FORGING

INDUSTRY-ACADEMIA FORUM
TO UNCOVER THE POTENTIAL OF
EMERGING ENABLING TECHNOLOGIES

Co-creating Use-cases on Novel Enabling Technologies for a Sustainable Future

D2.4 Facilitated discussions about the future of Emerging Enabling Technologies

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Deliverable abstract

The deliverable presents insights from the co-creation event series "*Novel Enabling Technologies for a Sustainable Future"* organized under Task 4.2 of the FORGING project. The series aimed at co-creating use-cases for the novel technologies most likely to have positive impact on society identified in previous project activities.

These events brought together a diverse group of stakeholders, both from academia and industry, to identify and explore potential use-cases for emerging enabling technologies across different strategic application and adoption sectors. The report captures insights at both the process level, reflecting on the effectiveness of co-creation methodologies, stakeholder engagement, and the practical application of some FORGING tools, and the content level, highlighting most promising technologies, industry challenges, and application opportunities.

The findings contribute to fostering sustainable, responsible innovation, incorporating key concepts such as human-centric approaches and value-sensitive design. The insights produced serve as a foundation for further collaboration and action in the evolving landscape of Industry 5.0.

Keywords

Enabling Emerging Technologies, Responsible Innovation, social responsibility, environmental sustainability, human-centricity, use-cases, co-creation.

Table of content

List of Figures

List of Tables

Executive Summary

This document summarizes the results of the workshop series "*Novel Enabling Technologies for a Sustainable Future"* organized by APRE within the framework of WP4 of the FORGING project. The final objective of the workshops was to **co-create use-cases** for **socially responsible** and **environmentally sustainable emerging technologies**. The report presents the main results regarding both the co-creation methodology and the use-cases elaborated.

The co-creation approach was considered crucial to ensure that different perspectives were considered in the process. For successful co-creation, certain considerations are in place. First, different stakeholders may use different languages (i.e., terminology related to one's field of expertise, verbal communication style) due to their personal and professional backgrounds. Therefore, the use of **language that is easy to understand** and supported by visualization tools is recommended to ensure that all the stakeholders involved have a common understanding of the core concepts. Second, multi-step, collaborative and highly interactive methodology guided by facilitators is key when conducting co-creation exercises, as it enhances dialogue between heterogeneous groups of people with different expertise. Third, the dialogue structure needs to retain a certain **flexibility to adapt** to the different needs and personalities of the actors involved. Finally, to enable informed and meaningful engagement, it is essential to provide participants with an overview of the initiative (i.e., project general presentation), **context** details (e.g., at what stage of the project is the workshop happening?), clear indications about the event **objectives**, and additional information regarding the **next steps.**

Below is a summary table of the **use-cases co-created** in the workshop series:

FRAMEWORK	USE-CASE TITLE	SHORT DESCRIPTION
ARTIFICIAL INTELLIGENCE	*Data-driven Resilient Farming*	Agriculture-focused modular micro-farms using Abductive Reasoning AI for climate-resilient food production with real-time data.
	ALICIA	Adaptive AI for automated Life Cycle Impact Assessment to support ethical, sustainable production in manufacturing sector.
	Data-driven Business Model	Adaptive AI enhances flexibility and sustainability in manufacturing through resilient, data-driven decision-making models.
	DIA-BEATER	Healthcare use-case leveraging Adaptive AI to offer personalized motivation tools for Type II diabetes prevention and wellbeing support.
CYBER-SAFE DATA TECHNOLOGIES	*TRULY*	Healthcare Zero Trust platform enabling portable, secure and interoperable access to medical data for improved inclusivity and trust.
	ZenCARE	Healthcare solution using Zero-knowledge Proofs and Zero Trust for user-centric, privacy-preserving medical data sharing and control.
	NEXT GEN P.A.	Public sector initiative leveraging Zero-knowledge Proofs for citizen-owned secure data systems, improving trust in digital services.
BIO-INSPIRED TECHNOLOGIES AND SMART MATERIALS	*Precision Forged from Chaos & Uncertainty*	Agriculture-focused localized farming using bio-inspired sensors, robotics, and AI to manage resources efficiently under climate uncertainty.
	METRIKOT/MEDRIKOT	Healthcare wearable sensor system using Organ-on-chip tech for early oxidative stress detection and health monitoring.
	VitriTex	Textile manufacturing use-case applying bio-engineered bacteria to create self-healing, pollutant-neutralizing, sustainable textiles.
REAL-TIME BASED DIGITAL TWINS	*HATOM*	Operational management tool using Cognitive Digital Twins to improve decision-making, transparency, and human-system integration.

AND SIMULATION TECHNOLOGIES	*BRIDE*	Manufacturing-focused robotics for battery recycling powered by Cognitive Digital Twins integrating worker expertise and predictive data.
	Twin2Win	Automotive sector uses Cognitive Digital Twins and XR for personalized worker training, boosting inclusivity and efficiency.
	PrevenTwin 4 WorCare	Workplace safety system with Cognitive Digital Twins for real-time risk monitoring, predictive analytics, and worker protection.
HUMAN-CENTRIC SOLUTIONS AND HUMAN-MACHINE INTERACTION TECHNOLOGIES	*SEAMLESS*	Manufacturing human-machine collaboration framework using NLP, haptics, vision and digital twins for ergonomic, inclusive production.
	TECHCARE	Healthcare-focused Digital Twin + AI + IoT solution for caregiver support and wellbeing monitoring in critical environments.
	You'll Never Fly Alone	Aviation system using NLP, IoT, and LLMs to assist pilots with communication protocols and situational awareness.
	AIMS	Aviation sector solution integrating Digital Twins and IoT for predictive maintenance and process efficiency in aircraft operations.
TECHNOLOGIES FOR ENERGY EFFICIENCY AND TRUSTWORTHY AUTONOMY	*MIXEES*	Energy storage platform combining MPC and battery tech for clean, grid-independent power systems, ideal for islands or remote areas.
	SMARTBEM	Building energy management system using MPC to optimize energy flows, reduce CO2 emissions, and engage citizens in sustainability.
	RE-VIVE	Urban building HVAC optimization via MPC and Digital Twins to reduce energy use and urban sprawl while improving comfort.
	CONVENSE	Mobility-focused solution using MPC and platooning to optimize electric fleet logistics through predictive and cooperative driving.

1. Introduction

1.1 FORGING overview and context

FORGING is an EU-funded project started in October 2022, with the overarching goal of exploring the potential of emerging enabling technologies to support the digital and green transitions. The project aims to foster human-centred technological visions and pathways that are environmentally and socially responsible, in line with Industry 5.0 concept[1]. FORGING explores all six technological frameworks of Industry 5.0:

- *Artificial Intelligence;*
- *Cyber safe data transmission, storage, and analysis technologies;*
- *Human centric solutions and human-machine interaction;*
- *Bio-inspired technologies and smart materials;*
- *Technologies for energy efficiency and trustworthy autonomy;*
- *Real time digital twins and simulations.*

This approach reflects the need to better integrate social and environmental priorities into technological innovation and shift the focus from the development of individual technologies to a systemic and sociotechnical approach to technological development.

FORGING provides a pioneer methodology to assist the growth and manifestation of emerging enabling technologies and support their uptake by industry and society.
The FORGING methodology consists of three main phases:

1. Technology uncovering through the identification of emerging technologies with expected economic, societal and environmental effects;
2. Analyzing future societal scenarios for the enabling technologies;
3. **Co-creating concrete use cases related to the uncovered technologies**.

The results of Deliverable 4.2, part of FORGING WP4 *"Co-create novel enabling technologies for a sustainable future*", are to be considered as an integral component of the third phase.

The FORGING consortium is composed by 6 European partners: **INL** (International Iberian Nanotechnology Laboratory), **GAC** Group, **STAM SRL**, **i2CAT** (The Internet Research Centre),

[1] Directorate-General for Research and Innovation (European Commission), Industry 5.0, Towards a sustainable, human-centric and resilient European industry, 2021, https://op.europa.eu/en/publication-detail/-/publication/468a892a-5097-11eb-b59f-01aa75ed71a1/

APRE (Agency for the Promotion of European Research), and **VTT** (Technical Research Centre of Finland).

1.2 Purpose of D4.2 and relation with FORGING WPs

As part of the FORGING process, D4.2 presents the co-creation activities aimed at elaborating use-cases from the sets of technologies identified during WP2 "*Explore emerging sciences and technologies*" (hereafter referred to as FORGING portfolio of technologies), particularly during Task 2.5 on technology prioritization[2], and lays the foundation for the development of technology pathways towards future technological applications. The clusters of technologies prioritised as "most promising" from a social and environmental perspective, developed in WP2, were further explored to develop concrete use cases. Based on these, specific technology pathways will be established and pursued through tech and innovation campaigns, with the aim to highlight opportunities for industry adoption and deployment of new enabling technologies (WP6). Cross-work package connections are highlighted in Figure 1 below.

This deliverable reports on the results from the second phase of the FORGING co-creation process, which engaged a wider range of multidisciplinary and multisectoral stakeholders.

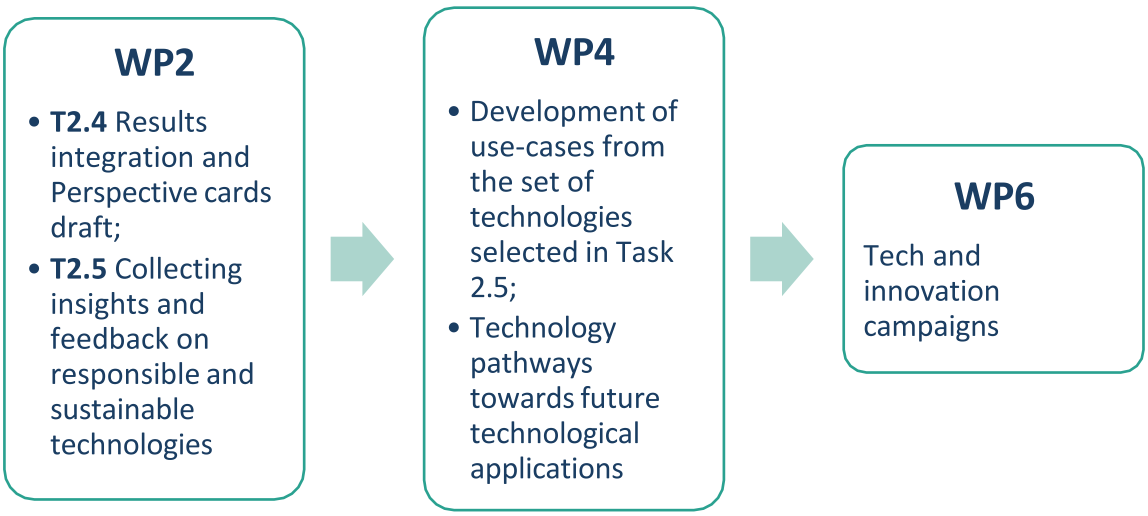

Figure 1. Links with FORGING WPs

[2] See Deliverable 2.3 Prioritizing responsible technologies: insights from FORGING Technology Clustering workshops.

2. Methodology

2.1 Co-creation events overview

The "*Novel Enabling Technologies for a Sustainable Future*" event series, organized and implemented by APRE with the support of the consortium, was held in-person between June 2024 and January 2025 with the final objective to **co-create technological use-cases** in previously identified strategic application and adoption sectors (WP2 and WP3), and based on the priority clusters selected in T2.5 and described in FORGING **Deliverable D2.3 "Prioritizing Responsible Technologies: Insights from FORGING Technology Clustering Workshops"** (July 2024). Table 1 below summarizes the timeline of the series, specifying the dates and venues where each workshop took place.

Dates	Topic	Location
12-13 June 2024	***Artificial Intelligence***	Luiss Guido Carlo University, Rome
13-14 June 2024	***Cyber safe data technologies***	Luiss Guido Carlo University, Rome
14-15 November 2024	***Bio-inspired technologies and Smart Materials***	INL - International Iberian Nanotechnology Laboratory, Braga
11-12 December 2024	***Real-Time Based Digital Twins & Simulation Technologies***	Comet Louise, Brussels
12-13 December 2024	***Human-Centric Solutions & Human-Machine Interaction***	Comet Louise, Brussels
30-31 January 2025	***Technologies for Energy Efficiency***	Comet Retiro, Madrid

Table 1. 4.2 events timeline

In addition to the consortium partners, each workshop was attended by 16 to 26 experts, bringing the total number of participants across the 6 events to **136 professionals** (details about participants' profiles are included in Annex I). To ensure a multidisciplinary and multi-sectoral representation, and to foster collaboration and knowledge sharing across different fields, experts were welcomed from a diverse range of backgrounds, including academia and research centres, research and technology organizations, business clusters, civil society organizations, and various industries.

