Circular TwAIn

AI Platform for Integrated Sustainable and Circular Manufacturing

Deliverable

# D6.1 - Methodology and Tools for Industrial Pilots coordination - 1st version

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# Definitions and acronyms

| | |
|---|---|
| *AutoML* | *Automated machine learning* |
| *CA* | *Consortium Agreement* |
| *DCS* | *Distributed Control System* |
| *DME* | *Dimethyl Ether* |
| *DoA* | *Description of Action* |
| *EC* | *European Commission* |
| *EG* | *Ethylene Glycol* |
| *EO* | *Ethylene Oxide* |
| *EU* | *European Union* |
| *GA* | *Grant Agreement* |
| *HCT* | *Hybrid Circular Twin* |
| *LS* | *Low Pressure Steam* |
| *PPE* | *Personal Protection Equipment* |
| *PC* | *Project Coordinator* |
| *Pilot* | *Each of the "groups" of partners that represent a sector in the Project* |
| *TC* | *Technical Coordinator* |
| *THB* | *Trial HandBook* |
| *Use Case* | *An application of the technologies within a Pilot* |
| *WEEE* | *Waste from Electrical and Electronic Equipment* |
| *WP* | *Work Package* |

# Disclaimer

# Executive Summary

D6.1 - Methodology and Tools for Industrial Pilots coordination is the first deliverable of WP6. This document contains the information gathering and initial planning for the pilots that has been carried on in T6.1 with inputs from the pilots' tasks T6.2. T6.3 and T6.4. This document also presents the structure of the Trial Handbook, which is the document and methodology to coordinate the information from the pilots and stablish a communication method with the technological developers. Finally, the activities planned in the pilots for the first iteration of the Project are presented with the expected results and associated KPIs.

# 1 Introduction

## 1.1 Scope of the deliverable

This deliverable aims to define the methodology and tools used to coordinate, define and plan action in the three industrial pilots of the Circular TwAIn Project. The scope of application of the tools presented in this document affects all tasks in WP6 by a) defining a common communication framework for the pilots' teams and b) presenting a plan of activities to implement the Circular TwAIn technologies in the pilots thorough the next years.

The main tool presented in this deliverable is the Trial Handbook (THB), a structured document associated to each Pilot and designed to track the pilots' implementation and evolution during the development of the Circular TwAIn Project. The THB indicates how to gather and format the information needed to keep track of the development of the pilots, normalizing the communication between teams and WP Leaders. The THB has been designed to contain information about the requirements of the pilots, it's Use Cases and overall state, among others. Finally, given that the THB is filled periodically by the Pilot's development team, it eases the control tasks of the WP Leaders.

On the other hand, this document serves as a board to present the activities plan of the first period (M6-M21) of the Project. The activities presented in the plan aim to implement the Circular TwAIn technologies in the pilots and are contextualized in a Gantt chart that shows its schedule.

## 1.2 Objectives

The goals of this deliverable are:

- Summarize the work carried on in T6.1 - AI for Circularity Pilots Coordination and Supervision.
- Present the structure of the Trial Handbook, the tool used to compile the information about the pilots.
- Present the activities planned for the first period (M6-M21) of the Project in each one of the pilots.

## 1.3 Relation to other WPs

This deliverable constitutes an important roadmap for the integration and evaluation tasks of the Project, as such, it has several dependencies and impact in other WPs.

The partners of WP2 and WP6 collaborated closely in the definition of the Pilots and Use Cases, to better orchestrate the communication between tech partners and pilots. This collaboration is reflected on this deliverable, which leans on the information compiled in the deliverable D2.1 "Requirements Engineering Methodology - 1st version". D2.1 summarizes the methodology used for requirement collection and present the basis of the THB that has been used to collect the Pilot's information. Furthermore, this deliverable is strongly linked with D2.2 "User Scenarios, Requirements and Performance Indicators - 1st version", where the information of the pilots is modelled as technological requirements.

The work presented is also linked with the technical WPs WP4 and WP5, that will develop data solutions that can be used for the scenarios defined by the pilots.

Finally, D6.1 is critical for WP6, since it contains the roadmap that each pilot has to follow to integrate their scenarios with the Circular TwAIn Framework and enable the development of the data platforms, Digital Twins and AI modules.

