, Local Government, Environmental NGOs, Project Partners (LI, K-UTEC).	High
LC003	Regulatory/Policy	End-of-Waste (EoW) Criteria	Lack of clear or harmonized EoW criteria for LAR, creating uncertainty for its classification as a product/SRM rather than waste.	Market entry barriers, legal uncertainties, increased compliance costs.	Regulatory Bodies (National, EU), Project Partners, Waste Management Sector.	High
LC004	Regulatory/Policy	Standardization & Certification	Absence of specific standards for LAR-based products or difficulty meeting existing ones for construction/ceramic materials.	Limited market access, lack of trust from end-users, hindrance to commercialization.	Standardization Bodies, Certification Bodies, Industry Associations, End-users.	High
LC005	Economic/Market	Cost Competitiveness	LAR-derived SRMs and final products may not be cost-competitive with primary raw materials due to processing, logistics, or quality costs.	Low market adoption, economic unviability of upcycling process.	Project Partners, End-users (Ceramic, Cement, Construction), Investors.	High

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority Level
LC006	Economic/Market	Market Acceptance by Industry	Conservative nature of construction/ceramic industries; reluctance to adopt new materials derived from waste streams.	Slow market penetration, low demand for LAR-based products.	End-users (Ceramic, Cement, Construction), Industry Associations, Supply Chain Actors.	Medium
LC007	Technical/Operational	Feedstock Variability	Inconsistent chemical/physical properties of LAR from different sources or batches, affecting process stability and product quality.	Production inefficiencies, inconsistent product performance, increased QC costs.	Lithium Iberia, K-UTEC, UL, ICV, KERABEN, ACCIONA.	High
LC008	Technical/Operational	Scale-up Challenges	Difficulties in scaling up LAR processing technologies from lab/pilot to industrial scale while maintaining efficiency and quality.	Delays in commercialization, higher than expected production costs.	K-UTEC, Technology Providers, Investors.	Medium
LC009	Environmental	Life Cycle Impact	Concerns about the overall environmental footprint of LAR upcycling (energy, water, chemicals used) compared to primary materials.	Negative public/regulatory scrutiny, challenges in demonstrating sustainability.	Environmental NGOs, Regulatory Bodies, General Public, Research Institutions.	Medium
LC010	Informational	Lack of Awareness/Data	Insufficient knowledge among potential end-users and stakeholders about the benefits, properties, and safe use of LAR-derived SRMs.	Low adoption rates, misperceptions, resistance to change.	End-users, General Public, Policymakers, Construction Professionals, Architects.	Medium
LC011	Social/Cultural	Skills and Training Gaps	Lack of skilled workforce for new LAR processing technologies and for handling/incorporating LAR-based materials in downstream industries.	Operational inefficiencies, quality issues, slower adoption of new practices.	Workforce in Mining, Processing, Construction, Ceramics sectors; Educational Institutions.	Medium
LC012	Regulatory/Policy	Permitting Processes	Complex, lengthy, or uncertain permitting processes for facilities handling or producing LAR-based materials.	Project delays, increased development costs, investment uncertainty.	Project Partners (LI, K-UTEC, etc.), Regulatory Bodies, Local Government.	Medium

5.2.2. Application-Specific Barriers: Ceramic

Table 2 Application-Specific Barriers for LAR Upcycling in Ceramic Applications (Demo Case 1)

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority Level
CER01	Technical/Operational	Product Quality	Ensuring LAR-derived materials meet stringent ceramic quality requirements (e.g., color, purity, firing behavior, mechanical properties).	Rejection by manufacturers, inconsistent final product quality, reputational risk.	KERABEN, ICV, Ceramic Industry, End-users.	High
CER02	Economic/Market	Integration Costs	Costs for ceramic manufacturers to adapt their existing processes and formulations to incorporate LAR-based raw materials.	Reluctance to adopt, impact on product pricing.	KERABEN, Ceramic Industry.	Medium
CER03	Technical/Operational	Impurity Impact	Potential impact of trace impurities in LAR on ceramic properties (e.g., defects, discoloration, reduced strength) or kiln performance.	Production issues, lower product yield, damage to equipment.	KERABEN, ICV, K-UTEC.	High
CER04	Regulatory/Policy	Chemical Safety in Use	Ensuring ceramic products made with LAR meet all chemical safety standards for consumer goods (e.g., heavy metal leaching from glazes).	Product recalls, consumer health risks, legal liabilities.	KERABEN, Regulatory Bodies (Consumer Safety), Certification Bodies, General Public.	High
CER05	Economic/Market	Aesthetic Acceptance	Ensuring LAR-based ceramics meet aesthetic expectations of consumers and designers (color, texture, finish).	Lower market demand, difficulty competing with established ceramic products.	KERABEN, Designers, Architects, Consumers.	Medium

5.2.3. Application-Specific Barriers: Cement and Concrete

Table 3 Application-Specific Barriers for LAR Upcycling in Cement and Concrete Applications (Demo Case 1)

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority Level
CC001	Technical/Operational	Performance & Durability	Ensuring concrete with LAR meets long-term strength, durability (e.g., resistance to sulfates, chlorides, ASR), and shrinkage requirements.	Structural failures, reduced service life of infrastructure, liability issues.	ACCIONA, Cement/Concrete Industry, UL, Construction Companies, Engineering Firms.	High
CC002	Technical/Operational	Reactivity Control	Managing the pozzolanic or cementitious reactivity of LAR to ensure predictable setting times and strength development in concrete.	Inconsistent concrete properties, construction delays, material incompatibility.	UL, Cement/Concrete Producers, ACCIONA.	High
CC003	Regulatory/Policy	Construction Codes	Lack of inclusion or specific provisions for LAR-based materials in existing building codes and construction standards.	Limited use in regulated construction projects, need for extensive testing for approval.	Standardization Bodies, Regulatory Bodies (Construction), ACCIONA, Engineering Firms.	High
CC004	Economic/Market	Conservative Industry	High degree of conservatism in the cement and concrete industry, resistance to adopting new SCMs or aggregates without extensive track record.	Slow adoption, preference for traditional materials, market penetration challenges.	Cement/Concrete Industry, Construction Companies, ACCIONA.	Medium
CC005	Technical/Operational	Interaction with Admixtures	Potential unknown interactions between LAR and common chemical admixtures used in concrete, affecting workability or performance.	Unpredictable concrete behavior, need for extensive compatibility testing.	UL, Cement/Concrete Producers, Admixture Suppliers, ACCIONA.	Medium
CC006	Environmental	Leaching Concerns	Concerns about potential leaching of elements from LAR-containing concrete structures into soil or groundwater over time.	Environmental contamination, regulatory non-compliance, negative public perception.	Environmental Agencies, Local Communities, ACCIONA, UL.	Medium

5.2.4. Application-Specific Barriers: Road Applications

Table 4 Application-Specific Barriers for LAR Upcycling in Road Applications (Demo Case 1)

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority Level
RD001	Technical/Operational	Mechanical Performance	Ensuring LAR-based materials meet mechanical requirements for road layers (e.g., bearing capacity, stability, fatigue resistance, rutting).	Premature road failure, increased maintenance costs, safety concerns.	ACCIONA, Road Authorities, UL, Construction Companies.	High
RD002	Technical/Operational	Durability & Weathering	Assessing the long-term durability of LAR in road applications under various environmental conditions (freeze-thaw, moisture, salts).	Reduced road lifespan, unexpected degradation, higher repair costs.	ACCIONA, Road Authorities, UL.	High
RD003	Regulatory/Policy	Road Material Specs	LAR-based materials may not be covered by existing specifications for road construction materials, requiring new approvals.	Delays in adoption, need for specific pilot projects and validation by road authorities.	Road Authorities, Standardization Bodies, ACCIONA.	High
RD004	Economic/Market	Cost of Treatment	Cost of necessary treatments (e.g., salt removal, grading) for LAR to be suitable for road applications versus virgin aggregates.	Economic unfeasibility if treatment costs are too high.	ACCIONA, K-UTEC, Lithium Iberia.	Medium
RD005	Environmental	Runoff Contamination	Potential for contaminants to leach from LAR-based road layers into water systems via runoff.	Water pollution, harm to aquatic ecosystems, regulatory penalties.	Environmental Agencies, Local Communities, Road Authorities, ACCIONA.	Medium
RD006	Technical/Operational	Workability & Compaction	Ensuring LAR-based materials can be easily handled, placed, and compacted using standard road construction equipment and techniques.	Construction difficulties, increased labor costs, suboptimal layer quality.	ACCIONA, Construction Companies (Road Paving).	Medium

5.2.5. Application-Specific Barriers: Hydraulic Backfilling

Table 5 Application-Specific Barriers for LAR Upcycling in Hydraulic Backfilling Applications (Demo Case 1)

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority Level
BF001	Technical/Operational	Geotechnical Stability	Ensuring the long-term geotechnical stability and strength of LAR-based backfill to support surrounding rock mass and prevent subsidence.	Mine instability, safety risks for workers, environmental damage from collapses.	Lithium Iberia (or other mine operators), UL, K-UTEC, Mining Regulatory Bodies.	High
BF002	Technical/Operational	Flow & Pumping Properties	Achieving suitable rheological properties of LAR slurry for efficient pumping and placement into underground voids.	Pumping difficulties, blockages, inefficient void filling, increased operational costs.	Lithium Iberia, UL, K-UTEC, Mining Contractors.	High
BF003	Environmental	Groundwater Interaction	Potential for LAR backfill to interact with groundwater, leading to changes in water quality or leaching of substances.	Groundwater contamination, regulatory non-compliance, impact on local water resources.	Environmental Agencies, Local Communities, Lithium Iberia, UL.	High
BF004	Regulatory/Policy	Mine Safety Regulations	Compliance with specific mine safety regulations regarding backfill materials, their placement, and long-term performance.	Operational restrictions, permitting issues, potential for mine closure if non-compliant.	Mining Regulatory Bodies, Lithium Iberia.	Medium
BF005	Economic/Market	Cost vs. Alternatives	Cost-effectiveness of using LAR for backfill compared to traditional backfill materials (e.g., tailings, quarried rock, cement).	Limited adoption if economically unfavorable.	Lithium Iberia, Mining Companies.	Medium
BF006	Technical/Operational	Binder Compatibility	Ensuring compatibility and effective interaction of LAR with binders (e.g., cement, alkali activators) used in backfill formulations.	Poor strength development, instability of backfill, unpredictable performance.	UL, K-UTEC, Lithium Iberia, Binder Suppliers.	Medium

5.3. High-Priority Barriers for LAR Upcycling

Based on the detailed mapping in Section 3.2, and considering their potential to significantly hinder market uptake or derail the demo case, the following social and non-technological barriers are identified as high priority for the upcycling of Lithium Aluminosilicate Residue (LAR). These priorities consolidate common and application-specific concerns:

1. **Social Acceptance, Public Perception, and Trust:** This is a paramount concern across all applications (LC001, LC002). It encompasses the negative "waste" stigma associated with LAR, public and community concerns about health and environmental safety (e.g., chemical safety in ceramics - CER04, leaching from concrete - CC006, runoff from roads - RD005, groundwater interaction in backfilling - BF003), and potential NIMBY (Not In My Backyard) reactions to processing facilities. Without robust public and end-user trust, market penetration and social license to operate will be severely challenged.

2. **Regulatory Frameworks, Standardization, and Certification:** The lack of clear and harmonized End-of-Waste (EoW) criteria for LAR (LC003) and the absence of, or difficulty in meeting, specific product standards and certifications for LAR-based materials in ceramics (CER04), cement/concrete (CC003), road applications (RD003), and potentially backfilling (BF004) create significant market entry barriers and investment uncertainty. This includes alignment with construction codes and road material specifications.