Each workshop consisted of two main sessions (see 2.2):

- The first session began with a keynote speech delivered by an expert on the focus topic, to provide participants with a technical overview of the subject and with practical insights into the work conducted by someone with extensive expertise and/or research experience in the field. This was followed by a general presentation of the FORGING project by APRE, showcasing the project history and latest results. Participants were also introduced to the most promising technologies as identified during the technology clustering workshops and assessed based on their technical, environmental and social potential.
- During the second session, participants were actively involved in working groups and took part in an interactive exercise to identify **which of the presented technologies could best address specific human needs,** ultimately defining a concrete use-case for each technology. Working groups included 6-to-7 people and were facilitated by one or two members of the FORGING consortium.

Minor improvements to this structure were periodically implemented, based on stakeholder composition and feedback gathered through satisfaction questionnaires, which were developed by i2CAT and filled out by participants at the end of each workshop. Feedback was carefully analysed to identify areas for improvement, including the comprehensibility of FORGING results, the clarity of the instructions for working groups, and participant engagement levels. By integrating participant feedback into the iterative development of the event structure, the process remained dynamic and adaptive, ensuring that each workshop built upon previous lessons learned.

Overall, more than 130 experts from across the European Union were actively involved in the event series, a total of 22 use-cases were co-created in all six technological frameworks of Industry 5.0, and around 10 specific industries and/or application sectors were covered, as shown in Figure 2.

Figure 2. Key figures in a nutshell

2.2 Event design and facilitation strategy

The event series was designed in line with the co-creation approach outlined in FORGING [Deliverable D1.3 Exploring the potential of co-creation in Emerging Technology: challenges and success factors](), stating that the digital era necessitates collaboration across various sectors and

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disciplines, often calling for expertise beyond conventional or strictly technical skills, and describing co-creation as a key strategy to address the complex, interdisciplinary challenges of modern innovation. Throughout the T4.2 workshop series, co-creation proved itself a key enabler for structured collaboration, joint design exercises and cross-sectoral knowledge exchange.

In addition to the many advantages typically associated with a co-creation approach - such as fostering trust, inclusivity, and the identification of social concerns, as well as the potential implications and impacts of emerging technologies - certain challenges inherent to this approach were also considered, first and foremost the management of heterogeneous groups of participants with various backgrounds, knowledge, languages, assumptions, motivations, and priorities. In the context of FORGING, these complexities are also compounded by the intrinsic uncertainty and unpredictability of emerging technologies. Given that mutual understanding cannot be assumed, dialogue becomes a crucial tool for bridging knowledge gaps and encouraging shared learning. Therefore, effectively facilitating discussions among stakeholders requires a combination of tools and an understanding of the diverse perspectives of all participants involved. With the aim of maximizing dialogue effectiveness, ensuring fairness in the representation of interests, and fostering win-win exchanges, the workshop structure and conduction were designed to create a favorable and supportive environment where attendees felt comfortable sharing personal views and engaging in open discussion.

Each workshop spanned one afternoon and one morning, as follows:

- The **afternoon session** was meant as an introductory session (setting the stage for the core activities in the following morning session) and it consisted of an opening keynote speech, a presentation of the FORGING project and its main results, and a final networking cocktail serving as "icebreaker" before group activities started the day after. In all but the first two workshops (on Artificial Intelligence and Cyber safe data technologies), a "pitching" session was added to the agenda, allowing participants to present their own use-cases related to the technologies discussed in the workshop. This addition significantly boosted connection and networking by establishing a shared foundation for dialogue and providing inspiration for the collaborative exercise in the morning.

Artificial Intelligence

- "*AI & Machine Learning*", Prof. Giuseppe Italiano, Luiss Guido Carli University

Cyber safe data technologies

- "*The Digital Empowerment Paradox: The Experience in Denmark*", Prof. Richard Baskerville, Georgia State University

Bio-inspired technologies & Smart Materials

- "*InsectNeuroNano: a new way of bio-inspired efficient computation*", Dr Bruno Romeira, International Iberian Nanotechnology Laboratory (INL)

Digital Twins technologies

- "Demystify Industrial Metaverse: Unlocking value for Industry 5.0 with Digital Twins and Extended Reality", Dr. Xinyi Tu, Aalto University

Human-Machine Interactions

- "*Social Robotics in Healthcare*", Dr Davide De Tommaso, Italian Institute of Technology (IIT)

Technologies for Energy Efficiency

- "Transitions and distruption", Dr Francesco Reda, Technical Research Center of Finland (VTT)

Figure 3. Details of the Keynote Speeches

- During the **morning session**, participants engaged in co-creation activities to co-develop concrete and actionable use-cases for the presented technologies. To encourage discussion and stimulate individual engagement, participants were organized into small groups working in separate tables – each equipped with canvases and other materials to support the collaborative work (e.g., sticky notes, pens) – and with one or two members of the FORGING consortium acting as facilitators in each table.

The methodology applied for the collaborative exercise was specifically grounded in a **human-centric and need-driven approach**, aligning closely with the principles of the Industry 5.0 framework. According to it, the potential of novel enabling technologies needs to be evaluated by considering the benefits they bring to people and to society, rather than merely focusing on their technical features. As such, the co-creation methodology started with the identification of sector-specific issues concretely faced by human beings, to ensure that the discussion addressed pressing needs within specific contexts and that the resulting solutions were aligned with human-centered values.

The process unfolded in three interconnected phases, each supported by dedicated canvases to guide participants step by step. The canvases were designed in a way that allowed all groups to gradually narrow down their discussion: they began with a broad conversation around sector-specific needs and progressively focused on a more detailed framing of the envisaged solutions. This structured approach eventually enabled them to define the core features of the proposed solutions, thus ensuring a clear and concise outcome by the end of the exercise. A detailed description of the three steps, one per canvas, can be found below (all canvases are included in **Annex II)**.

1. As a first step, facilitators supported participants in the identification of a **key problem** in the focus sector[3] using the "Problem and Solution Tree" canvas, specifically designed to pinpoint a critical issue requiring resolution. This first step entailed an exploration of the root causes and main effects of the identified problem. After that, the exercise focus shifted to developing a potential solution and to creating a positive counterpart to the previous discussion. At this stage, those issues indicated as "causes" were reframed as **key needs** to be addressed, while the "negative effects" of the problem were turned into the expected impacts of the proposed solution.
2. In a second step, participants were asked to populate the "Feature Canvas" and to provide a detailed exploration of the foundational elements of their group's solution. Guided by facilitators, the groups had to analyze and indicate sector-specific contexts, relevant technologies to use, key actors involved, value propositions, resource requirements, and potential obstacles or feasibility limits in the implementation of their solution. This step was mainly aimed at refining broad ideas into concrete, feasible, and more articulated proposals. A key component of this canvas was the **selection of one or more technologies** (from the FORGING portfolio elaborated in the WP2 tasks) that best aligned with the proposed solution and that would most effectively help address the problem identified in the previous canvas. 3. The third and last step was dedicated to the refinement and final definition of each group's use-case, with a particular focus on **social and environmental considerations**. Additional tools, such as the Perspective Cards[4] developed by VTT, were provided to participants to expand their analysis and to evaluate aspects that may have been previously overlooked.
3. The final canvas placed special emphasis on distinguishing between beneficial outcomes - which are inherently positive – and broader impacts, which can have either positive or negative implications on the environment and on society.

[3] At the beginning of the exercise, each group chose the sector they wished to focus on, taking inspiration from the sectors outlined in the FORGING Strategic Matrix (included in FORGING Deliverable D2.1 "T*echnology Scouting: Strategic Matrix, Potential Application Areas and Technology Clusters*", labelled as sensitive). However, the final decision was left to the participants, in line with the principles of co-creation, ensuring that their interests and perspectives were respected throughout the process.

[4] Perspective cards are a tool developed by VTT as part of the FORGING Toolbox. Perspective Cards are designed to foster empathy and understanding of different stakeholder viewpoints when designing applications for emerging technologies. The card deck consists of technology cards—highlighting emerging technologies and their key application areas—and six perspective cards, which provide prompts to explore societal and environmental impacts as well as stakeholder interests. This approach encourages critical discussions on responsible and inclusive technology development.

All workshops in the series followed the same methodological structure, summarized in Figure 3, with minor improvements over the first two pilot workshops on Artificial Intelligence and Cyber-safe Data Technologies held in Rome on June 12th to 14th, 2024.

Figure 4. Outline of methodological approach

3. Insights from Use-cases Co-development

The following section provides an overview of the use-cases developed within each technology framework, detailing the sets of technologies presented at the beginning of each workshop, the application sectors covered by the group discussions, and a description of all use-cases co-created.

The technological portfolio presented during the workshops as starting point for the co-creation exercise resulted from the integration of (i) the outcomes of the Technology Clustering workshops[5] and (ii) the second round of desk analysis, conducted by STAM and consisting of a comprehensive review of strategically relevant documents and repositories on emerging science and emerging technologies, as documented in FORGING **Deliverable *D2.2 "Report on the identification and description of opportunity"***[6].

3.1 Artificial Intelligence

3.1.1 Initial set of most promising technologies

During the workshop on Artificial Intelligence (held in Rome on June 12 and 13, 2024), the following technology portfolio was presented as a cluster of most promising technologies in social and environmental terms:

[5] Specific results from this workshop series are available in ***Deliverable 2.3 Prioritizing responsible technologies: insights from FORGING Technology Clustering workshops***.
[6] This deliverable is classified as sensitive.

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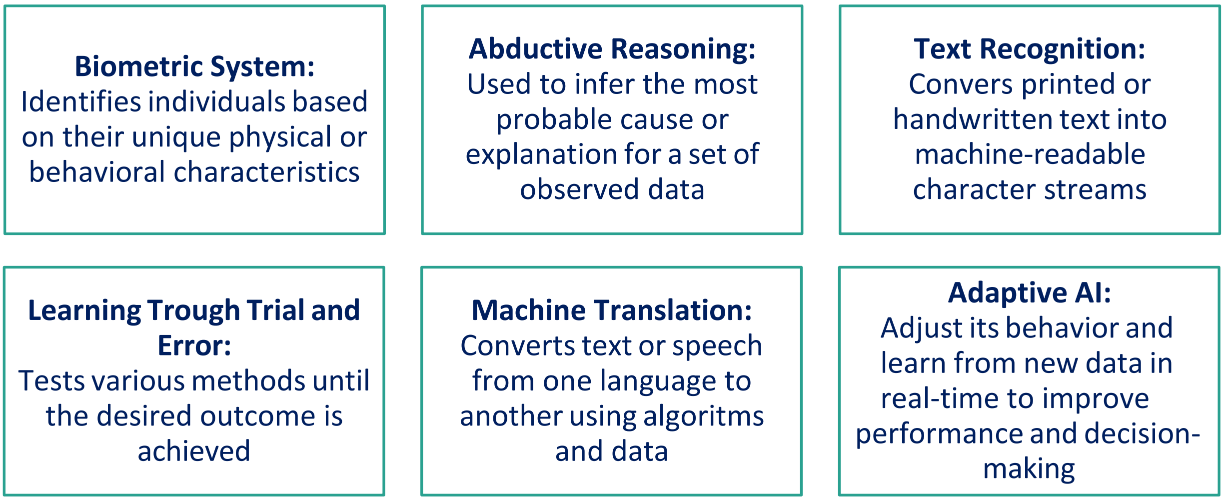

Figure 5. Artificial Intelligence workshop technological portfolio

3.1.2 Use-cases elaborated

USE-CASE 1:
Data-driven Resilient Farming For Sustainable Food Market

SECTOR:
Agrifood

TECH:
Abductive reasoning AI

The group chose Agriculture as a focus sector and throughout the exercise redefined the sector as Agrifood. The main issues raised for this sector were heavy regulation, waste management and climate change induced crops loss as well as crops loss due to disease. Lack of pollinators in certain ecosystems has also been highlighted as a challenge. The root cause of the environmental issues raised is climate change and the main effects that come with it are unpredictability, unreliability and fragility of the environment. The result of this leads to the farmers needing to be able to adapt quickly.