## 1.4 Structure

This deliverable follows the next structure:

- Chapter 1: Introduction: This chapter introduces the deliverable and explains its links with other deliverables work packages of Circular TwAIn Project.
- Chapter 2: The Trial Handbook. The THB is descripted in these pages, breaking down the document and providing an in-depth knowledge of it for further comprehension. In this chapter, the relation between the THB and how it relates with the rest of the Project is presented.
- Chapter 3: Pilots' implementation plan. For each Pilot, a description of the tasks to be developed in the next years will be presented, contextualizing them with a Gantt chart, along with The KPIs to measure the performance of said tasks.

- Chapter 4: Conclusions and Future Outlook. Finally, at the end of the document, a summary of the document will be given, presenting the next steps of the Circular TwAIn Project.

# 2 The trial Handbook

The main tool for coordination of the industrial pilots is the Trial Handbook or THB. This document contains all the relevant information of a Pilot and their Use Cases of the Circular TwAIn Project, as well as a log of its evolution throughout the time in a centralized document. The main goal of the THB is to serve as a live document where the developers of the pilots can update their advances through the evolution of the Project, enabling the assessing of said advances on the go, the communication of this information to other partners, and to act both as a roadmap and implementation plan to achieve the goals and KPIs of the Project.

Given the THBs are meant to be used within a circularity domain or sector, each Pilot of the Circular TwAIn Project (WEEE, Battery and Petro-Chemical sectors) has a separate document where the specifics of its domain are detailed.

## 2.1 THB structure

The THB is structured in several chapters, each one focusing on the collection of a certain type of data. The chapters are designed to provide support to a circular development process, by compartmentalizing the information in iterations. This form of structure the document helps to update it easily.

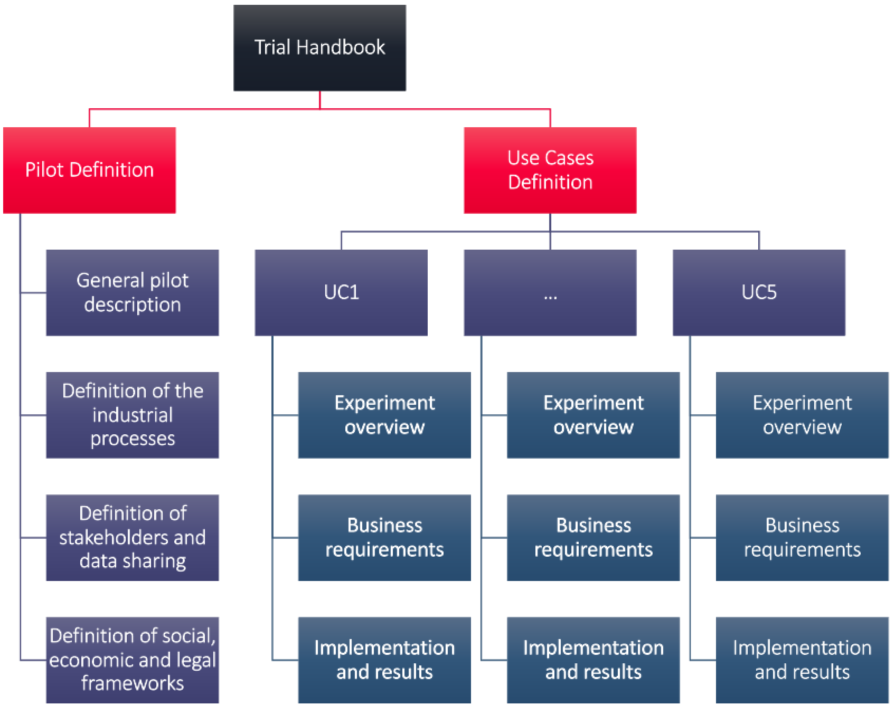



Figure 2-1: Structure of the THB

**Pilot Definition**

The first section of the THB contains overall information about the Pilot. In this section, the pilots' activities, processes, stakeholders and legal/economic frameworks are defined:

- **General Pilot description:** This section contains general information about the Pilot and members.
- **Definition of the industrial processes:** This section dissects the day-to-day activities of the pilots in individual steps and specifies the products and information flow and the involvements of workers, to be considered during the technology development.
- **Definition of stakeholders and data sharing:** This section provides an overview on the stakeholders involved in the Pilot's business scenarios and how they exchange and communicate data.
- **Definition of social, economic and legal frameworks:** This section provides an overview of the social, economic and legal considerations that apply to the Pilot sector.