3. **Technical Performance, Product Quality, and Long-Term Durability:** Ensuring that LAR-derived SRMs and the final products consistently meet or exceed the stringent technical and quality requirements of each specific application is critical. This includes:

4. **Feedstock Variability and Impurity Impacts (LC007, CER003):** Managing the inherent variability of LAR and the potential negative effects of impurities on final product quality (e.g., in ceramics, cement).

5. **Application-Specific Performance:** Demonstrating adequate product quality in ceramics (CER001), performance and durability in cement and concrete (CC001, CC002), mechanical performance and durability in road applications (RD001, RD002), and geotechnical stability and flow properties in hydraulic backfilling (BF001, BF002).

6. **Economic Viability and Cost Competitiveness:** The entire LAR upcycling value chain, from residue processing to the final application, must be economically viable (LC005). LAR-derived products need to be cost-competitive with existing primary raw materials and conventional products in each target market (ceramics, cement, concrete, road construction, backfilling) to ensure market adoption.

5.4. Suggested Co-creation Actions and Guidelines for Demo Case 1

To effectively address the high-priority social and non-technological barriers identified for Demo Case 1 (Upcycling Lithium Aluminosilicate Residue - LAR), a multi-faceted co-creation approach is suggested. The following actions are proposed for consideration by the demo leaders (UL, K-UTEC, LI, KER, ICV, ACC), with support from SOF and other relevant partners. Partners may choose to implement none, one, or several of these actions based on available resources, time, and budget. However, it is important to note that not implementing actions to mitigate these high-priority risks significantly increases the likelihood of project delays, market rejection, or failure to achieve desired impacts.

These suggestions aim to build trust, ensure regulatory and market alignment, and foster technical and economic viability through collaborative engagement with key stakeholders, applying the overarching co-creation strategies detailed in Chapter 7.

1. Implementing the ICARUS Strategy for Building Societal Trust and Acceptance (see Section 8.1): *(Addresses High-Priority Barrier 1; related to LC001, LC002, CER04, CC006, RD005, BF003)*

- Suggestion 3.4.1: Tailor Communication Materials for LAR Context.
- *Action for Demo Leaders (UL, ACC, with REV - WP3, SOF):* Utilize the *Unified ICARUS Communication & Transparency Framework* (8.1.1). Conduct participatory workshops specifically focused on LAR with local communities near LI and K-UTEC operations, environmental NGOs monitoring mining impacts, and public health officials.
    - *Purpose:* To co-develop information packages (brochures, website sections, FAQs) that transparently address LAR-specific concerns such as "waste" stigma, safety (including any radiological aspects if relevant to the specific LAR source, and leaching potential), and the benefits of its upcycling in ceramics, concrete, roads, and backfill.
    - *Additional Consideration:* The PSCG should co-validate these materials.
- Suggestion 3.4.2: Establish LAR-Specific Participatory Monitoring.
- *Action for Demo Leaders (LI, K-UTEC, with UL, ICV):* Implement the *ICARUS Co-designed Participatory Monitoring & Open Data Initiative* (8.1.2) for LAR. Co-design protocols with local communities and environmental agencies for monitoring dust, water quality, and other relevant parameters around LAR processing and application sites.
    - *Purpose:* To ensure transparency regarding the safety of LAR handling and use. Make LAR-specific monitoring data and safety assessments (leaching, radiological if applicable) publicly accessible via the ICARUS open data portal.
- Suggestion 3.4.3: Organize LAR-Focused Site Visits and Demonstration Showcases.
- *Action for Demo Leaders (LI, K-UTEC, ACCIONA, KERABEN, with REV - WP17):* Apply the *ICARUS Cross-Demo Showcase and Site Visit Protocol* (8.1.3) to LAR. Organize guided tours of LAR processing facilities and showcase tangible demonstration projects (e.g., LAR-ceramic tiles, LAR-concrete sections, LAR-road segment).
    - *Purpose:* To demystify LAR upcycling technology and provide tangible evidence of product performance and safety, incorporating these into T17.1 demo events.

2. Implementing the ICARUS Strategy for Co-creating Supportive Regulatory Landscapes and Standards (see Section 8.2): *(Addresses High-Priority Barrier 2; related to LC003, LC004, CER04, CC003, RD003, BF004)*

- Suggestion 3.4.4: Ensure LAR-Specific Needs are Addressed by the ICARUS Regulatory & Standardization Task Force.
- *Action for Demo Leaders (ACC - Project Coordinator, with ISQ - WP10, UL, KER, ACCIONA):* Actively feed LAR-specific regulatory challenges (EoW, product standards for ceramics, concrete, road materials, mine backfill) into the *ICARUS*

Regulatory & Standardization Co-creation Task Force (8.2.1). Within this Task Force, co-develop technical dossiers specifically for LAR-based products, highlighting safety and performance data relevant to each application.

    - *Purpose:* To ensure that the Task Force's engagement with regulatory bodies and standardization committees effectively addresses the unique requirements for LAR valorization across its diverse applications.

- Suggestion 3.4.5: Prepare Co-Validated Input for LAR-Relevant Standardization Committees.

- *Action for Demo Leaders (KERABEN, ACCIONA, with ISQ - WP10, ICV, UL):* In line with the *ICARUS approach to Standardization Contribution* (8.2.2), prepare technical data and proposals for LAR-relevant standardization committees (ceramics, cement/concrete aggregates, road materials, mine safety).
    - *Purpose:* To ensure these submissions are co-validated with end-users (KERABEN, ACCIONA) and the PSCG before formal submission, strengthening their impact.

3. Implementing the ICARUS Strategy for Ensuring Technical Viability and End-User Confidence (see Section 8.3): *(Addresses High-Priority Barrier 3; related to LC007, CER003, CER001, CC001, CC002, RD001, RD002, BF001, BF002)*

- Suggestion 3.4.6: Apply the ICARUS Quality Management Framework to LAR Value Chains.

- *Action for Demo Leaders (K-UTEC, UL, ICV, ACCIONA):* Utilize the *ICARUS Quality Management Framework for SRMs* (8.3.2) to co-develop LAR-specific quality specifications. Organize technical workshops for each LAR application (ceramics, cement/concrete, roads, backfill) involving Lithium Iberia, technology providers, and end-users (KERABEN, ACCIONA).
    - *Purpose:* To collaboratively define critical quality parameters for LAR-SRMs and final products, and establish QC protocols to manage feedstock variability (LC007) and impurity impacts (CER003).

- Suggestion 3.4.7: Conduct LAR Application Co-Validation through the ICARUS Platform (WP15).

- *Action for Demo Leaders (KERABEN, ACCIONA, UL for backfill, with WP15 leader):* Leverage the *ICARUS End-User Co-Validation Platform/Methodology* (8.3.1) for LAR-based products. Co-design pilot testing programs with end-users for LAR-ceramics, LAR-concrete, LAR-roads, and LAR-backfill.
    - *Purpose:* To involve end-users in evaluating performance (CER01, CC001, RD001, BF001), durability, and usability, and to co-develop modifications based on feedback.

4. Implementing the ICARUS Strategy for Co-developing Economically Viable Solutions (see Section 8.4): *(Addresses High-Priority Barrier 4; related to LC005)*

- Suggestion 3.4.8: Develop LAR-Specific Business Models via Co-creative Workshops (WP4, WP12, WP18).

- *Action for Demo Leaders (PNO, with LI, K-UTEC, KERABEN, ACCIONA, UL):* Apply the Business *Model Canvas Workshop* approach (8.4.1) to the LAR value chain, involving demo case partners and cross-demo case participants.
    - *Purpose:* To co-create value propositions and business models for each LAR application, ensuring cost-competitiveness by transparently analyzing techno-economic data (linking to TEE/LCC work in WP5/13/16).

- Suggestion 3.4.9: Optimize the LAR Value Chain through Collaborative Forums (T2.1, T16.5).
- *Action for Demo Leaders (ACC - Project Coordinator, with LI, K-UTEC, end-user partners):* Utilize the *ICARUS Value Chain Integration Forums* (8.5.1) to specifically map and optimize the LAR value chain.
    - *Purpose:* To collaboratively identify and address inefficiencies, cost drivers, and logistical bottlenecks for LAR, from extraction to final product, exploring industrial symbiosis opportunities.

Note on Implementation: The specific actions undertaken by demo leaders and partners will depend on the evolving context of the project, resource availability, and the specific nuances of each LAR application. Regular review of these suggestions and adaptation based on ongoing learning and stakeholder feedback is highly recommended. Failure to proactively address these high-priority barriers through such collaborative measures will likely increase project risks and reduce the potential for successful innovation and market uptake of LAR-derived products.

6. Demo Case 2: Upcycling Urban Waste Cellulose

6.1. Overview of Demo Case 2 and Key Stakeholder Groups

Demo Case 2 focuses on an innovative circular system for upcycling Secondary Raw Materials (SRMs) derived from urban waste cellulose. The primary feedstocks are: i) Cellulose recovered from Wastewater Treatment Plants (WWTPs), ii) Cellulose-based materials from post-consumer Absorbent Hygiene Products (AHPs), such as diapers and sanitary products.

The goal is to process these waste sources to obtain high-quality cellulose fibers (and potentially Super Absorbent Polymers - SAP from AHPs) for upcycling into the construction sector, specifically targeting large-volume applications like concrete pavements to prevent cracks due to drying shrinkage. This offers an alternative to currently used polypropylene microfibers. The key partners leading different aspects of this demo case include ACCIONA Agua (WWTP cellulose recovery), IFOR and SMC Group (AHP and WWTP cellulose recycling technology), and ACCIONA (construction applications).

Key Stakeholder Groups for Demo Case 2:

The success of upcycling urban waste cellulose hinges on engaging a complex network of stakeholders spanning the entire lifecycle, from waste generation to final product application. These stakeholders can be grouped into several key categories:

- **Waste Generators and Primary Sources:** This group includes Households and the General Public, who are the primary source of post-consumer AHP waste and indirectly contribute to the WWTP-derived cellulose found in municipal wastewater. Institutions such as hospitals, elderly care facilities, nurseries, and schools are also significant generators of AHP waste and crucial for targeted collection schemes. For WWTP-derived feedstock, Wastewater Treatment Plant Operators (e.g., ICARUS partner ACCIONA Agua) are responsible for the collection and initial recovery (e.g., via RBFs), although the cellulose itself originates primarily from the public. **Waste Management and Logistics Sector: Municipalities and Local Authorities** play a vital role in defining urban waste management strategies, authorizing collection schemes, and potentially providing public infrastructure or support. **Private Waste Management and Wastewater treatment Companies** are key operational partners for the collection, transportation, sorting, and pre-processing of AHP waste and, potentially, for handling WWTP sludge.

- **Technology Providers and SRM Producers:** This category includes the developers and implementers of the core recycling technologies. For ICARUS, this involves **Technology Providers for AHP/WWTP Cellulose Recycling** (e.g., ICARUS partners IFOR, SMC Group) who are responsible for the sterilization, purification, and fiber recovery processes.

- **End-User Industries and Downstream Markets:** The primary target for the upcycled cellulose fibers is the **Construction Industry**, specifically **Concrete Producers** and **Construction Companies** (e.g., ICARUS partner ACCIONA) who would use the fibers as an additive in concrete formulations. Beyond this, the **Chemical Industry** represents a potential downstream market for valorizing cellulose or recovered SAP into products like carboxymethylcellulose (CMC) or other chemical intermediates.

- **Regulatory, Policy, and Standardization Bodies:** These entities shape the legal and normative framework. They include **National and EU Environmental Agencies** (for waste classification, End-of-Waste criteria, emissions from processing facilities), **Health Authorities** (critical for ensuring the safety of recycled materials from sensitive sources like AHPs and WWTP sludge), **Waste Management Authorities**, and **Construction Standards Bodies** (e.g., CEN, national bodies) responsible for approving new construction additives and updating relevant codes. **Policymakers** at all levels influence waste management policies and circular economy incentives.