A solution proposed to address these issues is permaculture-inspired data-driven resilient farming in the form of modular micro-farms where diverse crops would be planted together based on indications provided by AI tools using soil, weather, disease and other relevant data. The solution would need to be powered with data collection and analysis technologies (sensors) as well as decision making and implementation support using abductive reasoning AI technology. The major benefit of this systemic solution is democratization of food growth for one´s own purposes. Modularity also enables micro-farm growth if/when desired. In terms of the environment, there are also benefits in soil regeneration and more efficient pest control. As a side-solution related to the pest control the group came up with an idea of biometrics for plants and pests as a data-collection mechanism supporting early recognition of any issues with the

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plants and enabling directed, early response to such issues. For this kind of solution to be able to be implemented we need to be able to share the data. The best place to start would be supporting pilots and developing new business models in the existing permaculture communities and growing from there. Of course, regulatory frameworks would need to be adapted as well to account for a different model of farming/growing.

USE-CASE 2:
ALICIA – Automated Life Cycle Impact Assessment

SECTOR:
Manufacturing

TECH:
Adaptive AI

The group chose to focus on the Manufacturing sector. Several critical issues in the sector were considered such as the resilience of the supply chain, the poor working conditions, the lack of accountability of externalities, the lack of integration of data. It was then considered that many of these shortcomings were part of the specific problem related to the lack of an adequate life cycle assessment. This issue brought the discussion to the low level of circularity in the management of resources (causing waste of raw material), a non-sustainable supply chain and an overall degradation of the environment. Among the root causes, the lack of standards, massive production, and the mindset focused solely on economic profit were the main ones identified. On the other hand, policies, more transparency, education, sustainable and responsible production were the major needs considered.

This is why the group proposed a standard Life Cycle Assessment encompassing the process from resources to product retirement. The solution aims to bring value created out of waste, to improve the resilience of the supply chain, making it more sustainable as well as to improve working conditions providing indicators, best practices and standards. The value proposed to bring with the solution is an ethics-driven approach to manufacturing improving the sustainability of production while enhancing transparency of the process and awareness. Adaptive AI was considered as the most suitable technology to address the solution because of its capacity to learn and adapt from both historical and real time data.

The primary stakeholders in this initiative include manufacturers, suppliers, developers, and investors. The solution necessitates technical contributions from developers and support from educators to assist in the creation of the tool. Ultimately, the main beneficiaries will be consumers and the general public/citizens.

Some restrictions and limitations may hinder the resolution of the problem such as access to quality data, fragmentation of data (affecting data integration and interoperability) as well as business models that do not incentivize data sharing.

Concluding, the group envisaged an Adaptive AI-based system able to provide sustainable indicators to manufacturers and suppliers: Automated Life Cycle Impact Assessment (ALICIA). The solution would bring both social benefits in terms of value-based manufacturing and environmental benefits such as responsible use of resources (that implies a waste reduction) and more sustainable production. Among the main impacts, it is worth mentioning that the solution will entail a reorganization of the supply chain, redistribution of profits, and job creation. New positions will emerge as auditors, LCA (Life Cycle Assessment) experts, AI implementers, SSH (Social Sciences and Humanities) experts, and business model specialists.

USE-CASE 3: ***Data-Driven Business Model in Manufacturing*** | **SECTOR: Manufacturing** | **TECH: Adaptive AI**

The group picked manufacturing as their sector of interest and indicated a lack of flexibility as the main problem to address, meaning an understated capacity to adapt to ever-changing circumstances – e.g., economic and financial crises, rapid digitalization processes, regulatory changes, market conditions, and so forth. The problem encompasses several issues affecting the focus sector, such as the lack of a holistic approach to management. Consequently, manufacturing companies might face higher risk exposure and higher maintenance costs, as well as reduced production levels, lower competitiveness, a little-to-no sustainable supply chain, and unbalanced use of resources. Although indirect, another effect might be a low level of workforce satisfaction and wellbeing. The main root causes identified by the group include poor accessibility of emerging technologies (especially for SMEs), low TRLs (Technology Readiness Levels), outdated data collection and management systems, insufficient democratization of technology, limited digital skills, and low trust in emerging enabling technology adoption.

Therefore, the enhancement of business flexibility and adaptability is the proposed solution to address common needs of manufacturing companies, and namely: a fair trade-off between sustainability and productivity, a more efficient resource allocation, increased confidence investing in digital upskilling and in the uptake of emerging technologies, enhanced connectivity and better data management capabilities. The group convened that adaptive AI is the most suitable technology. In fact, by combining several different scenarios and considering ever-changing external and internal conditions, it can improve the quality of decision-making processes based on data, thus ensuring a better fulfillment of the identified needs.

All-sizes manufacturing companies would benefit from the adoption of a data-driven, adaptive AI-powered business model flexible enough to adapt to different scenarios and to develop resilience. Business managers – the chosen target group – are thus encouraged to rely on this use-case when conducting their periodic evaluations, as it has the potential to lead to increased efficiency, productivity and more sustainable production, as well as to provide them with key cross-cutting insights and the ability to predict challenging conditions. It would benefit other actors in the supply chain as well, such as the workforce itself (at all levels), system integrators, and the final consumers, by delivering efficiency, innovation, and more space for personal and professional growth.

Socially speaking, the group agreed that the envisaged solution would lead to a workforce upskilling and overall workplace satisfaction and welfare, although the effects on employment rates remain uncertain. Environmentally speaking, the data-driven business model would enhance a more efficient management of resources and ultimately result in an alignment with the international sustainability goals and regulations.

The key resources needed to achieve the proposed model are financial, technological, and human: appropriate funding, advanced knowledge of processes, ownership of enabling technologies (e.g., sensors), and best practices exchange are essential factors to the pursuit of a successful data-driven business model.

Some feasibility issues have emerged during the group discussion. Possible limitations might be represented by a lack of funding or by regulatory matters, or else by a broader fear of change that sometimes managers show. Such factors may limit access to enabling technologies and prevent manufacturing companies from relying on a data-driven, AI-powered business model.

USE-CASE 4: ***DIA-BEATER*** | **SECTOR:** **Health** | **TECH:** **Adaptive AI**

The group initially chose "health" as its focus, intending to combine it with "agriculture". However, they eventually redefined their focus to 'wellbeing', emphasizing prevention, lifestyle choices and environmental factors that contribute to a healthy and fulfilling life. The central problem identified by the group is the lack of a wellbeing ecosystem for citizens.

The main causes are low levels of willpower and self-control, the negative effects of intensive agriculture, limited knowledge of how different sectors affect health and well-being, the rapidly changing technological landscape and the negative effects of intensive agriculture. These issues contribute to an overburdened health care system, a shortage of caregivers for a growing population, inadequate prevention, an increase in diabetes and related diseases, and a sedentary lifestyle among the population.

The proposed solution is to create a fully functioning ecosystem for wellbeing, powered by data collection and analysis using AI tools such as 'learning through trials and errors' and 'adaptive AI'. To achieve this, citizens need technological solutions and tools to support their actions and measure their impact on their lives. The group decided to focus on a specific population: people at high risk of type II diabetes.

They plan to develop a tool called "DIA-BEATER" that will provide tailored support and adaptive motivational triggers for healthy behavior. The benefits of this use case include reducing the burden on hospitals, improving mental health, enhancing preventative care and promoting healthy lifestyles.

3.2 Cyber-safe Data Technologies

3.2.1 Initial set of most promising technologies

Quantum Cryptography Uses quantum mechanics principles to encrypt and transmit data, ensuring its confidentiality and integrity	**Zero Knowledge Proof:** Cryptographic method where one party proves to another that they know a specific piece of information without revealing it	**Attribute-based Encryption:** Grants access to encrypted data based on the attributes or characteristics of the user rather than their identity
Homomorphic Encryption: Allows computations to be performed on encrypted data without needing to decrypt it	**Zero Trust:** Assumes no implicit trust in any user or system, requiring continuous verification for access to resources	**6G Network:** Forthcoming generation of wireless technology, delivers faster speeds and more advanced connectivity features than 5G

Figure 6. Cyber-safe Data Technologies workshop technological portfolio

3.2.2 Use-cases elaborated

USE-CASE 1: ***TRULY – Trustworthy Health Data Access & Share Anytime, Anywhere, by Anyone*** | **SECTOR:** **Healthcare** | **TECH:** **Zero trust**

Healthcare is the sector that the group decided to focus the discussion on. More specifically, they wanted to tackle data management issues within public healthcare services. In this domain, an initial discussion highlighted an overall lack of efficient data sharing systems among medical care providers in European countries. With some country-specific exceptions (like Portugal) most healthcare national systems cannot really count on a structured, integrated, portable, easily accessible, and shareable data management system that allows an efficient use and transfer of citizens' medical data. When it comes to people's medical data, there is very limited communication between healthcare providers both in the private and the public sector. For instance, no hospital can access a patient's medical data gathered by another, no healthcare emergency operator has access to a patient's medical history, and so forth.

If health data is not accessible (or difficult to access) even for healthcare operators themselves, it means that there is a substantial lack of interoperability, which impacts the quality of healthcare systems at large, for a number or reasons: it makes it more difficult for citizens to access medical services, increases the risk to lose data, undermines the inclusivity of medical services, raises resource waste concerns, and might even expose citizens to physical risks. This affects a wide variety of actors - from patients (citizens) to doctors (directly), from third-party services (e.g., system integrators) to regulatory bodies and policymakers (indirectly).

According to the group, the root causes of such problems are found in obsolete processes (which often prevent healthcare systems from adapting to technological progress), in an active resistance to (and a mistrust in) new technology adoption shown by medical personnel, in digital illiteracy, and in policy and regulatory gaps.

So, how to efficiently storage and share personal health data to enhance more inclusive, agile, safe, and trustworthy healthcare systems? The solution envisaged by this group is the establishment of a secure and usable health data management service that is accessible anywhere, at any time, and by any (authorized) healthcare operator. The technology deemed to be the most appropriate to achieve this solution is zero trust: by tackling data accessibility issues, it builds trustworthy access to data, thus facilitating data sharing among relevant stakeholders.

This explains why the use-case was named "TRULY - Trustworthy Health Data Access & Share Anytime/Anywhere/by Anyone". Such solution would enhance reliability, security, efficiency, resilience and inclusivity in the healthcare sector, all while building trust in healthcare institutions. It would also contribute to a smarter use of resources, allowing less medical waste, less papers, less medical examinations, and so forth. Therefore, it would bring both social and environmental benefits, even though the effects on energy consumption remain uncertain.

USE-CASE 2:
ZENCARE - Zero-Knowledge Enhanced Network for Confidential and Reliable Healthcare

SECTOR:
Healthcare

TECH:
Zero Knowledge Proofs + Zero Trust

The group focused on the Healthcare sector, starting the activity by identifying several critical issues such as: continuity of operations against attacks, lack of adequate certification and the security of sensitive data. The inadequate level of protection of personal data was then identified as the most crucial problem. This is because it affects various stakeholders, including healthcare

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workers who require secure access to patient data for effective treatment while ensuring confidentiality, and patients concerned about the privacy and security of their health information. A poor level of protection and the potential exposure of data leads to higher risk of breaches and a lack of trust on the part of patients.

The proposed solution involves a combination of Zero Knowledge Proofs and Zero Trust technologies. Zero Knowledge Proofs allow for data verification without exposing the data itself, enhancing privacy and security. The Zero Trust framework requires strict verification for every person and device trying to access resources, minimizing the risk of data breaches. This solution aims to create a user-centric privacy-preserving system where users have control over their data, preventing unauthorized access and ensuring that only necessary data is shared.

The value proposition of this solution includes empowering users with control over their data, thus ensuring they can check who accesses their information. The solution aims to foster transparency and trust ensuring that users are more confident in the secure handling of their data.

Implementing this solution faces several barriers. Regulatory challenges involve complying with lack of harmonized implementation of data protection regulations among countries. Ensuring all stakeholders adopt and effectively use the new technologies presents a technology adoption challenge. Overcoming resistance to change and gaining user trust is also crucial for social acceptance. Additionally, addressing gaps in the current IT infrastructure to support new security measures is necessary. Interoperability concerns also need to be addressed to ensure seamless integration with existing healthcare IT systems.

Key resources required for the successful implementation include education and training for healthcare workers, clinicians, and other stakeholders to effectively use new technologies.

Legal and regulatory frameworks need updating to support advanced data protection measures. Expertise in software engineering and ZKP is essential for developing and implementing secure solutions. A robust IT infrastructure capable of supporting these new security measures is also crucial.

The social impacts include increased user trust, improved service delivery, and job creation in cybersecurity and IT fields. The implementation of such a solution may also cause a gap between those who can use this technology and those who are under-educated in digital terms (inter-generational gaps, custodial problems etc.). For this reason, training and awareness campaigns are needed. More broadly, the implementation of such a solution may also lead to increased longevity of people (due to an improved healthcare service). In environmental terms, the digital approach reduces paper waste, but the high level of energy consumption needs to be considered.