In general, the Pilot definition contains the overall representation of the current Pilot activities and business and acts as context for the development of the Use Cases where the Circular TwAIn framework will be integrated in certain business scenarios and processes.

**Use Case Definition**

The second section of the THB is Use Cases definition. In this section each individual Use Case is analysed to determine its requirements and implementation plan within the Project. This section contains three chapters per Use Case:

1. Experiment Overview
2. Business Requirements
3. Implementation and Results

**1. Experiment Overview.** This chapter gathers overall information of the Pilot, compiling it to allow a comprehensive understanding of the experiments that will be carried out to test the pilots. For each experiment, the THB contains a general description and motivation, a set of tangible objectives to accomplish, a portrayal of the stakeholders involved in its development, a detailed depiction of the environmental framework that surrounds it (whether they are social, economic or ethic restrictions) and technical information. From the technical point of view, the experiments are detailed by providing a description of the world before and after implement the procedures evaluated by said experiment, as well as the KPIs measured in both scenarios. Along these scenarios an analysis of weakness and bottlenecks of the Pilot and a listing of the technologies needed to tackle them and achieve the goals of the experiments successfully.

The structure of Chapter 1 is the following:

- General description and motivation
- Objectives & benefits
- Experiment's team
- Experiment's framework
- Social framework
- Economic framework
    - Legal and ethical framework
    - As-is Scenario
    - Weaknesses and Bottlenecks
    - To-be Scenario
- Expected results and KPIs
- Technical Information (As Is)
    - Trial technologies
    - Existing Platforms
    - Data and Standard

**2. Business Requirements.** This chapter aims to collect the business information needed to define a set of business processes for the experiments, enabling the analysis of the requirements to meet. To achieve that, for each process defined, an objective and impact is detailed, and a set of requirements is listed. These requirements are defined by a brief description, as well as an evaluation of its priority and a description of its area of evaluation.

- Business process
    - Business objective
    - Business impact
    - Area
- Business Requirement
    - Name of Business Requirement
    - Short description
    - Priority: critical, preferred or optional
    - Application area
    - Functional or non-functional requirement

**3. Implementation and Results.** Finally, in this chapter a plan for implementing each experiment is defined. In short, this plan will detail a collection of prototypes designed to achieve final goal solution incrementally throughout the development of the Project. For each prototype, a description, a time window, a set of requirements of met and a depiction of its coverage will be provided to contextualize it in the big picture of the experiment.

- Implementation
- Schedule/plan
- Implementation/execution
- Barriers and difficulties faced
    - Results and Lessons learnt
    - Final Experiment and Business Requirements KPIs
- Exploitation plan

An example of the structure and contents of the THB is provided in Annex I.

## 2.2 Mapping to D6.1

The THB specifies in detail every aspect of the data needed to manage the pilots, from the gathering methods to the data types, or their format, as well as, outlining its overall direction. This sets a common framework for the pilots' teams to work and document their advances, unifying the communication space among them.

Given the nature of the THB, which has been designed to be frequently updated and easily accessible for Team Leaders and Managers, it is idoneous for use as the central control tool for coordination and management of the pilots. By placing the THB in a common repository every agent involved in the management can check the THB allowing a non-invasive asynchronous communication between management and pilots' development teams, and, given that the THB itself indicates the format of the information contained, there's no understanding problems between them.

The first version of the THB was completed as part of the activities carried on WP6 and its results will be reflected in the upcoming deliverables D2.2 "User Scenarios, Requirements and Performance Indicators - 1st version" and D6.1 "Methodology and Tools for Industrial Pilots coordination - 1st version". In particular, the requirements and scenarios indicated in the Chapter 2 of the THB will be used as inputs in D2.2, and the implementation plan of Chapter 3 have been used as inputs in this deliverable.

# 3 Pilots' implementation plan

In this section a summarized version of each Pilot implementation plan contained in the THB is presented.

## 3.1 WEEE Pilot

### 3.1.1 Pilot and Use Case introduction

In 2019, Europe generated a total of 12 MT of e-waste equivalent of 16.2 kg per capita. 42.5% i.e., 5.1 MT was documented to be properly collected and recycled. In terms of economy value of the raw materials in e-waste, it is equivalent to 12.9 billion US dollars. In terms of CO2 emissions in the form of greenhouse gases from undocumented waste, it is equivalent to 12.7 MT.