- **Civil Society, and Research Community: AHP Manufacturers** are important as their product design choices (eco-design) significantly impact recyclability. **Retailers and Distributors of AHPs** can be key partners in collection schemes or public awareness campaigns. **Civil Society Organizations (CSOs), Environmental NGOs, and Health Advocacy Groups** will scrutinize the process for its environmental and public health implications. **Research Institutions and Academia** (e.g., ICARUS partner CAR) provide crucial technical expertise, independent testing and validation, Life Cycle Assessments (LCA), and contribute to innovation.

- **Economic and Financial Actors: Investors and Funding Agencies** are essential for financing the scaling-up of recycling facilities and the commercialization of the cellulose-based SRMs.

Engaging these diverse stakeholders, understanding their specific needs, concerns (particularly around hygiene, safety, and cost for this demo case), and potential contributions, is fundamental for overcoming the non-technological barriers to upcycling urban waste cellulose.

6.2. Mapped Social and Non-Technological Barriers for Cellulose Upcycling

This section details the social and non-technological barriers identified for the upcycling of urban waste cellulose, distinguishing between common barriers and those specific to AHP or WWTP feedstocks.

6.2.1. Common Barriers for Cellulose Upcycling (AHP & WWTP)

Table 6 Common Social and Non-Technological Barriers for Cellulose Upcycling (AHP & WWTP - Demo Case 2)

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority
CCU01	Social/Cultural	Public Perception ("Yuck Factor")	Negative public reaction to using materials from AHP waste or WWTP sludge in construction due to hygiene/contamination concerns.	Market rejection of end-products, reputational damage to project and partners, difficulty in siting facilities.	General Public, Construction End-Users, Local Communities, Policymakers.	High
CCU02	Regulatory/Policy	End-of-Waste (EoW) Criteria	Lack of clear, harmonized, or established EoW criteria for processed cellulose from AHP/WWTP sources, hindering its use as an SRM.	Market entry barriers, legal uncertainty, increased compliance costs, delays in commercialization.	Regulatory Bodies, Project Partners (IFOR, SMC, ACCIONA Agua), Waste Management Sector, Construction Industry.	High
CCU03	Technical/Operational	Product Quality & Consistency	Ensuring consistent quality (purity, fiber length, absence of contaminants) of cellulose SRMs from variable waste feedstocks.	Inconsistent performance in concrete, rejection by end-users, processing difficulties.	ACCIONA (Construction), Concrete Producers, IFOR, SMC, Research Institutions (CAR).	High
CCU04	Economic/Market	Cost Competitiveness	Processed cellulose SRM may not be cost-competitive with virgin cellulose or existing synthetic additives (e.g., polypropylene fibers).	Low market adoption, economic unviability of the upcycling process.	ACCIONA (Construction), Concrete Producers, Project Partners (IFOR, SMC, ACCIONA Agua), Investors.	High
CCU05	Regulatory/Policy	Health & Safety Standards	Meeting stringent health and safety standards for the SRM and its end-use in construction, ensuring no risk from residual contaminants.	Product recalls, legal liabilities, loss of consumer/worker trust, and market access restrictions.	Health Authorities, Regulatory Bodies, Construction Workers, General Public, End-Users, Project Partners.	Medium

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority
CCU06	Economic/Market	Market Acceptance by Construction Industry	Reluctance of the conservative construction sector to adopt novel SRMs, especially from unconventional waste sources.	Slow market penetration, low demand, preference for established materials.	Construction Companies, Concrete Producers, Architects, Engineers, Specifiers.	Medium
CCU07	Informational	Lack of Awareness/Data	Insufficient knowledge among end-users and specifiers about the benefits, performance, and safe use of cellulose SRMs in concrete.	Low adoption rates, misperceptions, resistance to change.	Construction Professionals, Concrete Producers, Policymakers, General Public.	Medium
CCU08	Technical/Operational	Scale-up of Technology	Challenges in scaling up the recycling and purification technologies from pilot to industrial scale efficiently and economically.	Delays in commercialization, higher production costs, inability to meet market demand.	IFOR, SMC Group, Investors, Technology Licensors.	Medium
CCU09	Logistical	Supply Chain Complexity	Establishing a new, complex supply chain for collection, transport, processing of AHP/WWTP waste, and distribution of SRMs.	High logistical costs, supply disruptions, coordination difficulties.	Waste Management Companies, Municipalities, ACCIONA Agua, IFOR, SMC, ACCIONA (Construction), Logistics Providers.	Medium

6.2.2. Barriers Specific to AHP Feedstock

Table 7 Application-Specific Barriers for Cellulose Upcycling from AHP Feedstock (Demo Case 2)

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority
AHP01	Social/Cultural	Citizen Participation in Collection	Low citizen participation in separate AHP collection schemes due to inconvenience, lack of awareness, or privacy concerns.	Insufficient feedstock quantity/quality, high collection costs, scheme failure.	General Public, Municipalities, Waste Management Companies, IFOR, SMC.	High
AHP02	Logistical	AHP Collection Infrastructure	Lack of widespread, efficient, and hygienic infrastructure for separate collection and pre-sorting of AHP waste.	High collection costs, contaminated feedstock, limited geographical reach.	Municipalities, Waste Management Companies, Retailers, Institutions (hospitals, care homes).	High
AHP03	Technical/Operational	Feedstock Heterogeneity (AHP)	High variability in AHP product composition (brands, materials, SAP content) and contamination levels (organic matter).	Processing challenges, inconsistent SRM quality, higher purification costs.	IFOR, SMC Group, Technology Developers.	High
AHP04	Economic/Market	Cost of Separate Collection	Higher costs associated with establishing and operating separate AHP collection systems compared to mixed waste disposal.	Financial burden on municipalities or consumers, potential for schemes to be unviable.	Municipalities, Waste Management Companies, Consumers.	Medium
AHP05	Regulatory/Policy	Data Privacy (AHP)	Concerns regarding data privacy if AHP collection involves tracking or personal information (e.g., from institutions).	Reluctance from institutions/individuals to participate, legal compliance issues.	Institutions (hospitals, care homes), Individuals, Data Protection Authorities.	Low
AHP06	Informational	Awareness of AHP Recycling Options	Low awareness among public and policymakers about the possibility and benefits of AHP recycling.	Lack of political will for collection schemes, low citizen engagement.	General Public, Policymakers, Municipalities, Media.	Medium

6.2.3. Barriers Specific to WWTP Feedstock

Table 8 Application-Specific Barriers for Cellulose Upcycling from WWTP Feedstock (Demo Case 2)

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority
WWT01	Technical/Operational	Contaminant Profile (WWTP)	Presence of diverse and potentially harmful contaminants in WWTP sludge (heavy metals, pathogens, pharmaceuticals, microplastics).	Complex and costly purification needed, risk of SRM contamination, negative public perception.	ACCIONA Agua, IFOR, SMC, Health Authorities, Environmental Agencies, Research Institutions.	High
WWT02	Technical/Operational	Cellulose Recovery Efficiency	Efficiency and selectivity of cellulose recovery technology (e.g., RBFs) from WWTP sludge; impact of wastewater characteristics.	Low yield of cellulose, high operational costs, inconsistent SRM quality.	ACCIONA Agua, Technology Providers (RBF), Research Institutions.	Medium
WWT03	Economic/Market	Cost of Cellulose Extraction	Economic viability of extracting and purifying cellulose from WWTP sludge compared to its market value or alternative disposal costs.	Process may not be economically sustainable without subsidies or high SRM value.	ACCIONA Agua, Investors, Policymakers.	Medium
WWT04	Regulatory/Policy	Sludge Management Regulations	Existing regulations for sewage sludge disposal and use may conflict with or not adequately cover its valorization into SRMs.	Legal uncertainties, permitting challenges for recovery facilities.	Environmental Agencies, Waste Regulators, ACCIONA Agua.	Medium
WWT05	Logistical	Integration with WWTP Operations	Integrating cellulose recovery units into existing WWTP infrastructure and operations without disrupting core treatment processes.	Operational complexities, space constraints at WWTPs, potential for process interference.	ACCIONA Agua, WWTP Operators.	Medium

6.3. High-Priority Barriers for Cellulose Upcycling

Based on the detailed mapping in Section 4.2, the following social and non-technological barriers are identified as high priority for the upcycling of urban waste cellulose from both AHP and WWTP sources. These are critical for achieving market uptake and the overall success of Demo Case 2:

1. **Public Acceptance and Trust (Hygiene & Health Concerns - CCU01, CCU05):** The "yuck factor" associated with feedstocks like AHPs and WWTP sludge, coupled with perceived health risks from potential contaminants, poses a major hurdle. Gaining public and end-user trust in the safety and appropriateness of the derived SRMs is paramount.

2. **Regulatory Framework and End-of-Waste (EoW) Status (CCU02, AHP01, WWT04):** The lack of clear, harmonized EoW criteria for processed cellulose from these specific waste streams creates significant legal uncertainty and market entry barriers. This is compounded by the need for robust health and safety standards for the SRMs and their end-products.

3. **Feedstock Collection, Quality, and Consistency (AHP01, AHP02, AHP03, WWT01, CCU03):**

    a. For AHPs, establishing efficient, hygienic, and widely adopted separate collection schemes is crucial for obtaining sufficient and suitable quality feedstock. Low citizen participation is a key risk.

    b. For both AHP and WWTP sources, the inherent heterogeneity and potential contamination of the feedstock present significant technical challenges to producing a consistent, high-quality, and safe SRM.

4. **Economic Viability and Market Competitiveness (CCU04, AHP04, WWT03):** The entire value chain, from waste collection and processing to the final application in concrete, must be economically viable. The upcycled cellulose SRM needs to be cost-competitive with existing alternatives (like polypropylene fibers) and demonstrate clear performance benefits to convince a conservative construction industry.

5. **Demonstrating Product Performance and Safety to End-Users (CCU03, CCU05, CCU06):** The construction industry requires robust evidence of the technical performance (e.g., crack reduction, durability) and safety of any new material. Overcoming skepticism and integrating the cellulose SRM into existing practices will require strong validation and clear communication of benefits.

6.4. Suggested Co-creation Actions and Guidelines for Demo Case 2

To effectively address the high-priority social and non-technological barriers identified for Demo Case 2 (Upcycling Urban Waste Cellulose), a comprehensive co-creation approach is essential. These actions are suggestions for the demo leaders (ACCIONA Agua, IFOR, SMC Group, ACCIONA Construction) with support from SOF, CAR, and other relevant partners. Implementation will depend on resources, but inaction on these high-priority areas carries significant risk. The overarching co-creation strategies detailed in Chapter 7 should be applied and tailored as follows:

1. Implementing the ICARUS Strategy for Building Societal Trust and Acceptance (see Section 8.1): *(Addresses High-Priority Barrier 1: Public Acceptance and Trust - CCU01, CCU05)*

- Suggestion 4.4.1: Tailor Communication Materials to Address "Yuck Factor" and Hygiene Concerns for Cellulose.

- *Action for Demo Leaders (IFOR, ACCIONA Agua, with SOF, REV - WP3):* Utilize the *Unified ICARUS Communication & Transparency Framework* (8.1.1). Conduct participatory workshops specifically focused on AHP and WWTP cellulose with diverse public segments (parents, elderly care representatives, environmental groups, local residents). The PSCG and a dedicated "Cellulose Upcycling Community Panel" should co-validate these materials.
    - *Purpose:* To co-develop information packages that transparently explain the sterilization, purification (T8.2), and safety testing (CCU05) processes, directly addressing the "yuck factor" and health concerns. Emphasize the transformation from "waste" to a safe, high-quality SRM.
- Suggestion 4.4.2: Implement Cellulose-Specific Participatory Monitoring & Open Data Initiatives.
- *Action for Demo Leaders (IFOR, SMC, ACCIONA Agua, with Health Authorities):* Apply the *ICARUS Co-designed Participatory Monitoring & Open Data Initiative* (8.1.2) for cellulose SRMs. Co-design protocols with community representatives and health authorities for transparently sharing data on contaminant removal efficacy and final product safety.
    - *Purpose:* To build confidence by demonstrating adherence to the highest safety standards (CCU05) through accessible data.
- Suggestion 4.4.3: Organize Co-designed Showcases for Cellulose Recycling and Application (Enhancing T17.1).
- *Action for Demo Leaders (IFOR, SMC, ACCIONA Construction, with REV - WP17):* Apply the *ICARUS Cross-Demo Showcase Protocol* (8.1.3) to the cellulose demo. Focus on showcasing the advanced recycling technology (mobile unit for AHP/WWTP cellulose - T8.2) and the performance of cellulose-enhanced concrete (T8.3).
    - *Purpose:* To allow stakeholders (including public, policymakers, construction industry) to witness the process and product, ask questions, and build trust. Co-design "Open Day" elements with local communities.