The “ZENCARE” solution aims to enhance data protection in healthcare through user-centric privacy technologies, ultimately leading to a more secure, transparent, and trusted healthcare system. The solution's impact extends beyond security, fostering user's empowerment, inclusivity and improving the overall healthcare service.

GROUP 3: ***NEXT GEN P.A.***	**SECTOR:** **Public Administration**	**TECH:** **Zero Knowledge Proof**

The group chose Public Administration as the sector of focus due to its vast distribution across different institutions such as courts, immigration office, municipalities, fiscal and social security services, national registry and other. All these different institutions deal with citizen (personal) data and use systems that often lack interoperability and run on old IT infrastructure. Another major issue identified was also lack of awareness of cyber threats that people working in the public administration have as well as citizens themselves. The main problem the group decided to address was personal data being treated as a commodity and not as an asset enabling access to power. The issues identified result in lack of trust in the public administration and consequently government as well as in the increase in cybersecurity incidents.

The solution to this problem proposed was enforcement of security measures through a distributed data storage using a standardized data classification methodology as well as cyber aware database naming. The systems used need to be secure by design. Data integrity needs to be assured as well as continuous training and awareness rise at all levels of society and the public administration employees. To deliver this solution, the group agreed it was important to have an international court dedicated to personal data protection that would enable citizens to enforce regulations in case of any personal data leaks.

The solution proposed by the group can be delivered using zero knowledge proof, a technology already being used in blockchain based systems. To implement this solution investments in cryptography infrastructure are needed as well as cybersecurity specialist knowledge. The major social benefit of this solution is seamless public service engagement and therefore trust in public services and the government. Further social impacts of this solution are recognition of the value of personal data by the citizens, knowledge-empowered citizens as well as citizens feeling safer (or not). Major environmental benefit stems from paperless, digitalized processes that may have an impact on the environment through increased need for computer power.

3.3 Bio-inspired Technologies and Smart Materials

3.3.1 Initial set of most promising technologies

Artificial photosynthesis: Mimics natural photosynthesis by using sunlight/water/carbon dioxide (renewable way to generate clean energy)

Radiative cooling: Natural process where surfaces lose heat by emitting infrared radiation to the colder sky, helping to cool objects/buildings without using energy

Self-healing material: Automatically repairs damage by triggering a healing response and restoring their original properties

Bioengineered Food Crops & Plants: GMOs enhancing desirable traits such as pest resistance or nutritional value through genetic modifications

Engineered bacteria: Genetically modified microorganisms to perform specific tasks (e.g., breaking down pollutants) by altering their DNA

Xenobot: Microscopic, bioengineered organism created from frog cells that can move, self-organize, and perform simple tasks

Organ-on-chip: Micro-engineered device that mimics the structure and function of human organs by integrating living cells on a chip to simulate biological processes

Figure 7. Bio-inspired Technologies and Smart Materials workshop technological portfolio

3.3.2 Use-cases elaborated

USE-CASE 1: ***Precision Forged from Chaos & Uncertainty*** | **SECTOR: Agrifood** | **TECH: Bio-inspired sensing technologies, robotics and AI**

The group focused on the agri-food sector. After exploring a series of problems of the sector – such as desertification, food losses due to pests and climate adversities, and soil fertility issues – the group identified the root causes of those problems. The group also touched upon the cultural aspects of food consumption and the effects of education as well as “excessive” globalization of food value chains and diffusion of pollution. Water scarcity and saline intrusion were also root causes discussed. The effects of the problems manifest in environmental factors, such as diversity loss and ecosystem degradation, and in socio-economic factors, such as food pricing at farmer level and the length and "globalization" of value chains. The proposed solution focuses on localization of production (0 km paradigm) and on the use of technologies enabling precision agriculture to ensure sustainable and responsible use of resources. This solution leads to less food waste, more efficient crop productivity, and fairer prices for the farmers.

The group developed a thesis that the sector operates in a chaotic environment influenced by climate and (subsequently) the weather, resulting in uncertainty for the farmers, the key stakeholder in the agri-food sector that the group zoomed in on. Food production consumes significant resources, whether we are talking about water, land area, agricultural equipment and other resources needed to increase productivity. The current use of resources, based on an overexploitation of resources, is quite inefficient and creates a set of issues. The group proposes precision agriculture as a solution that is fueled by a series of technologies such as bio-inspired sensing technologies, robotics and artificial intelligence (for scenario creation improving crop yield) enabling a more sustainable use of resources, lowering the negative impacts on the environment (specifically on water and soil), and ultimately ensuring healthier and safer food availability for the growing population. The support of AI and biosensors enables precise data gathering, thus providing the necessary tools for better resource management. Key enabling resource for the proposed solution is technology co-creation with the farmers and exposing the hidden costs of the proposed digital solution. Key limitations preventing the solution from being implemented are beyond the technology development and have to do with a systemic change encompassing a renovated education system to better connect natural environments and technology and an increase in the social acceptance of technology itself.

The group agreed that precision, localized farming practices would create socio-economic benefits for farmers and environmental benefits through more efficient and effective use of resources enabling long-term sustainability and healthy society.

USE-CASE 2:
MeTrikot & MeDrikot

SECTOR:
Healthcare

TECH:
Organ-on-chip

This working group's discussion was centered around the healthcare sector. As a first step towards the co-creation of their use-case, participants identified several problems producing negative effects in the focus sector, such as higher chances of disease spread, reduced fertility, reduced life expectancy and quality of life. Some of the most discussed issues were the lack of awareness in the general public, misinformation and poor transparency resulting from business interest of specific categories operating in the market, scarce prevention, the gap between tech development processes and market uptake, the overload of medical personnel, the little societal acceptance of in-vitro models, the low transition of drugs into the market, and the cross-contamination in healthcare facilities due to pollutants and human-induced materials. Several solutions were presented to address the identified problems: an increase in incentives for health insurance and in public funding to promote prevention, communication and education campaigns to raise awareness, the design of user-friendly and accessible devices (e.g., wearable devices), the introduction of cheap solutions for early detection, the delivery of in-vitro methods to the market, and the development of sensors to detect contamination.

The group decided to focus on prevention with the aim of supporting a healthy lifestyle for all individuals. The final use-case is a solution enabling convenient, user-friendly, and early detection for the prevention of triggers. It consists of two types of multi-sensing wearable devices that monitor oxidative stress, a key indicator of physiological issues: (i) tattoo-like sensors and smart garments for continuous measuring (MeTrikot), and (ii) micro-needling for invasive (or minimally invasive) sensing for targeted monitoring (MeDrikot). Such solutions can be enabled by an organ-on-chip during the validation phase through in-vitro models. Key resources for their development would be biocompatible and recyclable materials, funding, and external data centers (also meaning synergies with external providers). They are beneficial both to society and the environment. In fact, by promoting preventive medicine, they empower individuals to self-monitor their health status, to become more conscious about their own health, and to early detect diseases. As a result, the use-cases have the potential to lower individual health care costs, to enhance individuals' quality of life, to reduce hospitalization rates, and to lighten the workload of medical personnel in healthcare facilities. Their environmental impact is also positive, as they do not rely on biohazards in laboratories and would generate less biohazardous waste. However, this solution may pose some concerns in terms of data privacy, societal acceptance, accessibility, long critical trials, invasiveness (at least during the first stages), and poor adaptability to market needs (especially to the interests of major players).

GROUP 3: ***VitriTex*** | **SECTOR: Manufacturing (Textile industry)** | **TECH: Bio-engineered bacteria**

The focus sector of this group was manufacturing, and specifically the textile industry. After identifying a list of challenges that this industry faces – including air, water and soil pollution, the lack of natural resources, and overconsumption – participants agreed that the main problem they wanted to address was the recyclability of textiles and how to increase their self-healing properties, in order to make the manufacturing processes more “bio-inspired”, environmentally friendly, and socially responsible. In fact, among the negative effects caused by the identified problems, participants indicated the lack of circular strategies, poor working conditions, and the high financial and environmental costs of raw materials extraction.

The group built a solution entailing bio-based, reusable, recyclable, scalable and circular self-healing materials with a potential of application and adoption in other sectors too, such as energy, mobility, construction, and healthcare. The envisaged solution was named “VitriTex” - a combination of “vitrimers” and “textile” - and it consists of bio-based vitrimers for protective clothing. Bio-engineered bacteria play a pivotal role in the development of this solution: they are employed to create textiles that can break down harmful pollutants in the environment, thus significantly reducing the ecological footprint of textile production. Bacteria are engineered to produce bioactive compounds that can be incorporated into textiles and thereby accelerating healing processes, offering both safety and durability for first responders, sports and workers that work in harsh environments.

Key resources to develop VitriTex include: biocompatible materials to ensure that the textiles are safe for the environment, materials that are compatible with the bio-engineered bacteria, advanced research facilities, significant investment from both public and private sector, partnerships with universities and research institutions, and an enhanced regulatory framework ensuring that all safety and efficacy standards are met before the products reach the market. To foster acceptance and proper use of these innovative textiles, awareness initiatives will also be necessary to inform the consumer base about the benefits and maintenance of such textiles.

As for potential limits to the feasibility of VitriTex, participants mentioned the lack of funding in the broader Research & Development ecosystem, the increasingly high cost of raw materials, and the fact that this solution may be challenging in terms of scalability and complex chemistry.

3.4 Real-Time Based Digital Twins and Simulation Technologies

3.4.1 Initial set of most promising technologies

Building Information Modelling: Digital representation process to create and manage data about a construction project

Cognitive Digital Twins: Advanced digital models replicating physical objects/systems/processes with cognitive computing capabilities

Predictive Maintenance: Real-time data driven method to monitor the equipment health and anticipate problems

Prognostic & Health Management: Computational approach to detect anomalies, diagnose faults, and predict equipment degradation

Decision Making Processes: Real-time data, simulations, and predictive analytics for informed and efficient management

Figure 8. Digital Twins and Simulation Technologies workshop technological portfolio

3.4.2 Use-cases elaborated

USE-CASE 1: ***HATOM - Human Aware Digital Twins Complex Operational Management***

SECTOR: Management / Operations

TECH: Cognitive Digital Twins

Participants decided to tackle a cross-cutting challenge that affects different sectors: efficient and sustainable management of complex operational processes and systems. A series of issues were discussed, generally leading to systemic inefficiency, resource waste, and poor transparency and traceability in complex working environments such as airports, factories, and hospitals. Some of the most debated issues were the lack of structured databases, the need for different knowledge management processes (both at the operational stage and at the R&D stage), and the difficulty of tracking workflows thoroughly.

Then, the group started building up a general and adaptable solution to enhance better decision-making, knowledge gathering and elicitation, and ecosystem collaboration in complex workplaces. They ultimately envisaged that Cognitive Digital Twins could help combine tacit knowledge (human knowledge) with sensor-based and data-driven knowledge, by providing a simplified reflection of the real system and ultimately enabling and facilitating the inclusion of the human element in the realm of digital twins. The added value of this solution lies in the fact that it provides managers and decision-makers with a new understanding of complex operational systems and with an easily attainable, dynamic visualization of the system itself. Not only does the solution increase efficiency and sustainability, but it also has potential to reduce process costs, to enhance accountability and transparency, as well as to "humanize" complex systems' digital twins by including information both from the physical and the human environments.

In this framework, cognitive digital twins represent enabling technology to build the necessary digital infrastructure and to regulate information flows. Additional key resources for the development of the proposed solution include reality measurement systems (e.g., sensors, questionnaires, data...), AI support, wide data centers availability, and compatible, interoperable devices and systems.

As for the main feasibility limits, the proposed solution is quite demanding in terms of data maintenance, energy consumption, and better regulation. Moreover, it poses several challenges when it comes to sensitive data protection and social acceptance of "surveillance" mechanisms. At the same time, many benefits were mentioned: human and financial capital retention and valorization, improved working conditions, and increased inclusivity in the workplace.

USE-CASE 2: BRIDE - Battery Recycling Innovation through Digital Twins Re-engineering	**SECTOR: Manufacturing**	**TECH: Cognitive Digital Twins**

Participants initially focused on a common challenge for SMEs: integrating robotics into manufacturing, particularly in retrofitting processes for better efficiency. The exercise began with mapping out problems and solutions, identifying high costs, regulatory compliance, and digital gaps as key hurdles. These issues are linked to the need for remaining competitive and sustainable in an environment marked by skilled labor shortages and lack of trust in new technologies. Proposed solutions emphasize human-centric approaches, enhanced training, operational guidelines, and the development of a unified EU digital framework. Addressing these challenges requires fostering a culture of digitalization, reskilling workers, and providing robust technical and financial support to implement effective robotics solutions.