The directive imposes the responsibility for the disposal of WEEE on the manufacturers or distributors of such equipment. IT and telecommunications equipment make more than 10% of the total WEEE in Spain, mainly in form of personal computers, mobile phone and tablets. These elements, which are commonly discarded because of devaluation, can be easily reintroduced to the market if they are still functional or recycled into valuable materials if not.

Circular TwAIn Project aims to improve the generated value and environmental impact of the de/re-manufactured waste, and to enable automation in this sector through the use of AI and Digital Twins. This Pilot will implement the Circular Twain Technologies in 5 Use Cases related to the WEEE de/re-manufacturing:

1. Computer-vision driven product identification for the disassembly of IT equipment:
    - Given 2D/3D images of the computer, count and identify the subcomponents. The type of subcomponent (e.g., cpu, ram, etc) should be identified. The exact model will have some error in the assessment so uncertainty should be considered in the analysis.
2. Characterization and assessment of components and subcomponents:
    - Each identified subcomponent should be characterized visually. Information from diagnosis board may be included to accurately identify and diagnose the subcomponents. Once fully identified, the component should be labelled as fit for remanufacturing or not.
3. Real time planning of the disassembling operations:
    - From the list of identified subcomponents, a list of steps for the disassembling of the component. This list must be generated in real time and updated with the information provided by the sensors.
4. Collaborative robotics for the support of manual operations:
    - When the actions allow it, a collaborative robot will perform the actions automatically. Otherwise, the disassemble sequence will be performed in collaboration with the worker.
5. Market oriented holistic decision-support-system for WEEE de- and re-manufacturing:
    - Holistic optimization the value and lifecycle of the subcomponents and products.

### 3.1.2 Activities for the next period

Phase 1: Experiment design

Table 3-1: WEEE Pilot's phase 1 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A1.1 Complete the trial handbook section 1 | Complete the THB section 1, where the pilots' processes, organization, stakeholders and circularity are described. | M06-M09 – Activity Completed | All |
| A1.2 Complete the trial handbook section 2 | Complete the THB section 2, where the Use Cases, applications, business and technical requirements and | M06-M09 – Activity Completed | All |

| | | | |
|---|---|---|---|
| | implementation plan are described | | |
| A1.3 Identification of major research questions | Analise the SotA and identify technologies, risks and issues that may arise during the execution of the Project | M06-M09 – Activity Completed | All |
| A1.4 Selection of response variables | Define the required information flow and exchange between the Use Cases, AI Modules and Digital Twins | M06-M09 – Activity Completed | All |
| A1.5 Choice of factors, levels, ranges | Define a set of computer models and parts for the implementation of the Circular TwAIn developments. The selected parts have to represent the variability of the WEEE waste while avoiding extreme cases that will not add anything to the Project. | M06-M09 – Activity Completed | All |
| A1.6 Collection of PC's at Aimen facilities from Revertia | Collect a sample of WEEE waste to start the characterization of the sensors and the dataset building activities in the Technology provider facilities. | M06-M09 | All |
| A1.7 Definition of the technologies | Definition of concrete technologies and requirements to be implemented in the Project. | M06-M09 | All |

Phase 2: Pilot set-up and datasets recording

Table 3-2: WEEE Pilot’s phase 2 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A2.1 Definition of sensors, grippers, and actuators | Define sensors and camaras to be used. Model the data coming from these sensors. | M08-M11 | Automation of more than 25% of the operations; 30% reduction in time for the de-manufacturing operations |
| A2.2 Setting-up of equipment. | Set up sensors and cameras in a relevant environment. Capture data samples from them. | M11-M15 | Automation of more than 25% of the operations; 30% reduction in time for the de-manufacturing operations |
| A2.3 Product metadata digitalization | Model the product information and metadata and structure it | M12-M14 | 20% more value generated |

| | | | |
|---|---|---|---|
| | in an organized format and dataset. | | |
| A2.4 PCs images Dataset recording | Record a dataset on product images and components to develop the Use Case 1 AI modules | M12-M14 | 30% reduction in time for the de-manufacturing operations; 20% reduction in time for the testing and evaluation operations |
| A2.5 Product characterization dataset recording | Record a dataset on product state and components to develop the Use Case 2 AI modules | M13-M18 | 30% reduction in time for the de-manufacturing operations |
| A2.6 Market information dataset preparation | Compile a dataset with the historical values of products and materials to develop the Use Case 5 AI modules | M15-M17 | 20% more value generated |
| A2.7 Disassembly procedures dataset preparation | Compile a dataset with the procedure to disassembly WEEE Waste to develop the Use Case 3 AI modules | M17-M19 | Automation of more than 25% of the operations; 30% reduction in time for the de-manufacturing operations |
| A2.8 Data gathering from external stakeholders | Compile a dataset with the metadata and product information to develop the Use Case 5 AI modules | M13-M19 | 20% more value generated |