2. Implementing the ICARUS Strategy for Co-creating Supportive Regulatory Landscapes and Standards (see Section 8.2): *(Addresses High-Priority Barrier 2: Regulatory Framework and EoW Status - CCU02, CCU05, WWT04, AHP01)*

- Suggestion 4.4.4: Drive Cellulose-Specific Inputs to the ICARUS Regulatory & Standardization Task Force.
- *Action for Demo Leaders (ACCIONA - overall coordinator, with ISQ - WP10, IFOR, ACCIONA Agua):* Ensure the specific regulatory challenges for processed cellulose from AHP/WWTP (EoW criteria - CCU02, health & safety standards - CCU05, sludge management regulations - WWT04, AHP collection regulations - AHP01) are key agenda items for the *ICARUS Regulatory & Standardization Co-creation Task Force* (8.2.1).
    - *Purpose:* To collaboratively develop robust technical dossiers and policy recommendations with regulators to establish clear EoW pathways and appropriate safety standards for these novel SRMs.

3. Co-creating Solutions for Feedstock Collection, Quality, and Consistency: *(Addresses High-Priority Barrier 3; related to AHP01, AHP02, AHP03, WWT01, CCU03)*

- Suggestion 4.4.5: Implement Co-designed and Piloted AHP Separate Collection Schemes.

    - *Action for Demo Leaders (IFOR, SMC, with Municipalities, Waste Management Co., Retailers, Citizen Groups, SOF):* Execute the planned citizen engagement for AHP collection (DC2 Methodology, Phase 4) through participatory workshops to co-design practical, user-friendly, and economically viable separate collection systems for AHP waste in selected pilot areas.

    - *Purpose:* To increase feedstock quantity (AHP01) and quality (AHP03) by addressing collection infrastructure (AHP02). Explore different models (e.g., curbside, drop-off points, institutional collections), co-develop awareness campaigns (linking to WP3/11), and test incentive mechanisms. This is a unique action critical for the AHP stream.

- Suggestion 4.4.6: Intensify Collaboration with AHP Manufacturers on "Design for Recycling" through Co-creative Workshops.

    - *Action for Demo Leaders (IFOR, SMC):* Elevate the planned "Interviews with AHP manufacturers" (DC2 Methodology, Phase 4) to formal "dialogue and collaborative workshops."

    - *Purpose:* To co-explore and promote eco-design principles for AHPs that would enhance their recyclability (e.g., material choices, component separability, reduction of problematic substances), thus improving feedstock quality (AHP03) and addressing a specific upstream barrier.

- Suggestion 4.4.7: Apply the ICARUS Quality Management Framework to Cellulose Feedstock and SRMs.

- *Action for Demo Leaders (IFOR, SMC, ACCIONA Agua, CAR):* Utilize the *ICARUS Quality Management Framework for SRMs* (8.3.2). Work collaboratively with waste suppliers (municipalities, WWTPs) and technology providers in co-creative workshops to establish protocols for feedstock characterization (addressing WWT01 - contaminant profile, AHP03 - heterogeneity), pre-sorting, and quality assessment before and after recycling (T8.1, T8.2).

    - *Purpose:* To manage feedstock heterogeneity and minimize contaminants early, ensuring consistent quality cellulose SRM (CCU03).

4. Implementing the ICARUS Strategy for Co-developing Economically Viable Solutions (see Section 8.4): *(Addresses High-Priority Barrier 4; related to CCU04, AHP04, WWT03)*

- Suggestion 4.4.8: Develop Cellulose-Specific Business Models via Co-creative Workshops (WP4, WP12, WP18).

- *Action for Demo Leaders (PNO, with ACCIONA, IFOR, SMC, ACCIONA Agua, potential investors):* Apply the *Business Model Canvas Workshop* approach (8.4.1) to the urban cellulose value chain.

    - *Purpose:* To collaboratively develop and refine business models, transparently analyzing costs (AHP collection - AHP04, WWTP cellulose extraction - WWT03, overall processing) and identifying value propositions that ensure competitiveness of the cellulose SRM (CCU04).

5. Implementing the ICARUS Strategy for Ensuring Technical Viability and End-User Confidence (see Section 8.3): *(Addresses High-Priority Barrier 5; related to CCU03, CCU05, CCU06)*

- Suggestion 4.4.9: Utilize the ICARUS End-User Co-Validation Platform for Cellulose in Construction.
    - *Action for Demo Leaders (ACCIONA Construction, with CAR, concrete producers, construction firms, engineers, architects, WP15 leader):* Apply the *ICARUS End-User Co-Validation Platform/Methodology* (7.3.1) for the cellulose SRM in concrete (from T8.3). Jointly design testing programs. Involve panel members in reviewing results and co-authoring technical guidelines.
    - *Purpose:* To ensure testing protocols and performance evaluations (CCU03) are relevant to construction industry needs, build credibility against market acceptance barriers (CCU06), and validate safety (CCU05).
- Suggestion 4.4.10: Co-develop Case Studies and Demonstration Sites for Cellulose-Enhanced Concrete (Enhancing T17.1).
    - *Action for Demo Leaders (ACCIONA Construction, with REV - WP17):* As part of T17.1 demo events, identify and co-develop real-world demonstration projects for concrete containing upcycled cellulose.
    - *Purpose:* To showcase performance and build confidence. Co-develop case study materials (technical reports, videos, testimonials from users) with partners involved in these demonstrations.

Note on Implementation: The success of Demo Case 2 is heavily reliant on overcoming significant perceptual ("yuck factor") and logistical hurdles (AHP collection). The suggested co-creation actions are designed to be iterative and adaptive. Demo leaders should prioritize actions that build trust and demonstrate safety unequivocally, as these are foundational. Consistent and transparent communication, coupled with genuine stakeholder involvement in problem-solving and decision-making, will be critical.

7. Demo case 3: Steelmaking slag upgrading and valorisation through different stabilization methods

7.1. Overview of Demo Case 3 and Key Stakeholder Groups

Demo Case 3 focuses on upcycling steelmaking slags (specifically Basic Oxygen Furnace – BOF slag, Electric Arc Furnace – EAF slag, and Eletric Arc Furnace – Ladle slag) into alternative raw materials for the construction sector, incorporating Carbon Capture and Storage (CCS) through mineral carbonation. The process aims to stabilize the slags (addressing issues like volumetric expansion due to free lime) and potentially produce Precipitated Calcium Carbonate (PCC) as a valuable co-product. Targeted applications include:

- **Internal Valorization in Steelmaking:** Coarser slag fractions as a calcium and iron source.
- **Concrete Production:** Processed slags as a sand and/or filler replacement.
- **Ceramic Tiles:** Stabilized slags to replace chrome-based pigments.
- **Sustainable Precipitated Calcium Carbonate (PCC):** For various markets (e.g., paper, plastics, construction).

Key partners involved in leading various aspects of this demo case include ArcelorMittal (AMI3, AME, AMMR - slag generation and internal valorization), CALES DE LLIERCA (slag treatment and carbonation technology), ACCIONA (construction applications), and KERABEN/CSIC-ICV (ceramic applications).

Key Stakeholder Groups for Demo Case 3:

The valorization of steelmaking slags through mineral carbonation involves a wide array of stakeholders crucial for its technical, economic, social, and regulatory success:

- **Primary Industrial Actors:** This core group includes the **Steel Industry** (e.g., ICARUS partners ArcelorMittal - AMI3, AME, AMMR) as the generators of BOF and EAF slags and potential internal users of treated slag. **Technology Providers and Material Processors** (e.g., ICARUS partner CALES DE LLIERCA) are central to developing and implementing the slag treatment, carbonation, and PCC production technologies.

- **End-User Industries for Slag-Derived Products:**

- **Construction Sector:** This includes **Construction Companies** (e.g., ICARUS partner ACCIONA) and **Concrete Producers** who are potential users of stabilized slag as an aggregate or filler replacement. Other entities include **Cement Manufacturers** (for blended cements), **Road Construction Companies**, and **Manufacturers of Construction Products** (e.g., blocks, pavers).

- **Ceramic Industry:** (e.g., ICARUS partner KERABEN and research partner CSIC-ICV) are potential end-users of stabilized slags as pigments or raw material components in tiles and other ceramic bodies.

- **PCC Consumers:** A diverse group including industries such as **Paper (as filler/coating), Plastics (as filler), Paints & Coatings (as extender/filler), Adhesives & Sealants, and potentially Food/Pharma** (requiring very high purity, which may be a challenge for slag-derived PCC). This group also includes **Manufacturers of Construction Materials** that use PCC (e.g., in mortars, plasters, asphalt).

- **Steel Industry (Internal Use):** As mentioned, ArcelorMittal itself is an end-user for internal valorization of coarser slag fractions, potentially as a flux or raw material substitute in the steelmaking process.

- **CO_2 and Energy Value Chain: CO_2 Emitters/Suppliers** are critical if CO_2 is not solely sourced from the steel plant's flue gases; this could include other nearby industrial emitters (e.g., cement plants, power plants, refineries). **CO_2 Transportation and Logistics Providers** may also be involved. **Energy Providers** are relevant due to the energy demands of the carbonation process, with a preference for renewable energy sources to enhance sustainability.

- **Regulatory, Policy, and Standardization Bodies:** This group includes **National and EU Environmental Agencies** (regulating slag management, emissions, EoW criteria for treated slags and PCC), **Industrial Emissions Authorities** (governing CO_2 capture and industrial processes), **Climate Policy Bodies** (relevant for CCSU frameworks and CO_2 accounting, carbon pricing/ETS), and **Construction, Ceramic, and Chemical Standards Bodies** (e.g., CEN, ISO, national bodies like AENOR) responsible for product standards, safety, and performance criteria. **Policymakers** at all levels influence frameworks for CCSU, circular economy, industrial decarbonization, and green public procurement.

- **Civil Society, Local Communities, and NGOs: Local Communities** residing near steel plants or potential new slag processing/carbonation facilities are key stakeholders concerned with environmental impacts (dust, noise, traffic, land use, water quality) and socio-economic effects (jobs, local economy). **Environmental NGOs and Climate Action Groups** will scrutinize the CCSU aspects, the overall carbon footprint, the "permanence" of CO_2 storage in mineralized form, and the sustainability claims of the process. **Trade Unions and Worker Representatives** will be interested in occupational health and safety and job quality.

- **Research, Academia, and Technical Experts: Research Institutions** (e.g., ICARUS partner CARTIF, CSIC-ICV) and universities provide expertise in carbonation chemistry, material science, process engineering, LCA, socio-economic assessment, geology (for CO_2 sourcing if applicable), and public perception studies. **Technical Consultants and Engineering Firms** may also be involved in plant design, implementation, and safety assessments.

- **Financial and Market Actors: Investors, Banks, and Funding Agencies** are vital for financing the development and deployment of the technology. **Carbon Market Actors** (e.g., traders, verifiers) could become relevant if carbon credits or specific CO_2 pricing mechanisms are part of the business model. **Industry Associations** (e.g., steel, cement, chemical, construction, PCC producers) play a role in disseminating information, shaping industry perspectives, and advocating for supportive policies.