In the next phase, the group focused on a specific energy-related sub-sector that relies heavily on manual labor in harsh environments: battery recycling, with the goal of material recovery. The primary challenge identified was the availability of battery information to enable efficient robotic disassembly. The proposed solution involves using data from the battery's digital passport and predictive maintenance to ascertain the battery's end-of-life. This data, combined with worker expertise incorporated into Cognitive Digital Twins, would help train robots to improve the disassembly process, enhancing the process's specificity based on different battery components. This human-machine collaboration aims to improve material circularity in batteries, thus enhancing the sustainability of the energy sector and ensuring safer working conditions. Key stakeholders include battery manufacturers, the recycling industry, researchers, ethics specialists, policymakers, users (like the automotive and stationary sectors), and ultimately, the public. The success of this solution hinges critically on continuous investment in research and innovation, workforce training, and the integration of social sciences and humanities experts to address potential ethical and legal challenges. The availability of battery data, along with concerns about privacy and safety, including worker safety, could limit the implementation of this solution

The final use-case is "BRIDE – Battery Recycling Innovation through Digital-twins re-Engineering". It focuses on the efficient reuse of battery materials, and it involves re-skilling and up-skilling the workforce, addressing acceptance and trust in digital technologies. The core of the solution introduces new robotics into complex industrial processes, with robots trained based on worker expertise and battery data required to disassemble batteries. The implementation in real environments is anticipated within 5-8 years, targeting the recycling and battery industries. This solution is expected to create safer working conditions, reduce Europe's dependency on imported critical raw materials, lower the carbon footprint, and protect natural ecosystems. However, uncertainties remain regarding potential new pollutants and the energy demands of these new assisted processes. The long-term social impact includes the sovereignty of European industry and the potential application of retrofitting solutions across various sectors.

USE-CASE 3: *TWIN2WIN*

SECTOR: Automotive

TECH: Cognitive Digital Twins

The group directed their efforts on the automotive sector, specifically addressing the needs of engine assembly workers. Participants identified key challenges in training and supporting workers with diverse skills, abilities, and experience levels. The central problem was the lack of personalized, adaptive training systems to accommodate workers with varying characteristics, including those with disabilities or age-related impairments.

The proposed solution, named TWIN2WIN, leverages Cognitive Digital Twins to create a hyper-personalized training system. This system adapts to individual needs by simulating realistic scenarios through extended reality (XR) technologies, including virtual and mixed reality.

Workers interact with a digital twin of an engine, receiving customized guidance tailored to their skill level and experience. For example, novice workers receive step-by-step instructions, while experienced workers see only critical updates or new information. The system supports both on-site and remote interactions, enabling flexible training and reducing the need for physical resources. The solution emphasizes a collaborative and inclusive workspace, with workers and technology (such as robots) interacting dynamically. The use of sensors and factory telemetry ensures real-time data collection, which feeds into the digital twin for continuous adaptation and improvement. Augmented semantic features link virtual models to real-world applications, fostering an intelligent decision-making process. This iterative feedback loop enhances worker training and performance over time.

Participants highlighted the potential benefits of TWIN2WIN. Socially speaking, the system improves inclusivity, allowing a more diverse workforce to thrive, including individuals with disabilities or age-related challenges. It fosters motivation, supports knowledge transfer, and empowers workers by providing accessible and effective training. Environmentally speaking, the reliance on digital twins minimizes waste by reducing the need for physical prototypes or excessive resource consumption during training. The broader impact of TWIN2WIN extends beyond the factory floor. The system's scalability allows it to be adapted for academia, schools, and other industries, enabling students and trainees to gain hands-on experience through simulations. This approach promotes a paradigm shift in manufacturing, fostering more inclusive, efficient, and environmentally sustainable practices.

In summary, TWIN2WIN represents an innovative application of cognitive digital twins in the automotive sector. It creates a personalized, human-centred training system that addresses diverse workforce needs, enhances productivity, and supports sustainable development, positioning it as a transformative solution for modern manufacturing challenges.

USE-CASE 4:
PrevenTwin for WorCares

SECTOR:
Management / Operations

TECH:
Cognitive Digital Twins

The group focused on the industrial environment, identifying poor working conditions as a critical issue affecting workers. The main problem identified was the lack of real-time monitoring and predictive tools in workplaces, which may lead to increased injuries, absenteeism, and significant economic costs. The root causes of these challenges were attributed to limited access to advanced safety training, inadequate technological resources, and a lack of systematic data-driven approaches to safety. The visible effects included an increase in workplace hazards, reduced productivity, and diminished morale among workers.

To address these challenges, the group proposed a solution that leverages emerging technologies, specifically Cognitive Digital Twins. These tools would enable real-time monitoring and predictive analysis of workplace risks by simulating environmental conditions and worker behaviour. This solution was designed to meet the critical needs of real-time data collection, advanced analytical capabilities, and user-friendly tools for both workers and managers. The expected outcomes included a significant reduction in workplace accidents, improved safety, and enhanced worker morale, ultimately fostering a safer working environment.

The participants refined further the problem and solution, identifying specific challenges in implementing predictive technologies within dynamic workplace environments. The Cognitive Digital Twins were positioned as a core technological enabler, offering capabilities to simulate various scenarios, analyse real-time data, and provide actionable insights to prevent risks. The key stakeholders involved were identified as workers, safety officers, technology providers, and workplace managers, each playing a critical role in implementing and benefiting from the solution. Resources such as access to comprehensive workplace data, technical expertise, and funding were considered essential for success. The group also highlighted potential limitations, including ethical concerns around data privacy, legal and regulatory constraints, and resistance to change from certain stakeholders.

In the final phase, the participants detailed the use-case, giving the solution the name PrevenTwin for WorCares. The system would utilize Cognitive Digital Twins to collect and analyse critical workplace data, such as environmental conditions, equipment status, and worker activities. By simulating different scenarios and identifying potential risks, the system could provide real-time recommendations to prevent accidents. The expected benefits were both social and environmental. Socially, the system would enhance workplace safety, reduce injury rates, and foster greater job satisfaction and trust among workers. Environmentally, it would optimize the use of resources, improve machinery and equipment monitoring, and support sustainable operational practices. The overall impact of the solution was envisioned as a transformative improvement in workplace safety, addressing immediate concerns while promoting long-term efficiency and sustainability.

3.5 Human-centric Solutions and Human-Machine Interaction

3.5.1 Set of most promising technologies

Digital Twins: Virtual representation of an object/system updated from real-time data and designed to reflect its physical counterpart

Hapitc technology: Uses tactile feedback to recreate the sense of touch, for immerse interaction with digital objects

Natural Language Processing: Uses machine learning to computers to communicate with human language

E-skin sensor: Flexible, stretchable, and ultra-thin electronic material designed to mimic the sensory functions of human skin

Internet of Things: Network of physical objects embedded with sensors, software and connectivity for data collection and sharing

Figure 9. Human-Machine Interaction workshop technological portfolio

3.5.2 Use-cases elaborated

USE-CASE 1: *SEAMLESS- Social Environment, Adaptative, Multiple modalities Low-x Ergonomics for Safety and Sustainability*

SECTOR: Manufacturing

TECH: Natural Language Processing

Human diversity was central to the group's discussions, focusing on manufacturing lines where human involvement is crucial due to technological challenges in adapting to various sensitivities needed for handling different components and product state uncertainties. The group identified seamless human-machine collaboration as a key issue, stemming from the low cost of human labor, the lengthy time robots require for precise assembly, and the monotony of repetitive, low-cognition tasks. The group proposes a shift to a seamless human-machine operations model, emphasizing ergonomic support and enhancing worker environments. This approach involves 'user-friendly learning and teaching factories,' where robots, acting as personal twins, are trained through human interaction. This setup aims for operations that are more dynamic and comfortable, with humans retaining ultimate decision-making authority.

The main issue addressed by the group is optimizing processes that cannot be fully automated, particularly in assembling and disassembling flexible, high-dexterity components. The proposed solution involves a personal digital twin that integrates adaptive, learning robotics. This solution will merge various technologies including Natural Language Processing to simplify process awareness, personal digital twins for worker recognition and diversity, e-skin sensors to enhance robot dexterity, and haptics and computer vision for improved interaction. The focus is putting workers at the center of the solution, with leaders and decision-makers playing a crucial role in adopting these technologies. Key participants will include mechanical and electronic engineers, and AI experts, with essential support from financial sources, research and innovation, and training programs for worker upskilling and reskilling. Challenges such as worker acceptance, the low readiness level of technologies, the need for new standards, and GDPR compliance are identified as major obstacles to implementing personalized production lines that maintain a motivated, safe, and inclusive workforce while potentially increasing company profits.

The final use case co-created by the group, named SEAMLESS: Social, Environmental, Adaptive, Multi-modal, Low-x Ergonomics for Safety and Sustainability. Its primary aim is to automate processes that are difficult to mechanize, to reduce production costs, simplify complexity, and enhance worker motivation and well-being. The proposed solution centers on seamless human-robot collaboration in manufacturing processes. Key technologies include digital twins to maintain machine context awareness on the shop floor and natural language processing to reduce complexity. This technology suite will be integrated directly into production lines where humans and machines collaborate. Full technology adoption could take 5 to 10 years, depending on R&I investment, though some group members anticipate up to 20 years, considering social factors. The target groups include production workers and the broader manufacturing sector. Expected benefits include improved workforce skills, increased worker engagement, and fewer product defects. Long-term, the group foresees reductions in healthcare costs and shifts in labor division. This solution aims to contribute to several Sustainable Development Goals (SDGs), specifically numbers 3, 8, 9, and 12.

USE-CASE 2: *TECHCARE* | **SECTOR: Healthcare** | **TECH: Digital Twins + Internet of Things + AI**

The primary issue discussed by the group was the well-being and decision-making support for caregivers and care receivers in high-stress and critical situations, particularly within elder care and care work. This included tackling loneliness, ensuring individuals feel safe and acknowledged, and managing workload stress for caregivers. Additionally, challenges such as cybersecurity, privacy concerns, and ethical considerations were also significant factors.

To address these challenges, the proposed solution involves developing a robust infrastructure that collects and analyzes real-time information about the care environment. This system would support decision-making protocols tailored for critical and stressful scenarios, ensuring care is delivered efficiently and empathetically.

The target groups and stakeholders include care workers and caregivers, who will benefit from improved workload management and reduced stress. Elderly individuals will experience a greater sense of safety, connection, and well-being. Families of care receivers will see reduced family conflicts and improved engagement with care processes. The broader stakeholders involved include hospitals, residential care facilities, and home care providers.

The solution would leverage key technologies to address these challenges. Digital Twins will be used for knowledge representation and modeling of real-life care environments, enabling predictive insights. Artificial Intelligence (AI) will analyze data and provide actionable recommendations, while the Internet of Things (IoT) will collect real-time data on care environments and the well-being of care receivers and caregivers.

The expected impact extends across multiple domains. Socially, the solution will improve decision-making, enhance the well-being of caregivers and care receivers, and help resolve family conflicts. Environmentally, it will optimize resource utilization and reduce energy consumption. From a technological perspective, it will enhance privacy controls and cybersecurity measures.

This use-case illustrates the potential of integrating innovative technologies with a human-centric approach, aligning with the goals of Industry 5.0 while addressing the ethical and societal aspects of caregiving.

USE-CASE 3:
You'll Never Fly Alone

SECTOR:
Aviation

TECH:
Natural Language Processing + Internet of Things

The initial input for this group discussion came from a participant working in the aviation sector, who highlighted some issues related to operational communication processes in safety-critical environments such as aircrafts and healthcare facilities. A debate followed about several problems that may arise in such environments. More specifically, participants mentioned difficulties in protocol implementation (with special regards to checklists), in communication processes between system operators, in maintaining good situational awareness, and in operational scaling when it comes to balancing efficiency and safety. These difficulties are caused by a variety of factors, for instance noisy environments, different dialects or accents, and disturbed or interfered signals. As a result, a series of negative effects are produced, from operational inefficiency to unexpected and potentially dangerous events (e.g., accidents).

The group embraced an approach based on human-machine teaming design that could help address the identified difficulties and develop a solution enhancing safety, reducing unexpected events, and refining human-machine interaction mechanisms in safety-intensive contexts. The discussion was then narrowed down to the specific context of aircrafts, entailing all phases of the aircraft journey – from pre-flight to landing. However, the proposed solution has the potential to be adaptable to other environments as well (e.g., hospitals).