Phase 3: Technology Integration

Table 3-3: WEEE Pilot's phase 3 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| **A3.1:** Integration of the Circular TwAIn framework | Integration the cloud tools of the Circular TwAIn framework in the local systems. This activity takes charge of the development of the core systems needed to disassemble WEEE waste products. In addition to that, during this activity the components needed to connect with the Circular TwAIn tools will be implemented. | M14 - M19 | 20% more value generated;<br>Automation of more than 25% of the operations |
| **A3.2:** Data Space and Data model integration | Design and integration of the data models for the disassembling process. In this activity data from the EU data market will be retrieved and | M14 - M16 | 20% more value generated |

| | | | |
|---|---|---|---|
| | processed to fit the needs of the work developed during the WEEE Pilot. | | |
| **A3.3:** Digital twin integration. Stage 1: Product and process. Stage 2: Human | Design and integration of models for the digital twins for product, processes and agents. A symbolic model for the digital twins will be generated, along with an ontology to simulate the processes needed to accomplish the goals set in the WEEE Pilot. | M15 - M19 | 20% more value generated |
| **A3.4:** Integration of AI-Modules | Integration of the AI-Modules in the disassembling robotic agent. During this activity the software developed in activities A3.2 and A3.4 would be included in the local systems, along with every utility component needed to link the different systems. | M17 - M20 | All |
| **A3.5:** Deployment | Deployment and testing of the modules and components developed during the current period in the installations of Revertia. This activity will take charge test the integrity the components before starting the experimentation process of the Use Cases. | M19 - M20 | All |

Phase 4: Experimentation and KPIs measurement

Table 3-4: WEEE Pilot's phase 4 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A4.1 Experiments of Use Cases | Evaluate the usage of the modules and components in a relevant environment by final users. | M19 - M21 | All |
| A4.2 KPIs measurement | Take measures of the evolution of the KPIs with the deployed modules and components. | M21 | All |
| A4.3 Evaluation algorithms and performance indicator analysis | Study the impact of the modules in the KPIs. Define what modules components need to be improved or added to reach the target values. | M20- M21 | All |
| A4.4 Comparison with the benchmarks | Compare the measured KPIs with the targets. | M20- M21 | All |

| | | | |
|---|---|---|---|
| A4.5 Compilation of the results and graphical representation | Compile the results and plan the next implementation phase. | M20- M21 | All |

Phase 5: Conclusion and Recommendation

Table 3-5: WEEE Pilot's phase 5 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| **A5.1:** Preparation of the report | Preparation of the end-of-cycle reports. This preparation consists in the writing and composition of every report and deliverable as well as the final version of the THB needed to divulge and justify the work developed during the current implementation period. | M21 - M22 | All |
| **A5.2:** Presentation of the results | Preparation and presentation of the results of the development realized during the Pilot implementation process. This activity takes charge of the composition of slides, demos and any additional material needed to divulge the WEEE Pilot's results. | M21 - M22 | All |