Successfully navigating the complexities of Demo Case 3 requires proactive and tailored engagement with these diverse stakeholder groups to address their specific interests, concerns, and potential contributions.

7.2. Mapped Social and Non-Technological Barriers for Steel Slag Upcycling with CCS

This section details the social and non-technological barriers identified for the upcycling of steelmaking slags with CCS, distinguishing between common barriers and those specific to the different applications.

7.2.1. Common Barriers for Steel Slag Upcycling with CCS

Table 9 Common Social and Non-Technological Barriers for Steel Slag Upcycling with CCS (Demo Case 3)

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority
SC001	Social/Cultural	Public Perception of CCS	Different public/stakeholder perceptions of Carbon Capture and Storage/Utilization (CCSU) technologies, concerns about safety and efficacy.	Opposition to project, permitting delays, reputational damage, difficulty securing social license to operate.	General Public, Local Communities, Environmental NGOs, Climate Action Groups, Policymakers.	High
SC002	Regulatory/Policy	CCS Regulatory Framework	Lack of clear, comprehensive, or supportive regulatory framework for mineral carbonation as a CCSU method, including CO_2 accounting and long-term storage liability.	Legal uncertainty, investment risk, difficulty in monetizing CO_2 reduction, permitting challenges.	Regulatory Bodies (Environmental, Climate), Policymakers, Steel Industry, Technology Providers.	High
SC003	Economic/Market	Economic Viability of Carbonation	High capital and operational costs of carbonation technology; economic feasibility dependent on carbon pricing, PCC market value, and cost of CO_2.	Process may not be economically viable, hindering industrial uptake.	Steel Industry (ArcelorMittal), Technology Providers (CALES DE LLIERCA), Investors, PCC Consumers.	High
SC004	Technical/Operational	Slag Feedstock Variability & Quality	Inconsistent chemical/physical properties of BOF/EAF slags affecting carbonation efficiency and quality of treated slag/PCC.	Inconsistent product quality, processing inefficiencies, and higher operational costs.	Steel Industry (ArcelorMittal), CALES DE LLIERCA, End-users (Construction, Ceramics).	High
SC005	Regulatory/Policy	End-of-Waste (EoW) for Treated Slag	Uncertainty in achieving EoW status for stabilized slags, impacting their marketability as SRMs rather than waste.	Market entry barriers, increased disposal costs if not EoW, legal compliance issues.	Regulatory Bodies, Steel Industry, End-users, Waste Management Sector.	High

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority
SC006	Environmental	Life Cycle Assessment (LCA) & Net CO_2	Difficulty in demonstrating a clear net CO_2 reduction and overall positive environmental impact through LCA, considering energy inputs for carbonation.	"Greenwashing" accusations, skepticism from environmental groups and policymakers, challenges in claiming carbon credits.	Environmental NGOs, Regulatory Bodies, Research Institutions (CARTIF), General Public.	Medium
SC007	Technical/Operational	Integration with Steel Plant Operations	Complexities and costs of integrating carbonation units with existing steelmaking processes (e.g., flue gas utilization, heat integration, space).	High retrofitting costs, operational disruptions, resistance from steel plant operators.	Steel Industry (ArcelorMittal), Technology Providers.	Medium
SC008	Informational	Lack of Awareness (Mineral Carbonation)	Limited understanding among stakeholders (including policymakers and public) about mineral carbonation as a specific CCSU pathway and its benefits for slag.	Low support for policy incentives, misperceptions, difficulty in differentiating from geological CO_2 storage.	Policymakers, General Public, Media, Industry Associations.	Medium
SC009	Social/Cultural	Community Acceptance (Processing Sites)	Potential local community concerns (NIMBY) regarding new slag processing/carbonation facilities (dust, noise, traffic, land use).	Permitting delays, local opposition, project delays.	Local Communities, Local Government, Steel Industry, Technology Providers.	Medium

7.2.2. Application-Specific Barriers: Sustainable Precipitated Calcium Carbonate (PCC)

Table 10 Application-Specific Barriers for Sustainable Precipitated Calcium Carbonate (PCC) from Steel Slag (Demo Case 3)

ID	BarrierType	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority
PCC01	Economic/Market	Market Competitiveness of PCC	PCC derived from slag must compete with established PCC (from limestone) and other materials in terms of price, purity, and performance.	Low market share, difficulty entering established PCC markets (paper, plastics, construction).	PCC Consumers, CALES DE LLIERCA, Steel Industry, Existing PCC Producers.	High
PCC02	Technical/Operational	PCC Quality & Purity	Achieving consistent PCC quality (particle size, morphology, brightness, purity) suitable for specific high-value applications.	Limited to lower-value applications, rejection by demanding customers (e.g., paper industry).	PCC Consumers (Paper, Plastics, Pharma), CALES DE LLIERCA, Research Institutions.	High
PCC03	Regulatory/Policy	Standards for PCC from SRMs	Lack of specific standards or certifications for PCC produced from SRMs, potentially creating market hesitancy.	Difficulty in market penetration, need for extensive customer-specific validation.	Standardization Bodies, Certification Bodies, PCC Consumers.	High

7.2.3. Application-Specific Barriers: Civil Construction (Slag as Aggregate/Filler Replacement)

Table 11 Application-Specific Barriers for Steel Slag as Aggregate/Sand Replacement in Civil Construction (Demo Case 3)

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority
CIV01	Technical/Operational	Long-term Durability & Performance	Ensuring stabilized slag aggregates provide equivalent or superior long-term performance and durability in concrete compared to natural aggregates (e.g., ASR, freeze-thaw).	Reduced service life of structures, liability concerns, reluctance from construction sector.	Construction Industry (ACCIONA), Concrete Producers, Engineering Firms, Research Institutions (UL, CARTIF).	High
CIV02	Regulatory/Policy	Construction Codes & Standards	Lack of inclusion or specific provisions for stabilized steel slags in building codes and aggregate/concrete standards.	Limited use in regulated projects, need for extensive testing and lengthy approval processes.	Standardization Bodies, Regulatory Bodies (Construction), Construction Industry, Engineering Firms.	High
CIV03	Economic/Market	Conservative Construction Sector	High degree of conservatism in construction, resistance to adopting new/alternative materials without a long, proven track record and clear cost benefits.	Slow market adoption, preference for traditional materials, difficulty in achieving widespread use.	Construction Industry, Concrete Producers, Specifiers, Contractors.	Medium
CIV04	Environmental	Leaching from Slag Concrete	Concerns about potential long-term leaching of substances from concrete made with stabilized slag.	Environmental contamination, negative public perception, regulatory scrutiny.	Environmental Agencies, Local Communities, Construction End-Users.	Medium

7.2.4. Application-Specific Barriers: Internal Use in Steelmaking

Table 12 Application-Specific Barriers for Internal Use of Treated Steel Slag in Steelmaking (Demo Case 3)

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority
INT01	Technical/Operational	Impact on Steelmaking Process	Ensuring the use of treated slag (coarser fraction) internally does not negatively affect sinter quality, blast furnace/EAF operation, or steel quality.	Operational issues in steel plant, reduced efficiency, off-spec steel, resistance from plant operators.	Steel Industry (ArcelorMittal - AME, AMMR), Plant Operators.	High
INT02	Economic/Market	Cost-Benefit of Internal Reuse	Demonstrating clear economic benefits (e.g., replacement of lime/iron ore, energy savings) of reusing treated slag internally versus other options.	Low adoption by steel plants if benefits are not significant or if processing costs are too high.	Steel Industry (ArcelorMittal), Financial Department of Steel Plants.	High
INT03	Technical/Operational	Handling & Logistics within Plant	Developing efficient and safe systems for handling, transporting, and introducing the treated slag back into the steelmaking process.	Increased operational complexity, potential safety hazards, logistical bottlenecks within the steel plant.	Steel Industry (ArcelorMittal), Plant Logistics, Health & Safety Dept.	Medium

7.2.5. Application-Specific Barriers: Ceramic Applications

Table 13 Application-Specific Barriers for Steel Slag in Ceramic Applications (Demo Case 3)

ID	Barrier Type	Barrier Subtype	Description	Foreseeable Impact on Project	Affected Stakeholders	Priority
CER_S01	Technical/Operational	Pigment Performance & Stability	Ensuring stabilized slag-based pigments provide desired color, consistency, and stability during ceramic firing and in the final product; avoiding defects.	Off-spec ceramic products, color variations, rejection by ceramic manufacturers, limited aesthetic appeal.	Ceramic Industry (KERABEN), CSIC-ICV, Ceramic Designers, Pigment Producers.	High
CER_S02	Regulatory/Policy	Chemical Safety in Ceramics	Ensuring ceramic products using slag-based pigments meet all chemical safety standards (e.g., heavy metal leaching from pigments/glazes).	Product recalls, consumer health risks, legal liabilities, market access restrictions.	Ceramic Industry, Regulatory Bodies (Consumer Safety), Certification Bodies, General Public.	High
CER_S03	Economic/Market	Cost vs. Conventional Pigments	Cost-effectiveness of producing and using slag-based pigments compared to existing chrome-based or other conventional ceramic pigments.	Low adoption by ceramic industry if not cost-competitive or if performance benefits do not justify potential cost increase.	Ceramic Industry (KERABEN), Pigment Producers.	Medium
CER_S04	Technical/Operational	Interaction with Glazes/Body	Ensuring compatibility of slag-based pigments with ceramic bodies and glazes, avoiding negative interactions that affect final product properties.	Defects in ceramic products (e.g., bloating, discoloration, poor glaze adhesion), production issues.	Ceramic Industry (KERABEN), CSIC-ICV, Glaze Manufacturers.	Medium

7.3. High-Priority Barriers for Steel Slag Upcycling with CCS

Based on the detailed mapping in Section 5.2, the following social and non-technological barriers are identified as high priority for the upcycling of steelmaking slags with Carbon Capture and Storage (CCS) via mineral carbonation. These priorities consolidate common and application-specific concerns:

1. **Public and Stakeholder Perception of CCS and Slag-Derived Products (SC001, SC009, CIV04):** This includes negative perceptions of CCS technologies in general, concerns about the safety and environmental impact of using "waste" (slag) and carbonated materials in applications like construction and ceramics, and potential NIMBYism related to processing facilities. Overcoming skepticism and building trust is fundamental.

2. **Economic Viability of the Integrated Process (SC003, PCC01, INT02, CER_S03):** The overall economic feasibility of slag carbonation and the subsequent use of treated slag and PCC is critical. This involves the cost of carbonation, the market value and competitiveness of the derived products (PCC, aggregates, pigments) against conventional alternatives, and the economic benefits of internal reuse within steelmaking.

3. **Regulatory Framework and Standardization (SC002, SC005, PCC03, CIV02, CER_S02):** The lack of a clear, supportive regulatory framework for mineral carbonation as a CCSU method, uncertainty in achieving End-of-Waste (EoW) status for treated slags, and the absence of or difficulty in meeting specific standards for carbonated slag products (PCC, aggregates, ceramic pigments) in various applications pose significant hurdles to market entry and investment. Chemical safety standards for end-products are also paramount.

4. **Technical Performance and Quality Consistency (SC004, PCC02, CIV01, INT01, CER_S01):** Ensuring consistent quality of the treated slag and PCC from variable feedstock (BOF/EAF slags) is crucial. Furthermore, these upcycled materials must meet or exceed the stringent technical performance and durability requirements of their respective end-use applications (PCC quality, long-term durability in concrete, impact on steelmaking, pigment performance in ceramics).