The final use-case co-created by the group was titled You'll Never Fly Alone, as it consists of a multisensorial, NLP-powered intelligent support system to enhance operational communication and refine human-machine-human interaction. The system represents a valid assistance tool for pilots in the implementation of protocols and for the purposes of situational awareness (both collective and within the cockpit). It uses different state-of-the-art sensors, collects data with Internet of Things, uses signal processing and Machine Learning techniques, and relies on large language models and Natural Language Processing to improve communication and summarize conditions.

Although the proposed solution may negatively impact the environment (due to the ecological footprint of LLM's production and usage) and increase cybersecurity risks, it may also be beneficial from a social perspective, as a better situational awareness would be a boost for better decision-making and for new safety standard, and it would ultimately increase the overall safety in the aviation sector (even by a very small percentage). Additional downsides mentioned are the possible reduction in human-human interaction and in employment rates, while an environmental advantage would be the decrease of waste and e-waste thanks to predictive maintenance systems.

USE-CASE 4:
AIMS – Aircraft Intelligent Maintenance System

SECTOR:
Aviation

TECH:
Digital Twins +
Internet of Things

The group chose to focus on aviation, identifying the aircraft maintenance process as a critical issue, particularly due to its high level of complexity. Key causes include the low level of automation in procedures, limited adoption of solutions despite strict regulations, and inadequate design specifications. The most evident consequences are the high cost of maintenance, operator stress, lengthy operations, and resulting delays in aircraft operations.

The group aims at reducing the complexity of the sector. To achieve this goal, identified needs include training and education for personnel, improved operator safety, greater adoption of technology, enhanced infrastructure, better design specifications, and timelier implementation of regulations. Expected outcomes include improved working conditions for operators (resulting in a lower risk of accidents), reduced downtime, lower maintenance costs, and faster, more efficient processes.

As the discussion progressed, the group recognized that the complexity of the maintenance process is a symptom of a broader issue: limited efficiency. The proposed solution seeks to enhance operational safety, improve working conditions for operators by reducing risks of failures and unexpected issues, and generally increase the efficiency of the process, making it smarter and more streamlined. The technologies identified as most suitable to address these needs are a combination of IoT systems and Digital Twins. IoT would facilitate data collection, while Digital Twins would enable predictive maintenance. Specifically, the group envisions an aircraft scanning system capable of promptly assessing the aircraft's health and identifying the maintenance tasks to be performed.

Key stakeholders affected by the problem and thus integral to the solution include aviation authorities, airport operators, airlines, and their boards of directors/management teams. Essential resources for implementing the solution include hardware and software components, technical equipment (such as the scanning device), technical experts, trainers, and an updated regulatory framework. Potential limitations or obstacles to the solution include low investment levels, the cost of technical equipment, and resistance from airlines and operators to adopt new technologies.

In conclusion, the group proposes AIMS - Aircraft Intelligent Maintenance System as an intelligent check-and-maintenance system designed to enhance the efficiency of maintenance processes. The system integrates IoT and Digital Twin technologies, includes robust data security measures, and is intended as a tool to support operators, who remain in control of its operation. The anticipated benefits include greater reliability of the maintenance process, easier task management for operators (resulting in reduced stress), and improved flight scheduling. From an environmental perspective, the system is expected to promote greater reuse of components, prevent unnecessary replacements, and reduce waste overall. Expected impacts include changes in workers' conditions, improved safety for both operators and passengers, and shorter wait times for takeoff. Considerations must also include energy consumption associated with implementing these new technologies and a potential increase in the overall number of flights.

3.6 Technologies for Energy Efficiency and Trustworthy Autonomy

3.6.1 Set of most promising technologies

Flow batteries: A type of rechargeable battery where energy is stored in liquid electrolytes contained in external tanks.

Lithium-ion batteries: A type of rechargeable battery that uses lithium-ions as the primary charge carriers

Platooning: Multiple vehicles travelling in a coordinated, closely spaced formation, managed through advanced communication and control technologies.

Model Predictive Control: Advanced control strategy that optimizes energy use by predicting future system behavior over a defined time horizon.

Algae: Algae usage within the cement industry may be an effective measure to boost energy efficiency while reducing CO2 production.

Electrochrominc Glass: A type of glazing that can change its light transmission properties in response to an applied electrical voltage.

Figure 10. Technologies for Energy Efficiency workshop technological portfolio

3.6.2 Use-cases elaborated

USE-CASE 1: ***MIXEES – Mixing Technologies for Efficient Energy Storage***

SECTOR: **Energy Storage and Provision Systems**

TECHNOLOGY: **Model Predictive Control + Flow Batteries**

The group focused on the energy sector, with an initial discussion revolving around renewable energy sources and the challenges of balancing production and demand when energy comes from renewable sources. One of the group members, who is from an island, shared their expertise on closed energy systems and the conversation shifted to the insights this could offer for energy communities.

The key issue identified is utility-scale storage in closed energy provision systems. This issue arises from the difficulties in matching production and demand, as well as from the growing societal electrical needs due to electrification and to the increased use of energy-hungry, AI-powered digital solutions. The difficulty in achieving efficient utility-scale storage results in inefficiencies within the broader energy industry and creates uncertainty about the profitability of storage solutions.

Funded by the European Union

To address these challenges, the group proposed a utility-scale storage system relying on a combination of flow batteries, lithium-ion batteries, BESS (battery energy storage system), predictive model control and development of novel materials. This solution would enable a better match between production and consumption and ensure grid stability: currently, fossil fuel-based production is needed to complement renewable energy generation in order to ensure grid stability and availability of electricity when renewable energy is not accessible. The implementation of the proposed solution, called MIXEES, has potential to enhance the maximization of clean energy production, availability and use, to facilitate a higher systemic resilience, and to support better price stability in the long term.

Materials research was identified as a key resource to achieve this value proposition, being a suitable tool towards the choice of widely available, reusable, recyclable and scalable materials for utility-scale storage. The storage should be part of a closed energy system enabling the provision of energy from renewable sources only for all users, always (summer, winter, day, night, low tide, high tide, with wind, and without wind). The ideal testbed for this solution would be an island, as island energy systems are necessarily closed, self-sufficient, and unable to feed from the grid. Learnings from this kind of testbed could be then transferred to energy communities on the mainland.

The major social benefits of this solution would be the availability of clean energy for all users and – consequentially – cleaner and healthier environments with improved air quality and reduced human-generated climate impact.

USE-CASE 2: *SMARTBEM*	SECTOR Buildings / Construction	TECH Model Predictive Control

The group decided to develop their use-case in the building sector. They began by identifying the main problems related to energy efficiency in this sector. Key issues included lack of access to energy sources, climate change and the need for adaptation, high dependency on energy suppliers, and low citizen awareness regarding energy consumption and optimization. These challenges highlighted the urgent need for innovative energy management solutions that can improve sustainability and operational efficiency in buildings. Next, the group identified several important needs to address. They emphasized the necessity for faster adoption of technology in society to improve system efficiency and higher energy literacy among citizens. Additionally, they highlighted the need to reduce dependence on centralized energy grids and enhance competitiveness in the energy sector. By addressing these needs, the group aimed to create a more resilient and efficient energy system. After a brief discussion, the group decided to focus on building inhabitants as their target audience. They identified low flexibility in energy source management as the primary problem. This lack of flexibility limits the ability of users to dynamically switch between different energy sources, leading to higher costs, inefficiencies and reduced sustainability.

To enhance flexibility and efficiency in energy source management for both new and existing buildings, the group proposed a solution based on Model Predictive Control. This technology used for energy management in buildings is an advanced control strategy that optimizes energy use by predicting future system behavior over a defined time horizon. The main objectives were to facilitate decision-making processes and optimize energy use. The proposed solution, named SMARTBEM, aimed to reduce CO2 emissions, improve social awareness, empowering citizens to actively engage in energy management, and lower operating costs, making energy solutions more accessible and cost-effective. To develop this solution, the group identified several relevant resources, including system modelling skills to create accurate energy consumption models; AI competencies, and technology selection and optimization tools to integrate the most effective energy solutions. They also highlighted key factors necessary for the development of this solution, such as the required investment, available user data, environmental and energy sector information (including demand, consumption, prices, and forecasts), and the need for user training to ensure efficient adoption and engagement with the system. The group suggested initially applying SMARTBEM to some existing piloting facilities for simulation. This allows for simulated testing and refinement before full-scale deployment.

The group also identified several limitations for this use-case, including potential low interest from investors in this solution, high implementation costs (particularly in retrofitting older buildings), difficulties in accessing data from building inhabitants, and infrastructure issues that could hinder full implementation, especially in outdated buildings with inefficient energy systems. These challenges could pose significant barriers to the widespread adoption of SMARTBEM. On the other hand, the group noted that SMARTBEM could offer substantial benefits. It has the potential to streamline regulatory and bureaucratic processes in the long term, reduce energy costs for citizens, create a more balanced and resilient energy framework, decrease reliance on traditional grids, and enhance overall sustainability in society. By addressing these key issues, SMARTBEM has the potential to drive long-term improvements in energy management, reduce carbon footprints, and enhance sustainability in the building sector.

USE-CASE 3: ***RE-VIVE*** → **SECTOR: Buildings / Construction** → **TECH: Model Predictive Control + Digital Twins**

The group did not focus on a specific sector initially but rather discussed several concrete challenges that humans and buildings face in relation to energy efficiency. These challenges include, for instance, the rise of energy consumption, the increase in energy prices, the looming shortage of energy, bad behavioral issues surrounding individual energy use, climate control issues inside cars, personal comfort within buildings, and the damage caused by harmful UV light from outside windows (such as to pieces of art in museums). Several possible solutions were explored, including the development and implementation of community energy systems, the use of more durable materials capable of blocking UV light, the deployment of better insulation systems, and more.

Eventually, the group chose to focus specifically on potential ways to improve individual comfort with temperature regulation inside buildings. This led them to the ideation of a hybrid and flexible system designed to control energy flows inside and outside urban buildings, with the goal of enhancing both physical and social well-being for individuals *and* creating more comfortable indoor environments.

The solution they envisioned, titled RE-VIVE, consists of a data-driven control system that combines predictive modelling with digital twin technology to enable better energy management, to forecast energy consumption more accurately, and to optimize HVAC (Heating, Ventilation, and Air Conditioning) operations and systems. RE-VIVE primarily targets citizens in urban areas, and its primary benefits include a decrease in energy consumption, hence in CO2 emissions, alongside a reduction of the so-called "*urban sprawl*": by making existing urban buildings more energy-efficient, the need for new construction in suburban areas would decrease, thus helping to limit gentrification.

The group agreed that the implementation of RE-VIVE would require active involvement and commitment from various actors, from technology providers and developers to building owners, from private banks to start-ups, from public institutions to citizens and citizen communities. For RE-VIVE to be successful, significant public and private investments, as well as effective efforts to persuade the public to trust the solution, would be required.

Finally, possible challenges and feasibility limits were mentioned with regards to the development of the solution envisaged, including societal resistance, long payback periods for investors, the difficulties of applying such technologies to older buildings, and the need for critical raw materials.

USE-CASE 4: *CONVENSE – Advanced Connected Vehicles to Enhance Safety and Energy* | **SECTOR: Mobility** | **TECH: Model Predictive Control + Platooning**

The group activity started with an initial brainstorming on the challenges posed with regards to energy efficiency. The group had a vivid and fruitful exchange on several key issues in this sector, encompassing different application areas and related problems.

Benefitting from the "Problem Tree" exercise, multiple causes were identified and clustered into energy consumption, flexibility, regulations and/or policies, production costs, labor skills, and data. At this stage, the group identified data management as the main problem to be tackled, entailing aspects such as data collection, data sharing and data analysis.

The group further elaborated on the context and recognized that efficient and sustainable road transportation is a critical component of supply chain logistics and mobility solutions. However, there are challenges related to insufficient data management and utilization concerning energy and environmental performance. This deficiency impacts the optimization of fleet operations, which must address variables such as road infrastructure, real-time weather conditions, obstacle detection, road works, and charging station availability in the case of electric vehicles.

Traditional fleet management strategies often lack the necessary real-time processing, predictive capabilities, and cooperative strategies that can enhance energy efficiency and reduce operational costs. Titled CONVENSE (Advanced Connected Vehicles to Enhance Safety and Energy), the proposed technological solution addresses these challenges through the integration of Model Predictive Control and Platooning to enable optimal route planning, load balancing, and coordinated vehicle movement.

While MPC enables predictive, real-time decision-making by continuously adjusting vehicle speeds, energy consumption, and routes based on dynamically changing conditions, platooning enables groups of electric vans to travel together at optimized distances, reducing energy consumption and enhancing safety and obstacle avoidance through shared sensor data.