7.4. Suggested Co-creation Actions and Guidelines for Demo Case 3

To effectively address the high-priority social and non-technological barriers identified for Demo Case 3 (Upcycling Steelmaking Slags via CCS), a robust co-creation strategy is proposed. The following actions are suggestions for the demo leaders (ArcelorMittal, CALES DE LLIERCA, ACCIONA, KERABEN, CSIC-ICV, CARTIF) with support from SOF and other relevant partners. Implementation will depend on available resources, time, and budget, but neglecting these high-priority areas significantly increases project risk. The overarching co-creation strategies detailed in Chapter 7 should be applied and tailored as follows:

1. Implementing the ICARUS Strategy for Building Societal Trust and Acceptance (see Section 8.1): *(Addresses High-Priority Barrier 1: Public and Stakeholder Perception of CCS and Slag-Derived Products - SC001, SC008, SC009, CIV04)*

- Suggestion 5.4.1: Tailor Communication Materials for Mineral Carbonation and Slag Valorization.

- *Action for Demo Leaders (ArcelorMittal, CALES DE LLIERCA, with REV - WP3, SOF):* Utilize the *Unified ICARUS Communication & Transparency Framework* (8.1.1). Conduct participatory workshops specifically focused on CCS via mineral carbonation and slag upcycling, involving local communities near steel plants, environmental NGOs, climate action groups, and science communicators. The PSCG and a dedicated "Steel Slag & CCS Community Panel" should co-validate these materials.

  - *Purpose:* To co-develop information packages that clearly explain mineral carbonation, differentiate it from other CCS methods, highlight benefits for slag valorization and CO2 mitigation, and transparently address concerns about safety, "greenwashing" (SC001), and environmental impacts (SC009, CIV04).

- Suggestion 5.4.2: Establish Slag-Specific Participatory Monitoring & Open Data Initiatives.

- *Action for Demo Leaders (ArcelorMittal, CALES DE LLIERCA, with CARTIF):* Implement the *ICARUS Co-designed Participatory Monitoring & Open Data Initiative* (8.1.2) for slag processing and carbonation sites. Co-design protocols with local stakeholders for monitoring parameters like air quality, noise, and leaching from stored/used materials.

  - *Purpose:* To ensure transparency regarding operational safety and environmental performance. Make relevant, non-sensitive data publicly accessible via the ICARUS open data portal.

- Suggestion 5.4.3: Organize Co-designed Showcases for Slag Upcycling and CCS (Enhancing T17.1).

- *Action for Demo Leaders (ArcelorMittal, ACCIONA, KERABEN, with REV - WP17):* Apply the *ICARUS Cross-Demo Showcase Protocol* (8.1.3) to the steel slag demo. Focus on showcasing the carbonation technology, the quality of treated slags and PCC, and their successful application in construction and ceramics.

  - *Purpose:* To allow stakeholders to witness the process and product, build confidence, and understand the net CO_2 benefits (linking to LCA work in SC006).

2. Implementing the ICARUS Strategy for Co-creating Supportive Regulatory Landscapes and Standards (see Section 8.2): *(Addresses High-Priority Barrier 3: Regulatory Framework and Standardization - SC002, SC005, PCC03, CIV02, CER_S02)*

- Suggestion 5.4.4: Ensure Slag & CCS-Specific Needs are Addressed by the ICARUS Regulatory & Standardization Task Force.

- *Action for Demo Leaders (ACC - Project Coordinator, with ISQ - WP10, ArcelorMittal, CALES DE LLIERCA):* Actively feed the specific regulatory challenges for treated slags (EoW - SC005), mineral carbonation as CCSU (SC002), and product standards (PCC03, CIV02, CER_S02) into the *ICARUS Regulatory & Standardization Co-creation Task Force* (8.2.1). Within this Task Force, co-develop technical dossiers and policy recommendations for clear regulatory pathways for treated steel slag products and for recognizing CO_2 utilization via mineral carbonation.

  - *Purpose:* To ensure the Task Force's engagement with regulatory bodies and standardization committees effectively addresses the unique requirements for slag valorization and CCSU accounting.

3. Implementing the ICARUS Strategy for Ensuring Technical Viability and End-User Confidence (see Section 8.3): *(Addresses High-Priority Barrier 4: Technical Performance and Quality Consistency - SC004, PCC02, CIV01, INT01, CER_S01)*

- Suggestion 5.4.5: Apply the ICARUS Quality Management Framework to Slag Feedstock, Treated Slag, and PCC.

- *Action for Demo Leaders (CALES DE LLIERCA, ArcelorMittal, with CSIC-ICV, CARTIF):* Utilize the *ICARUS Quality Management Framework for SRMs* (8.3.2) to co-develop quality specifications for BOF/EAF slags (SC004), treated steel slag aggregates, and PCC (PCC02).
    - *Purpose:* To collaboratively define critical quality parameters for each product stream and establish QC protocols to manage feedstock variability and ensure consistent performance in concrete (CIV01), internal steelmaking use (INT01), and ceramics (CER_S01).
- Suggestion 5.4.6: Conduct Slag Product Co-Validation through the ICARUS Platform (WP15).
- *Action for Demo Leaders (ACCIONA, KERABEN, ArcelorMittal, with WP15 leader):* Leverage the *ICARUS End-User Co-Validation Platform/Methodology* (8.3.1) for stabilized steel slag products. Co-design pilot testing programs with end-users for concrete applications, ceramic pigments, and internal reuse in steelmaking.
    - *Purpose:* To involve end-users in evaluating performance, durability, and integration challenges, and to co-develop modifications based on feedback.

4. Implementing the ICARUS Strategy for Co-developing Economically Viable Solutions (see Section 8.4): *(Addresses High-Priority Barrier 2: Economic Viability - SC003, PCC01, INT02, CER_S03)*

- Suggestion 5.4.7: Develop Slag/CCS-Specific Business Models via Co-creative Workshops (WP4, WP12, WP18).
- *Action for Demo Leaders (PNO, with ArcelorMittal, CALES DE LLIERCA, ACCIONA, KERABEN, potential investors):* . Apply the ICARUS Joint Business Model Canvas Innovation Workshop approach (8.4.1) to the value chain of treated steel slag, taking into account that the carbonation reaction occurs within the PCC (Precipitated Calcium Carbonate) process
    - *Purpose:* To co-create value propositions and business models for each product (PCC - PCC01, aggregates, pigments - CER_S03) and for internal reuse (INT02), considering the costs/benefits of carbonation (SC003) and potential carbon market mechanisms.
- Suggestion 5.4.8: Optimize the Steel Slag Treatment Process Value Chain through Collaborative Forums (T2.1, T16.5).
    - *Action for Demo Leaders (ArcelorMittal, CALES DE LLIERCA, with other value chain partners):* Utilize the *ICARUS PSCG contribution* to specifically map and optimize the steel slag treatment process through PCC process value chain, including CO_2 sourcing, energy inputs, and logistics for treated products.
    - *Purpose:* To collaboratively identify and address inefficiencies and cost drivers, and explore industrial symbiosis opportunities (e.g., using steel plant flue gas for CO_2 as planned, waste heat integration - SC007).

Note on Implementation: Demo Case 3 introduces the additional complexity of CCS technology, which has its own set of public perception and regulatory challenges. A highly proactive, transparent, and deeply collaborative co-creation approach is therefore indispensable. Demo leaders should prioritize building a shared, accurate understanding of mineral carbonation, demonstrating its safety and net environmental benefits, and working closely with all value chain partners to ensure technical and economic viability. Regular adaptation of these co-creation strategies based on stakeholder feedback and project learnings will be essential.

8. General co-creation strategies for the ICARUS Project

The analyses of Demo Cases 1, 2, and 3 reveal several recurring social and non-technological barriers, as well as common needs for co-creation and stakeholder engagement. This chapter aggregates these common themes and proposes synergistic co-creation strategies applicable across the ICARUS project. These overarching strategies are intended to complement the demo-specific actions and enhance the overall impact and sustainability of the project's outcomes.

8.1. Building Societal Trust and Acceptance for Upcycled Materials

A consistent high-priority barrier across all demo cases is the challenge of public perception, community acceptance, and overall trust in materials derived from waste streams (LAR, urban cellulose, steel slags). Concerns often revolve around safety, quality, environmental impact, and the "waste" stigma.

Aggregated Co-creation Strategy: Implement a project-wide, multi-channel approach to transparently communicate the safety, benefits, and sustainability of ICARUS SRMs, co-designed and validated with diverse stakeholders.

- 8.1.1. Co-develop a Unified ICARUS Communication & Transparency Framework (Leveraging WP3 and T5.4):
    - *Action for Consortium (led by REV - WP3, with SOF, and all Demo Leaders):* Utilize the stakeholder mapping (T3.1) and D&C Master Plan (D3.1) from WP3 as a foundation. Integrate insights from T5.4 co-design guidelines to co-create a project-wide communication strategy.
- *Co-creation Focus:* Involve communication experts, the PSCG (see 8.6), and public focus groups in co-designing core messages, visual identities, and accessible information packages (brochures, website content, infographics, videos) that address common concerns (e.g., "waste" stigma, general safety) and specific issues (e.g., "yuck factor" for cellulose, radioactivity for LAR, CCS perceptions for slags). The aim is to ensure materials are scientifically accurate, easily understandable, and resonate with target audiences.
    - *Synergy:* Provides consistent messaging and branding for ICARUS, while allowing demo-specific adaptation. Shared resources for high-quality material production.
- 8.1.2. Implement Co-designed Participatory Monitoring & Open Data Initiatives (Aligning with T1.4 DMP and Open Science Policy):
    - *Action for Consortium (led by technical WPs with support from SOF and research partners):* Building on the project's Data Management Plan (T1.4) and open-access repository commitment (Proposal Section 1.2.5), establish common principles for participatory environmental and safety monitoring.

  - *Co-creation Focus:* For each demo, co-design specific monitoring protocols (e.g., for dust, water quality, leaching, specific contaminants) with local communities, environmental agencies, and health officials. Train community volunteers where feasible. Utilize the ICARUS open data platform to share non-sensitive data in a user-friendly format, and co-host review meetings with stakeholders.
  - *Synergy:* Enhances transparency and credibility across the project. Shared methodologies for participatory monitoring and data presentation build collective expertise.

- 8.1.3. Organize Co-designed Cross-Demo Showcase Events and Site Visit Protocols (Enhancing T17.1):
  - *Action for Consortium (led by REV - WP17, with all Demo Leaders):* Ensure the demonstration events (T17.1) are opportunities for co-creative engagement. Develop a common protocol for safe, informative, and interactive site visits.
  - *Co-creation Focus:* Involve the PSCG and local stakeholder representatives in co-planning these events to ensure they effectively target diverse audiences, address pertinent questions, and incorporate "Open Day" formats for broader public interaction.
  - *Synergy:* Jointly planned or themed events can attract a wider range of stakeholders and policymakers. Shared protocols ensure consistent quality of engagement and trust-building.

8.2. Co-creating Supportive Regulatory Landscapes and Standards

All demo cases face challenges related to End-of-Waste criteria, product standardization, certification, and permitting processes. A coordinated, co-creative approach is essential.

Aggregated Co-creation Strategy: Proactively and collaboratively engage with regulatory and standardization bodies through a unified project-level task force to address common and specific needs for SRMs.

- 8.2.1. Develop Joint Technical Dossiers and Best Practice Guidelines through Collaborative Drafting:
- *Action for Consortium (led by technical WPs and research partners, coordinated by ISQ):* For SRMs with common applications (e.g., in construction), co-develop comprehensive technical dossiers.
  - *Co-creation Focus:* Involve end-users, certification bodies, and regulatory advisors (via the Task Force) in the co-review and refinement of these dossiers to ensure they meet market and regulatory expectations.
  - *Synergy:* Reduces duplication, provides a stronger evidence base for multiple SRMs.

8.3. Ensuring Technical Viability and End-User Confidence through Collaboration

Demonstrating the technical performance, quality, and long-term durability of upcycled materials is crucial for all demo cases.

Aggregated Co-creation Strategy: Implement a project-wide methodology for end-user co-validation and co-development of quality management practices for SRMs.

- 8.3.1. Implement an ICARUS End-User Co-Validation Platform/Methodology (for WP15):
    - *Action for Consortium (led by end-user partners like ACCIONA, KERABEN, ArcelorMittal, with WP15 leader and research partners):* Define a common co-validation methodology for WP15. This could involve an "End-User Co-Validation Platform" (virtual or workshops) for sharing feedback and validation data (from T7.3, T8.3, T9.4, T9.5, T15.1).
    - *Co-creation Focus:* Involve panels of industry professionals (architects, engineers, designers, plant operators from relevant sectors) to co-review test results, co-develop application guidelines, and provide input on product refinement.
    - *Synergy:* Shares best practices in end-user engagement. Cross-industry insights strengthen the technical case for ICARUS SRMs.
- 8.3.2. Co-develop an ICARUS Quality Management Framework for SRMs (for T2.2, T2.6):
    - *Action for Consortium (led by K-UTEC, IFOR, CALES DE LLIERCA, with technical/research partners, informing T2.2, T2.6):* Work towards a common framework for SRM quality control, addressing feedstock variability and impurity management.
    - *Co-creation Focus:* Organize cross-demo workshops with feedstock suppliers, technology providers, and end-users to co-define critical quality parameters and acceptable ranges for different applications, feeding into T2.2 (technical requirements) and T2.6 (QC tools).
    - *Synergy:* Establishes high-level quality commitment, enhancing SRM reputation. Supports DPP development (T2.5).

8.4. Co-developing Economically Viable Solutions and Market Pathways

Economic viability and cost-competitiveness are fundamental for the market uptake of all ICARUS innovations.

Aggregated Co-creation Strategy: Employ co-creative workshops and harmonized techno-economic analyses to develop robust business models and compelling value propositions for ICARUS SRMs.

- 8.4.1. Utilize Co-creative Workshops for Business Model Innovation (Enhancing WP4, WP12, WP18):
    - *Action for Consortium (led by PNO - WP4/12/18, with industrial/business partners):* Ensure business modelling WPs explicitly incorporate co-creative workshops.
    - *Co-creation Focus:* Use tools like the Business Model Canvas with demo case participants and cross-demo case partners to co-explore revenue streams, cost optimization, and value propositions for ICARUS SRMs.
    - *Synergy:* Sharing business model challenges/successes for different waste streams fosters robust models. Builds collective understanding of market barriers/enablers.
- 8.4.2. Conduct Cross-Demo Techno-Economic Analyses and Co-refine Value Propositions (Aligning with WP5/13/16):
    - *Action for Consortium (led by CAR - WP5/13/16, with PNO, technical partners):* Develop and apply a harmonized LCC/techno-economic assessment methodology (as per T5.2, T13.2, T16.2).
    - *Co-creation Focus:* Involve end-users and market experts in workshops to co-validate cost assumptions and co-refine SRM value propositions based on comparative economic and performance data.
    - *Synergy:* Standardized TEE/LCC strengthens credibility. Common economic hurdles can inform joint policy recommendations.

8.5. Strengthening Value Chains through Collaborative Engagement and Knowledge Sharing

Effective collaboration across the entire value chain, from waste generation to end-use, is critical for all demo cases.

Aggregated Co-creation Strategy: Foster holistic value chain integration and knowledge dissemination through dedicated forums and a centralized knowledge hub.

- 8.5.1. Develop an ICARUS Knowledge Hub on Upcycling Best Practices (Leveraging WP10 and Open Science commitments):
    - *Action for Consortium (led by research partners and ISQ - WP10 Skills Development, REV - WP3/11/17 for dissemination):* Create a central repository (integrated with project website and open-access repository from Section 1.2.5) for best practices, technical guidelines (T15.2), training materials (T10.3), and lessons learned from all demos.
    - *Co-creation Focus:* Involve all partners in contributing content. Use PSCG and end-user panels to co-review and validate material usefulness and accessibility.
    - *Synergy:* Creates a lasting project legacy, facilitates knowledge transfer, and supports skills development (Objective 010.2).

8.6. Operationalizing the Public Stakeholder Councilor Group (PSCG) for Co-creative Guidance

The ICARUS proposal already includes the establishment of a Public Stakeholder Councilor Group (PSCG) (Section 1.2.1, 2.1.1). This group is a critical asset for co-creation.

- **Suggestion:** Ensure the PSCG's mandate explicitly includes providing co-creative guidance on addressing social and non-technological barriers.
    - *Action for Consortium (ACC - Project Coordinator, SOF):* Strategically compose the PSCG with diverse representation (industry, regulators, academia, NGOs, consumer groups).
    - *Co-creation Activities:* Regularly engage the PSCG in dedicated workshops to review project progress on social aspects, act as a sounding board for co-creation strategies, help identify emerging barriers, facilitate connections to wider networks, and co-validate communication messages and policy recommendations.
- *Synergy:* The PSCG can provide high-level, cross-cutting insights that benefit all demo cases and ensure project activities remain aligned with broader societal expectations and needs.

8.7. Leveraging Digital Platforms as Enablers for Co-creation and Engagement

The project plans to use digital tools (DPP, monitoring tools, project website). These should be maximized for co-creation.

- **Suggestion:** Design and utilize all ICARUS digital platforms to actively support and enhance co-creation and stakeholder engagement activities.
    - *Action for Consortium (REV, ISQ, technical partners developing digital tools):* Ensure the project website (WP3) serves as a central hub for information on co-creation activities, sharing co-developed materials, and hosting online feedback mechanisms (surveys, forums).
    - *Co-creation Activities:* Employ virtual co-creation tools (online whiteboards, collaborative documents) for workshops where appropriate. Use the Digital Product Passport (T2.5, T15.3) development process as an opportunity for co-creation with value chain actors on data requirements and transparency.
    - *Synergy:* Digital platforms can broaden participation, facilitate ongoing dialogue beyond physical meetings, and create a transparent record of co-creative processes and outcomes.

8.8. Implementing an Adaptive Management Framework for Co-creation Activities

Co-creation is an iterative and emergent process.

- **Suggestion:** Establish a formal adaptive management framework specifically for the project's co-creation and stakeholder engagement efforts.
    - *Action for Consortium (SOF - T5.4 Lead, with all Demo Leaders and WP leaders involved in engagement):* Build in regular review points (e.g., at consortium meetings, specific WP meetings) to assess the effectiveness of co-creation activities, analyze stakeholder feedback, and identify the need for strategic adjustments.
    - *Co-creation Activities:* Use feedback from the PSCG and other stakeholder engagements to inform these reviews. Be prepared to flexibly adapt co-creation methods, timelines, and focus areas based on learnings and the evolving project context.
    - *Synergy:* Ensures that co-creation remains relevant, responsive, and effective throughout the project lifecycle, maximizing its contribution to overcoming barriers. This aligns with the quality assurance measures in T1.3/T6.3/T14.3.

8.9. Cultivating a Project-Wide Culture of Shared Learning in Co-creation

Effective co-creation requires a supportive internal project culture.

- **Suggestion:** Actively foster a culture of openness to external input and promote shared learning from co-creation experiences across the consortium.
    - *Action for Consortium (All Partners, facilitated by ACC and SOF):* Implement mechanisms for effective internal communication of insights from stakeholder engagements (e.g., dedicated sections in progress reports, internal workshops).
    - *Co-creation Activities (Internal):* Organize inter-demo case learning sessions focused specifically on sharing successes, challenges, and best practices in stakeholder engagement and co-creation.
- *Synergy:* Builds collective capacity within the consortium for effective co-creation, allows successful approaches to be replicated or adapted, and helps avoid repeating mistakes. This supports the overall project objective of fostering inter-sectorial collaboration.

9. Conclusions and Recommendations

The successful implementation of the ICARUS project's innovative upcycling technologies hinges significantly on proactively addressing social and non-technological barriers. This deliverable has outlined a methodological approach grounded in established principles of stakeholder engagement and co-creation, and has applied this to the three distinct demo cases.

General Recommendations for the ICARUS Consortium:

1. **Prioritize and Resource Co-creation:** Allocate sufficient resources (time, budget, personnel with facilitation skills) for the implementation of the co-creation strategies outlined for each demo case and for cross-cutting activities.

2. **Empower Demo Case Leaders:** Equip demo case leaders with the necessary support and autonomy to drive stakeholder engagement and co-creation activities relevant to their specific contexts, while ensuring alignment with the overall project strategy.

3. **Fully Operationalize the Public Stakeholder Councilor Group (PSCG):** Ensure the PSCG is actively involved from an early stage, providing strategic guidance and facilitating broader stakeholder outreach, particularly in guiding the co-creation strategies outlined in Chapter 8.

4. **Invest in Co-created Communication and Transparency:** Implement the unified communication framework (8.1), ensuring materials are co-designed with stakeholders to build trust and address concerns effectively.

5. **Foster Internal Collaboration on Social Aspects:** Encourage ongoing dialogue and knowledge sharing between Impact assessment and communication WPs and the technical WPs leading the demo cases, particularly in implementing the aggregated strategies.

6. **Implement Adaptive Management for Co-creation:** Formally adopt the adaptive management framework (8.8) to regularly monitor, evaluate, and adjust co-creation activities based on stakeholder feedback and project evolution.

7. **Document and Disseminate Lessons Learned via the Knowledge Hub:** Actively populate the ICARUS Knowledge Hub (7.5) with experiences, tools, and outcomes from all co-creation activities to build a valuable resource for the consortium and the wider circular economy community.

10. References

- Bonamigo, A., Dettmann, B., Frech, C. G., & Werner, S. M. (2020). Facilitators and inhibitors of value co-creation in the industrial services environment. *Journal of Service Theory and Practice, 31*(2), 226-250.
- Collinge, W. (2020). Stakeholder Engagement in Construction: Exploring Corporate Social Responsibility, Ethical Behaviors, and Practices. *Journal of Construction Engineering and Management, 146*(3), 04020003.
- Dobele, A. R., Westberg, K., Steel, M., & Flowers, K. (2013). An Examination of Corporate Social Responsibility Implementation and Stakeholder Engagement: A Case Study in the Australian Mining Industry. *Business Strategy and the Environment, 23*(5), 301-314.
- Durugbo, C., & Pawar, K. (2014). A unified model of the co-creation process. *Expert Systems with Applications, 41*(9), 4373-4387.
- Jones, P. (2018). Contexts of Co-creation: Designing with System Stakeholders. In P. Jones & K. Kijima (Eds.), *Systemic Design* (Translational Systems Sciences, Vol. 8, pp. 3-52). Springer Japan.
- Pauna, T., Lehtinen, J., Kujala, J., & Aaltonen, K. (2023). The role of governmental stakeholder engagement in the sustainability of industrial engineering projects. *International Journal of Managing Projects in Business, 16*(8), 77-99.
- Schoenung, J. M., & Olivetti, E. A. (2023). Sustainable development of materials: Broadening stakeholder engagement. *MRS Bulletin, 48*(4), 362-367.