The proposed integration of MPC and platooning into fleet route optimization services would represent an important step towards energy-efficient and trustworthy autonomous transportation. By leveraging real-time data processing, predictive analytics, and coordinated driving, the solution would enable smarter, more resilient logistics operations that benefit both businesses and the environment.

4. Conclusions

Based on the experience gained from organizing and implementing this event series, several lessons and key findings have emerged. These insights are presented below, addressing both the process level - with special regards to co-creation and stakeholder engagement methodologies – and in terms of potential applications of emerging technologies. Lessons learned and key findings collected by FORGING and described in the below paragraphs may be a valuable source for future initiatives seeking to refine collaborative approaches to maximize the impact of technological innovations.

4.1 Lessons learned in facilitating multistakeholder discussions

One of the key challenges encountered was that stakeholders from different backgrounds do not always immediately recognize their common interest in addressing the same issue. To overcome this lack of initial alignment, clear and easy communication is key: using simple language and incorporating impactful visual tools proved to be highly effective in ensuring a common understanding of key concepts among participants. Striking the right balance between depth and accessibility was essential to enhance meaningful participation from all stakeholders, regardless of their expertise and/or extent of technical knowledge with the topic.

Maintaining a structured yet inclusive and open discussion was also challenging. In this regard, the **use of canvas with clear guidelines** played a crucial role in keeping conversations focused and on track to meet the workshop's purposes, while ensuring adequate space and time for everyone to share their opinion and unique perspective. The role of facilitators was pivotal as well in steering the discussions and ensuring that they remained productive and inclusive at the same time. **Encouraging a safe space** for dialogue (i.e. creating an environment where all participants feel respected and comfortable sharing their thoughts) was equally important, as it allowed participants to share their insights more freely without hesitation. This was achieved by setting clear ground rules for respectful communication and actively inviting input from all voices throughout the discussion.

Flexibility in event design, namely adapting formats based on participant feedback, significantly smoothened engagement. For instance, the introduction of pitching sessions in later workshops not only facilitated networking but also offered participants the opportunity to **provide real-world examples** of emerging technologies, helping visualize their potential applications and prepare for collaborative use-case development exercise. One recommended action in this sense is to implement satisfaction questionnaires after each session, as they provided valuable insights for refining both structure and methodology. Adjustments made following the pilot sessions led to a more interactive and effective format in subsequent events.

Finally, another key factor boosting participant engagement was providing clear information on what would happen after the workshop. Clearly communicating the purpose of each event, its expected outcomes, and the next steps helped participants **contextualize their involvement**, leading to more meaningful overall engagement. Notably, engagement levels significantly improved when, on the first day, after presenting the FORGING results, the subsequent steps in the project were explained in detail – i.e., engagement in new workshops, both online and in-person, to advance the co-developed use-cases toward real-world market applications by the means of future calls for proposal under the European Commission's Framework Program.

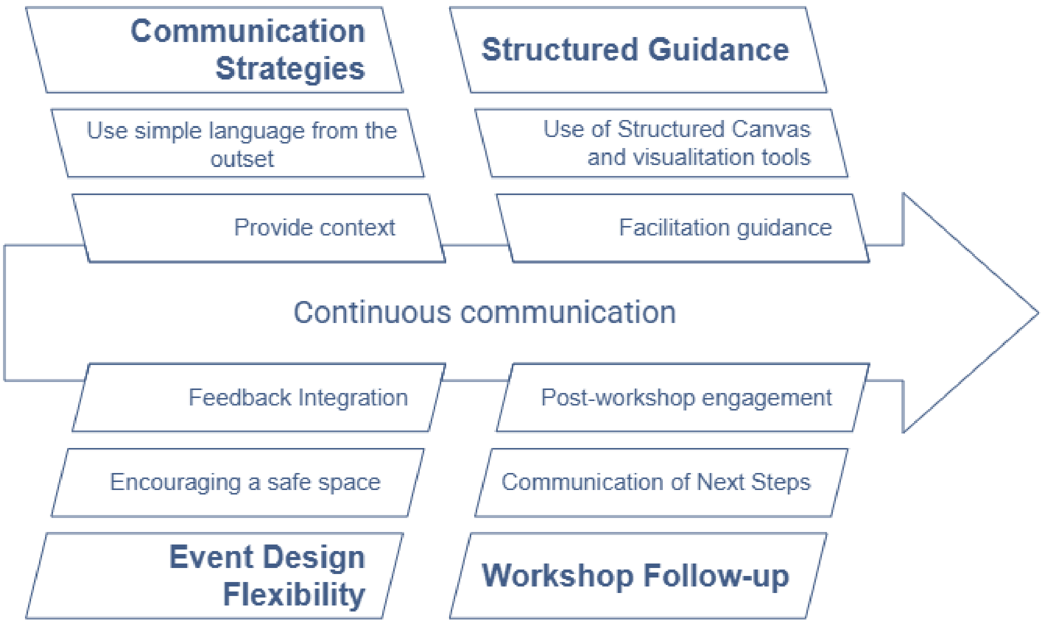


Figure 11. Enhancing stakeholder engagement in co-creation workshops

4.2 Summary of key findings

Considering new technologies as tools to address specific societal needs enables a human-centered and responsible approach to innovation. As emerged during the workshop series, the connection between human and/or social needs and emerging enabling technologies of Industry 5.0 enhances technological development processes aimed at accelerating the transition toward a more sustainable and responsible innovation. Several technologies explored in FORGING are recognized for their significant potential to deliver social benefits and to tackle environmental and social challenges.

1. **Artificial Intelligence.** **Adaptive AI** was considered by attendees as a promising solution in several industries such as in agriculture, manufacturing and healthcare. This technology can optimize workflows by analysing real-time data, identifying inefficiencies,

and automatically adapting. For instance, in manufacturing, they enable predictive maintenance, reducing downtime and increasing productivity. Through AI-driven forecasting, businesses are able to anticipate disruptions, e.g., raw material shortages or transport delays, and act in advance. Predictive analytics streamlines energy usage, material usage, and production scheduling. In agriculture, it helps farmers reduce water and fertilizer waste by predicting the optimum levels of usage.

2. **Cyber safe data technologies.** **Zero-trust** architectures and **zero-knowledge proofs** emerged particularly useful in deploying responsible solutions. Ensuring interoperability and data accessibility while maintaining security was a recurring challenge, with use cases demonstrating the need for innovative solutions that balance these priorities. Privacy-enhancing technologies were emphasized as crucial for securing sensitive data, especially in healthcare and public administration.
3. **Bio-inspired technologies and Smart Materials.** **Wearable biosensors** and **bio-based self-healing materials** emerged as key innovations capable of transforming sectors like healthcare, textiles, and agriculture. The most promising applications focused on reducing waste, enhancing material efficiency, and improving human health through bioengineered solutions.
4. **Digital Twins and Simulation technologies.** **Cognitive Digital Twins** were identified as being central to the optimization of complex processes in manufacturing, aviation, and logistics industries. The integration of sensor data, AI-driven simulation and human expertise was found to be particularly useful in predictive maintenance and operations decision-making. Digital Twins also support sustainability through improved resource allocation and enhanced energy efficiency.
5. **Human-Machine Interaction (HMI) technologies.** The facilitated discussions highlighted **Digital Twins**, **Internet of Things** (IoTs), and **Natural Language Processing** (NLP) as the most promising technologies to enable human-machine collaboration and automation. Digital Twins were found to be key enablers for real-time decision-making improvement, predictive maintenance, and process optimization across a variety of industries, such as manufacturing, aviation, and healthcare. IoT-enabled systems were recognized for their ability to collect, process, and analyze real-time data, leading to greater efficiency, reduced risks, and enhanced operational awareness. The development of adaptive, context-aware interfaces was identified as central to facilitating the uptake of automation in manufacturing and caregiving contexts. Inclusivity and accessibility of HMI technologies were emphasized, particularly for aging populations and individuals with disabilities.
6. **Energy Efficiency technologies.** Predictive control systems and energy management solutions were among the most promising solutions for increasing efficiency in both industrial and residential settings. **Model Predictive Control** (MPC) and energy storage technologies were specifically identified as instrumental to grid stability optimization and to the integration of renewable energy sources. The potential of these technologies to

contribute to carbon footprint reduction and circular economy solutions place them well for continued relevance in the green transition.

Overall, the co-development process of the use-cases outlined that the most impactful solutions combine **multiple technological domains**, underscoring the importance of **interdisciplinary research** and collaboration. As emerged from the T4.2 workshop series, the efforts of bringing together stakeholders from various industrial sectors representing different technology interests can also facilitate the definition of challenges and the design of cross-cutting solutions.

Finally, to ensure successful market adoption, workforce and citizens **training** as well as agile and **appropriate legislation** emerged as key aspects: societal resistance and lack of trust still represents a potential limit to the feasibility of new technological solutions, just as much as the need for improved regulatory frameworks and for increased public and private investments, as emerged from several group discussions.

4.3 Next steps for further engagement and implementation

A follow-up engagement process is in place for participants of the "*Novel Enabling Technologies for a Sustainable Future"* workshop series, as part of T4.3 and referred to (within the FORGING framework) as Technology Pathways Development. Led by INL, this further step aims at advancing the co-created use-cases toward real-world technological applications and at supporting their adoption by industry and society. Participants in this workshop series were asked to take part in this three-step process:

1. **Online workshop to map the use case against the funding opportunities, mapping of existing capabilities and identification of gaps**. The group will decide if there is sufficient critical mass to continue to move forward to Step 2.
2. **In-person workshop to develop the technology pathways**;
3. **Final online workshops for finetuning** the pathways.

The main goal is to **identify potential funding opportunities** that may facilitate the advancement of the use-cases towards the market uptake while providing targeted support to key stakeholders involved throughout the process. Through the three mentioned steps, participants who expressed interest in further involvement will collaborate on project proposals based on the use-cases produced during the workshops.

Annex I: Use-cases Overview

TECHNOLOGICAL FRAMEWORK	USE-CASE TITLE	APPLICATION/ADOPTION SECTOR	TECHNOLOGY(IES)
ARTIFICIAL INTELLIGENCE	*Data-driven Resilient Farming*	Agriculture	Abductive Reasoning AI
	ALICIA	Manufacturing	Adaptive AI
	Data-driven Business Model	Manufacturing	Adaptive AI
	DIA-BEATER	Healthcare	Adaptive AI
CYBER-SAFE DATA TECHNOLOGIES	*TRULY*	Healthcare	Zero Trust
	ZenCARE	Healthcare	Zero-knowledge Proof
	NEXT GEN P.A.	Government/Public Administration	Zero-knowledge Proof
BIO-INSPIRED TECHNOLOGIES AND SMART MATERIALS	*Precision Forged From Chaos & Uncertainty*	Agriculture	Bio-inspired Sensing Technologies + Robotics + AI
	METRIKOT/MEDRIKOT	Healthcare	Organ-on-chip
	VitriTex	Manufacturing (Textile Industry)	Bio-engineered Bacteria
REAL-TIME BASED DIGITAL TWINS AND SIMULATION TECHNOLOGIES	*HATOM*	Management/Operations	Cognitive Digital Twins
	BRIDE	Manufacturing	Cognitive Digital Twins
	Twin2Win	Automotive	Cognitive Digital Twins
	PrevenTwin 4 WorCare	Management/Operations	Cognitive Digital Twins
HUMAN-CENTRIC SOLUTIONS AND HUMAN-	*SEAMLESS*	Manufacturing	Natural Language Processing + E-skin Sensors + Haptics + Compute Vision + Digital Twins

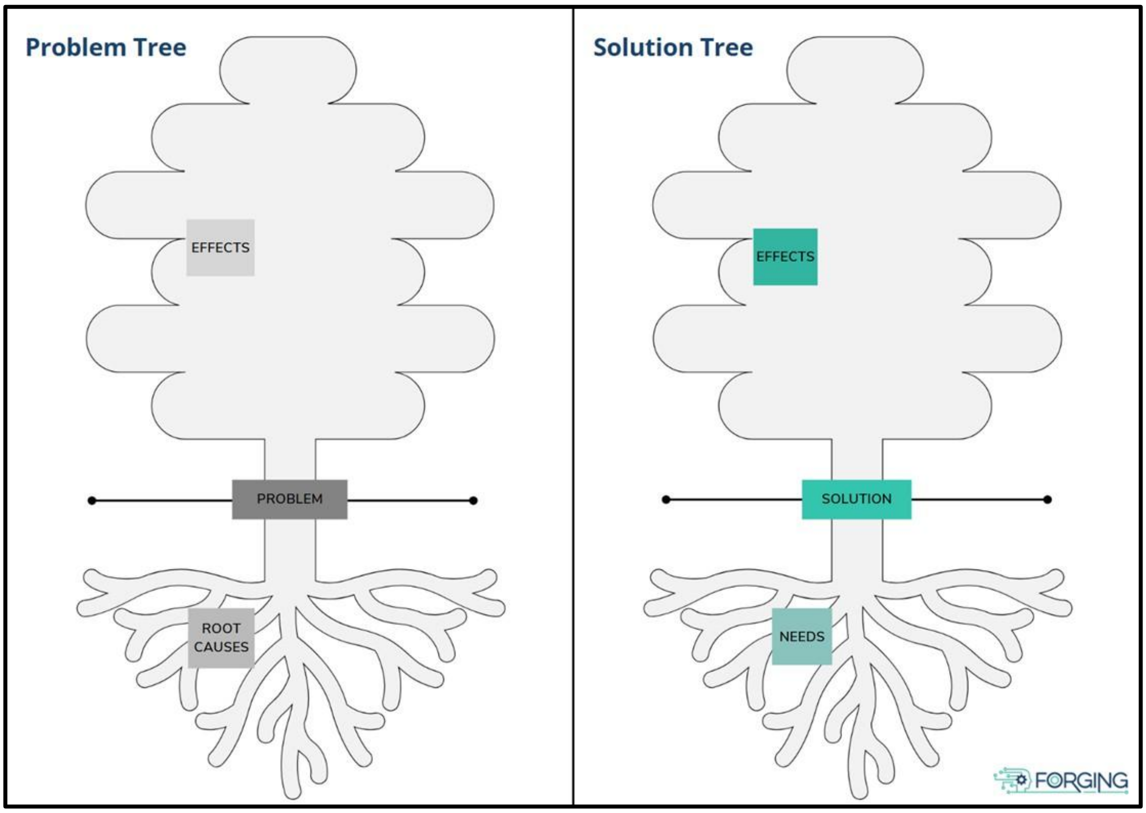
MACHINE INTERACTION TECHNOLOGIES	*TECHCARE*	Healthcare	Digital Twins + AI + Internet of Things
	You'll Never Fly Alone	Aviation	Internet of Things + Natural Language Processing
	AIMS	Aviation	Digital Twins + Internet of Things
TECHNOLOGIES FOR ENERGY EFFICIENCY AND TRUSTWORTHY AUTONOMY	*MIXEES*	Energy Storage	Model Predictive Control + Battery Energy Storage
	SMARTBEM	Buildings/Construction	Model Predictive Control
	RE-VIVE	Buildings/Construction	Model Predictive Control + Digital Twins
	CONVENSE	Mobility	Model Predictive Control + Platooning

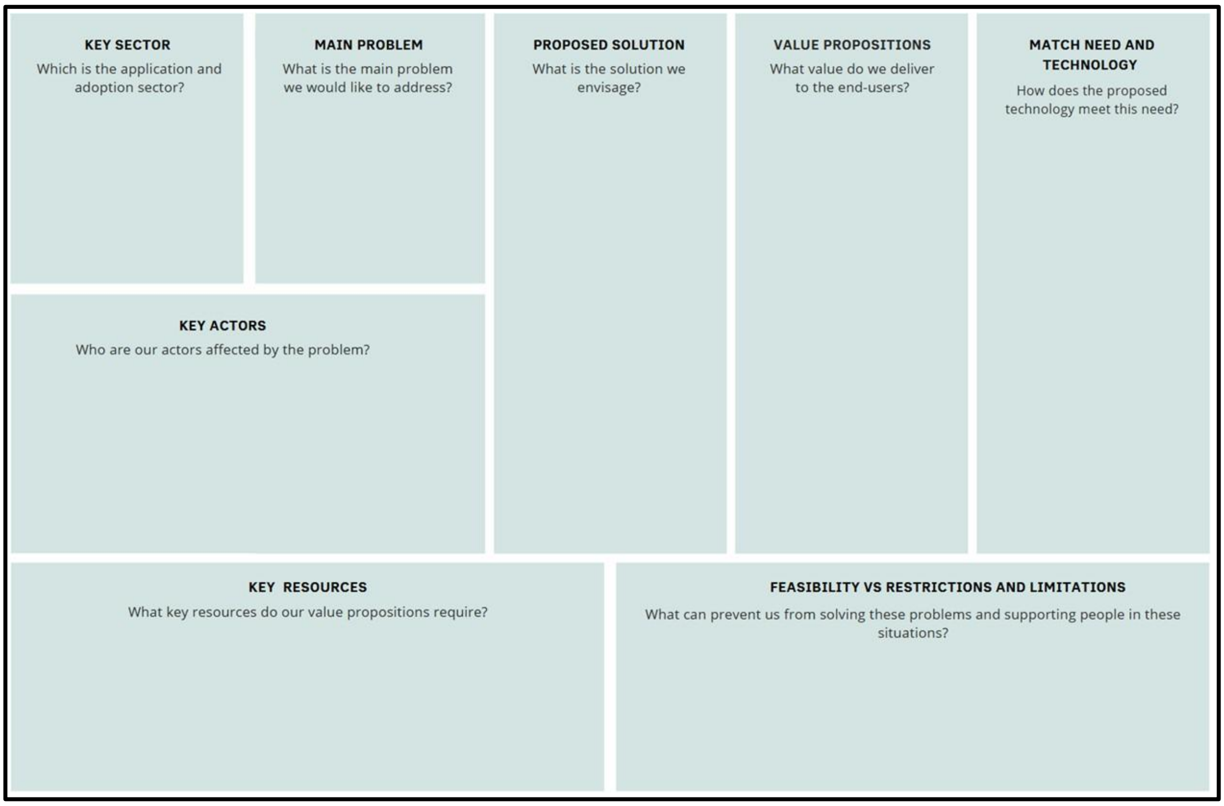
Table 2. Overview of all use-cases co-created per technological framework, sectors covered, and technologies suggested

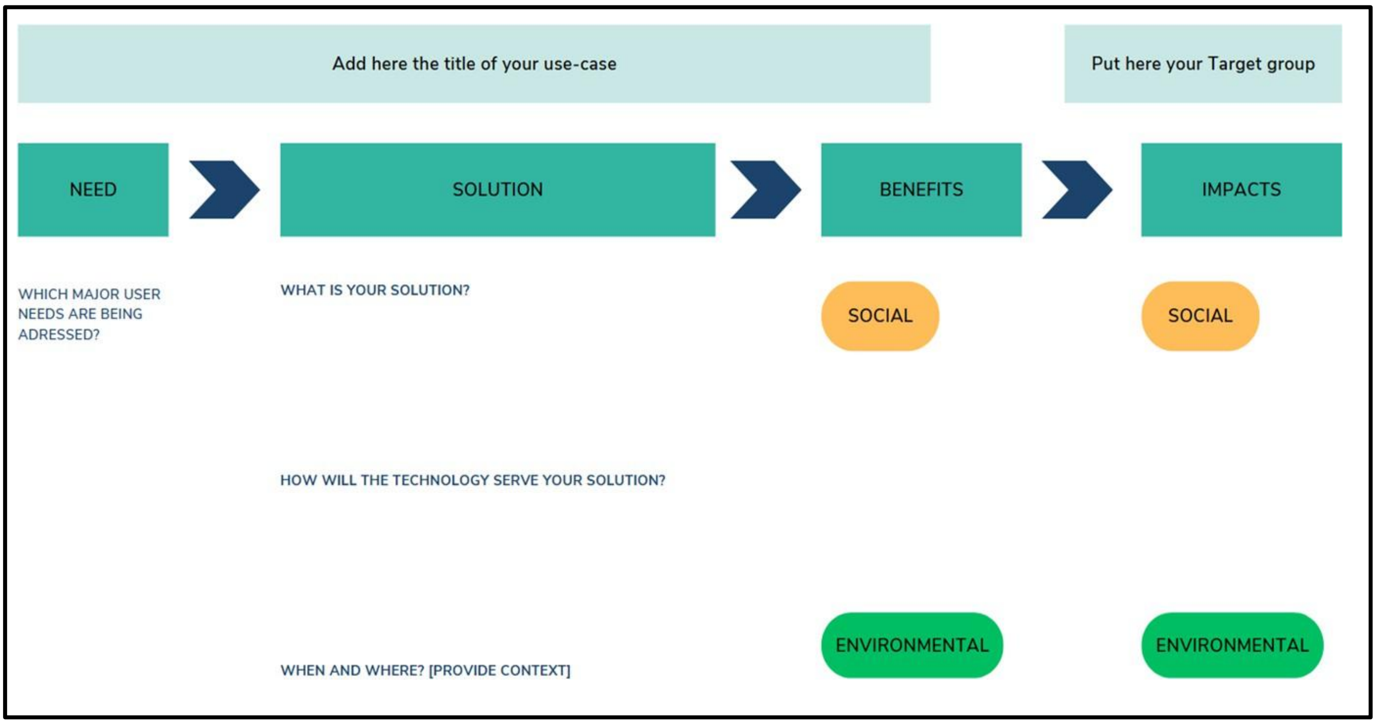
Annex II: Participants Overview

Workshop	Attendees N.	Profiles of the participants	Types organisations	Countries
Artificial Intelligence	19	Founder, Managing Directors, Senior Researcher, ICT experts, CyberSecurity Specialists, Senior Project Manager, Postdoctoral Research Fellow, General Manager, Urban Planner, Chief Operating Officer, Doctoral Researcher, Data Scientists	Tech community companies, SMEs, Public companies, Private firms, Universities, Innovation consulting firms, Collaborative laboratory	Greece, Italy, Portugal, France, Spain, UK, Finland
Cyber safe data tech	16	Researcher software engineer, Cybersecurity analysts/experts, Head of IT, Senior Project Manager, Managing Directors, Data Scientists, Founder/CEO, Head of Data Science & Analytics	Universities, Private firms, Research organisations, public entities, Innovation consulting firm	Finland, Italy, Spain, Portugal, Czech Republic, UK
Bio-inspired materials	23	Professors, PhD student, Directors/CEOs, Senior researchers, Scientific project manager, R&D scientist, Data Scientist	Universities, Research and Technology Centres, Research organisations, Private firms	Netherlands, Spain, Portugal, France, Austria, Italy, Finland
Digital Twin	26	Head of Innovation Unit, Directors, Senior Researchers, CEOs/Founders, Head of scientific-technical services, Project Managers, University professors, EU Policy Advisor	IT Cluster, Research and Technology organisations, private company, public entity, National Research Council, Cooperatives and non-profit social organisations, PA	Romania, Spain, Italy, Belgium, Portugal, Finland, Greece, France
Human-Machine Interaction	26	Head of Innovation Unit, Directors, University professors, Researchers, Head of research, CEOs/Founders, Technologists, Head of scientific-technical services, EU Policy Advisor	IT Cluster, public entities, private companies, Universities, Research and Technology organisations, Industrial Union, National Research Council, Cooperatives and non-profit social organisations, PA	Romania, Spain, Italy, Finland, Greece, Portugal, Belgium, UK
Energy Efficiency	26	Postdoctoral researchers, Directors, Founders/CEOs, R&D managers, Marketing manager, Cluster Coordinator,	Universities, National Technology Cluster, private companies, Research and Technology organisations, ICT Cluster	Spain, Portugal, UK, Norway, Italy, France, Slovakia, Portugal

Annex III: Co-creation Canvases




KEY SECTOR
Which is the application and adoption sector?
MAIN PROBLEM
What is the main problem we would like to address?
PROPOSED SOLUTION
What is the solution we envisage?
VALUE PROPOSITIONS
What value do we deliver to the end-users?
MATCH NEED AND TECHNOLOGY
How does the proposed technology meet this need?
KEY ACTORS
Who are our actors affected by the problem?
KEY RESOURCES
What key resources do our value propositions require?
FEASIBILITY VS RESTRICTIONS AND LIMITATIONS
What can prevent us from solving these problems and supporting people in these situations?


Add here the title of your use-case
Put here your Target group
NEED
SOLUTION
BENEFITS
IMPACTS
WHICH MAJOR USER NEEDS ARE BEING ADRESSED?
WHAT IS YOUR SOLUTION?
SOCIAL
SOCIAL
HOW WILL THE TECHNOLOGY SERVE YOUR SOLUTION?
WHEN AND WHERE? [PROVIDE CONTEXT]
ENVIRONMENTAL
ENVIRONMENTAL