11. Annex

The following are examples of models used for mapping non-technological barriers and co-creation processes

Democase 2: Feedback and co-creation(cellulose) example

Industrial process phase	Involved stakeholder type	Goals of engagement: Reduce or mitigate technological risks	Reduce or mitigate social risks	Reduce or mitigate political risks	Reduce or mitigate ecological risks	Reduce or mitigate legal risks	Generate social value for stakeholders	Compliance	Other	Frequency of engagement	Means and tools of engagment
Original waste end of life	Local communities	☐	☑	☐	☑	☐	☑	☐	☐	Every trimester	1 presential meeting and emails or newsletters
Procuct use	Local communities	☐	☑	☐	☑	☐	☑	☐	☐	Every trimester	1 presential meeting and emails or newsletters
Product end of life	Local communities	☐	☑	☐	☑	☐	☑	☐	☐	Every trimester	1 presential meeting and emails or newsletters
Original waste end of life	Water Authorities (tenders)	☐	☐	☑	☐	☑	☐	☐	☐	Every trimester	1 presential meeting and emails or newsletters
Waste production	Water Authorities (tenders)	☑	☐	☑	☐	☑	☐	☐	☐	Every trimester	1 presential meeting and emails or newsletters
Waste refinement	Water Authorities (tenders)	☑	☐	☑	☐	☑	☐	☐	☐	Every trimester	1 presential meeting and emails or newsletters
Waste trasnformation in new product	Water Authorities (tenders)	☑	☐	☑	☐	☑	☐	☐	☐	Once a year	1 presential meeting
Original waste end of life	Regional Authorities (hydrographyc and local authorities)	☐	☑	☐	☐	☐	☑	☑	☐	Once a year	1 presential meeting
Waste production	Regional Authorities (hydrographyc and local authorities)	☐	☐	☐	☑	☐	☑	☑	☐	Once a year	1 presential meeting
Waste refinement	Regional Authorities (hydrographyc and local authorities)	☐	☑	☑	☑	☐	☑	☑	☐	Once a year	1 presential meeting
Product end of life	Regional Authorities (hydrographyc and local authorities)	☐	☑	☐	☑	☐	☑	☑	☐	Once a year	1 presential meeting
Original waste end of life	National Authorities	☐	☑	☑	☐	☑	☐	☑	☐	Twice per project	1 presential meeting
Waste production	National Authorities	☐	☑	☑	☑	☑	☐	☑	☐	Twice per project	1 presential meeting
Waste refinement	National Authorities	☐	☑	☑	☑	☑	☐	☑	☐	Twice per project	1 presential meeting
Waste trasnformation in new product	National Authorities	☐	☑	☑	☑	☑	☐	☑	☐	Twice per project	1 presential meeting
Procuct use	National Authorities	☐	☑	☑	☑	☑	☐	☑	☐	Twice per project	1 presential meeting
Product end of life	National Authorities	☐	☑	☑	☑	☑	☐	☑	☐	Twice per project	1 presential meeting
Original waste end of life	Opperators	☐	☑	☐	☑	☑	☑	☑	☐	Every trimester	1 presential meeting and emails or newsletters
Waste production	Opperators	☑	☑	☐	☑	☐	☑	☐	☐	Every trimester	1 presential meeting and emails or newsletters
Waste refinement	Opperators	☑	☑	☐	☑	☐	☑	☐	☐	Every trimester	1 presential meeting and emails or newsletters
Waste trasnformation in new product	Opperators	☑	☑	☐	☑	☐	☑	☐	☐	Every trimester	1 presential meeting and emails or newsletters
Waste refinement	Big Enterprise	☑	☑	☐	☑	☐	☑	☑	☐	Once a year	1 presential meeting
Waste trasnformation in new product	Big Enterprise	☑	☑	☐	☑	☐	☑	☑	☐	Once a year	1 presential meeting
Procuct use	Big Enterprise	☑	☑	☐	☑	☐	☑	☑	☐	Once a year	1 presential meeting
Product end of life	Big Enterprise	☑	☑	☐	☑	☐	☑	☑	☐	Once a year	1 presential meeting
Waste refinement	SMEs	☑	☑	☐	☑	☐	☑	☑	☐	Once a year	1 presential meeting
Waste trasnformation in new product	SMEs	☑	☑	☐	☑	☐	☑	☑	☐	Once a year	1 presential meeting
Procuct use	SMEs	☑	☑	☐	☑	☐	☑	☑	☐	Once a year	1 presential meeting
Product end of life	SMEs	☑	☑	☐	☑	☐	☑	☑	☐	Once a year	1 presential meeting
Waste production	Academic	☑	☑	☑	☑	☐	☐	☐	☐	Once a year	1 presential meeting
Waste refinement	Academic	☑	☑	☑	☑	☐	☐	☐	☐	Once a year	1 presential meeting
Waste trasnformation in new product	Academic	☑	☑	☑	☑	☐	☐	☐	☐	Once a year	1 presential meeting
Procuct use	Academic	☑	☑	☑	☑	☐	☐	☐	☐	Once a year	1 presential meeting
Product end of life	Academic	☑	☑	☑	☑	☐	☐	☐	☐	Once a year	1 presential meeting

Democase 1: Non technological barriers (LAR) example

Type of potential barriers	Involved in		Description	Stakeholders involved	Possible causes	Possible consequences	likelihood of occurrence	Possible magnitude of impact
	Original waste end of life	Waste production						
Relations between different stakeholders	☐	☑	Conflicts of interest among key stakeholders such as material manufacturers, mining companies, and public administrations.	Material manufacturers, mining companies, public administrations	Conflicting priorities between sustainability and costs; lack of incentives to collaborate.	Resistance to the project from certain stakeholders; increased costs due to conflicts.	likely	high impact
Relations between different stakeholders	☐	☑	Lack of effective platforms or forums to facilitate communication and coordination among different stakeholders.	Material manufacturers, mining companies, public administrations	Absence of formal or informal structures for collaboration.	Lack of coordination leading to delays or ineffective decision-making.	possible	moderate imp…
Society and cultural factors	☐	☑	Social rejection due to perceived environmental risks associated with the use of recycled materials.	General public, environmental groups, local communities	Social unacceptance associated with the use of recycled materials; widespread misinformation.	Market rejection; negative campaigns discrediting recycled products.	likely	high impact
Society and cultural factors	☑	☐	Insufficient public awareness and education about the benefits of reusing waste in construction products.	General public, environmental groups, local communities	Lack of knowledge about the environmental and technical advantages of recycled materials.	Lack of social acceptance reducing demand for recycled products.	possible	moderate imp…
Political factors	☐	☑	Lack of specific policies to encourage the use of recycled materials over traditional ones.	Government bodies, public administrations, environmental agencies	Absence of subsidies or incentives for sustainable production processes.	Limited widespread adoption of recycled materials; dependence on traditional processes.	possible	high impact
Political factors	☐	☑	Existing regulations, such as the PG3, which may restrict or complicate the adoption of recycled waste.	Government bodies, public administrations, regulatory authorities	Complex or poorly adapted regulatory requirements for the use of recycled materials.	Increased costs and timeframes to comply with current regulations.	likely	high impact
Political factors	☐	☑	Influence from traditional industry lobbies opposing the use of recycled materials.	Traditional industry lobbies, policymakers, public administrations	Pressure from industry groups prioritising traditional raw materials.	Regulatory or political barriers hindering the development of the project.	likely	high impact
others	☑	☐	(Technical and Economic factors) Variability in the chemical and physical properties of lithium waste affecting the quality of the final product.	Mining companies, material manufacturers, research institutions	Waste with unstable characteristics that complicate consistent processing.	Issues with the quality of the final product; potential rejection in critical applications.	possible	high impact
others	☐	☑	(Technical and Economic factors) High initial costs in adapting infrastructure to process lithium waste as raw material.	Material manufacturers, technology providers, investors	Significant costs for initial machinery and technological development.	Lack of profitability in initial stages limiting large-scale implementation.	likely	moderate imp…
others	☑	☑	(Supply and Demand Dynamics) Risk of supply interruptions of lithium waste, affecting long-term production stability.	Mining companies, material manufacturers, supply chain managers	Limitations in the availability and extraction of lithium waste.	Supply chain disruptions; need to revert to traditional raw materials.	likely	moderate imp…
others	☐	☑	(Supply and Demand Dynamics) Dependence on unsustainable sources due to demand surges that recycled supply cannot meet.	Mining companies, material manufacturers, supply chain managers	Rapid growth in demand without planning to manage supply effectively.	Rapid growth in demand without planning to manage supply effectively.	likely	moderate imp…
others	☑	☐	(Management Factors) Economic and environmental impacts of transporting lithium waste by road compared to extracting aggregates on-site for asphalt production.	Mining companies, material manufacturers, public administrations	Greater distance from the mining site to the production plant; differences in fuel costs and carbon emissions.	Increased transport costs; higher carbon footprint; potential economic disadvantage compared to locally sourced traditional materials.	likely	moderate imp…
others	☐	☑	(Management factors) Logistical and economic differences between importing traditional raw materials for ceramics by ship and domestic transport of lithium waste.	Transport companies, mining companies, material manufacturers	Local transport may have a higher cost per kilometre compared to large-scale maritime transport.	Greater difficulty competing with traditional materials imported at low cost; supply chain imbalances due to limitations in land transport.	likely	moderate imp…
others	☐	☑	(Management factors) High moisture content in the waste increases its weight during transport, limiting the amount of material that can be transported per load.	Transport companies, mining companies, regulatory authorities	Inherent characteristics of lithium waste with high moisture content; legal weight limits for road transport.	Higher logistical costs due to more trips required; reduced transport efficiency; increased environmental impact from more vehicles on the road.	possible	high impact

Democase 1: Stakeholder mapping tool (LAR) example

Type of stakeholder	Involved in		Typology	Denomination	Location	Contact person name	Contact Person Surname	Contact Person Email	Contact Person Phone	Referee languages					
	Original waste end of life	Waste production								English	Spanish	Portuguese	German	Italian	Dutch
Workers	☑	☑	Workers' of the XX facility			[redacted]				☐	☐	☐	☐	☐	☐
Local communities	☐	☐	labour unions							☐	☐	☐	☐	☐	☐
Local communities	☑	☑	sectorial associations (ceramic/road/construction...)	Plataforma Tecnológica de la Construcción (PTEC)	Madrid. Spain					☐	☑	☐	☐	☐	☐
Local communities	☑	☑	sectorial associations (ceramic/road/construction...)	Asociación de Empresas Constructoras de Ámbito Nacional (SEOPAN)	Madrid. Spain					☐	☑	☐	☐	☐	☐
Local communities	☑	☑	sectorial associations (ceramic/road/construction...)	Asociación Española de fabricantes de azulejos y pavimentos cerámicos (ASCER)	Castellón. Spain					☐	☑	☐	☐	☐	☐
Local communities	☑	☑	sectorial associations	Asociación Regional de Empresarios de EE.SS. de Extremadura (ARESEX)	Villanueva de la Serena, Badajoz. Spain					☐	☑	☐	☐	☐	☐
Local communities	☑	☑	sectorial associations (ceramic/road/construction...)	Asociación Española de la Carretera (AEC)	Madrid. Spain					☐	☑	☐	☐	☐	☐
Local communities	☑	☑	Water confederations (confederacion hidrográfica del Tajo)							☐	☐	☐	☐	☐	☐
Local communities	☑	☑	Extractive industries	PINAEX ASOCIACIÓN EXTREMEÑA DE GRANITOS Y OTRAS PIEDRAS NATURAL	Quintana de la Serena Badajoz. Spain					☐	☑	☐	☐	☐	☐
Local communities	☑	☑	Extractive industries	COMINROC - Confederación de Industrias Extractivas de Rocas y Minerales Industriales	Spain					☐	☑	☐	☐	☐	☐
Local communities	☑	☑	agriculture cooperatives							☐	☐	☐	☐	☐	☐
Local communities	☑	☑	regional goverment and municipallities	Junta de Extremadura. Consejería de Infraestructuras y Transporte.	Mérida (Badajoz), Spain					☐	☑	☐	☐	☐	☐
Users	☑	☑	Road manufacturers	ACCIONA Construcción	Madrid. Spain					☑	☑	☐	☐	☐	☐
Users	☑	☑	Cement producers (Balboa)	Cementos Balboa. (Votorantim Cementos España, S.A.)	Alconera, Badajoz.Spain					☐	☑	☐	☐	☐	☐
Users	☑	☐	Waste recycler	Reciclados Caceres Sur S.A	Cáceres. Spain					☐	☑	☐	☐	☐	☐
Users	☑	☐	Waste recycler	Araplasa de Residuos S.A.	Cáceres. Spain					☐	☑	☐	☐	☐	☐