### *3.1.3 Gantt chart*

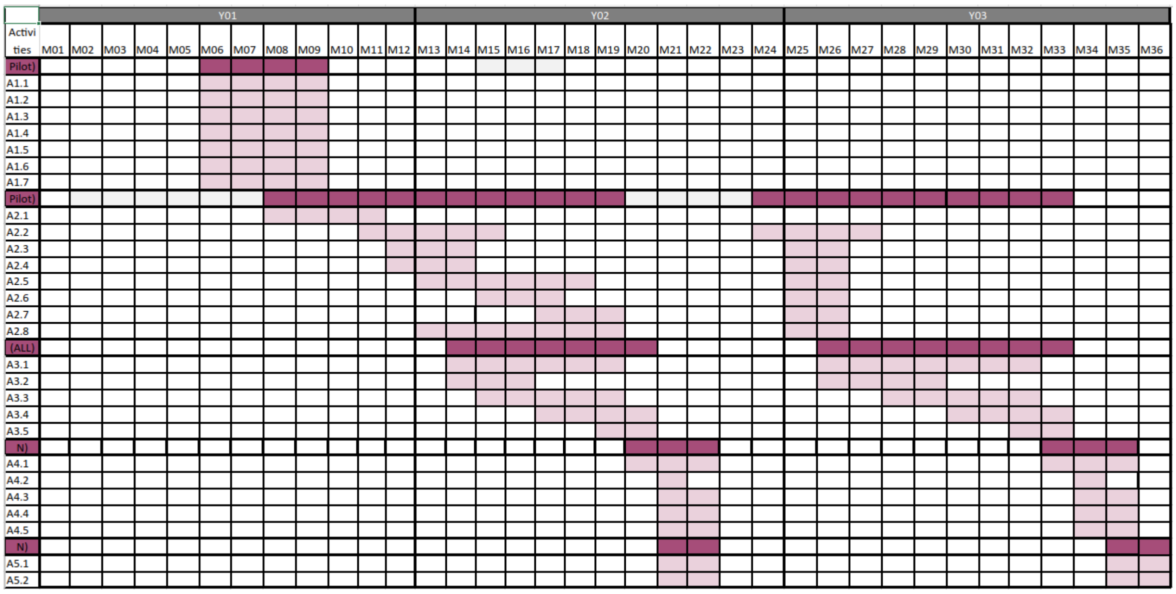



Figure 3-1: WEEE Pilot's Gantt chart for the first implementation period

### *3.1.4 Identified KPIs*

1. Description: 20% more value generated from the recycled/re-used components through an improved assessment of the component condition and its market value. Performance Indicator:

    Performance Indicators Anatomy:

**What is the value of the recycled/reused components?**

The value of recycling of the component is the selling cost of the end-of-life components by Revertia to the recyclers.

This value of the recycled components can be calculated by:

Selling cost of the lot (EUROS) = S = (n*a)

where, n is a constant multiplier, a is the recycle material recovered from each lot at the start of the re/de/manufacturing process.

Transportation cost (EUROS) = X

Overhead, rent, electricity, salaries, etc. (EUROS) = Y

Other additional cost, lot rejection etc. (EUROS) = Z

Net value generation NET_rcy= S_rcy – (X+Y+Z)

The value of the reused components can be calculated by:

Selling cost of the individual components (or mean cost) (EUROS) = S_reuse = (b)

where, b is number of specific component recovered for reuse from a lot at the start of the re/de/manufacturing process.

Courier or transportation cost = X

Overhead, rent, electricity, salaries, etc. (EUROS) = Y

Other additional cost, lot rejection etc. (EUROS) = Z

Net value generation NET_reuse= S_reuse – (X+Y+Z)

**What does improved assessment of component conditions meaning?**

The improvement of the assessment of component conditions means that with the Circular TwAIn framework the process of assessment improved as compared to present process and technology.

Example: For the given lot size of the PC components, the identification of the components that operate normally (consider for reuse) in terms of quantity 'n' improves. Today, assuming a is the quantity of the components (in kgs) that can be recycled after the assessment process and b is the quantity of components that can be useable. The lot size at the entrance of the process is x = a + b. After the Circular TwAIn framework implementation, the value of b improves such that, the total value generated as discussed in previous question increase by 20%.

The global indicator will look like:

Net recycle/reuse value = Net_rcy + Net _reuse

**What does improved assessment of component market value?**

This PI is related with the assessment of the component such that the previous market value with present process and technology improved. This question has more circular economy sense. This is because a component that work normally but has more operational life is not similar in market value to a component with less operational life. Similarly, a component operational load during its lifetime and historical operating conditions are other factors that can influence its market value. Depending on the clarification of the above questions separate performance indicator for the market value and its relationship with assessment of the components will be used.

This could be another performance indicator. The indicator that can evaluate the difference between before and after deployment of Circular TwAIn framework on component market value by improving the component assessment. The assessment process must involve multiple stakeholders or simulated data could be used in case such data is not available. The perception system alone could identify the visual condition of the component and can estimate some operational aspects, but the accurate operational conditions information can be collected from the component history usage or an alternative method.

**Involved use-cases**: UC2, UC5

2. Description: Automation of more than 25% of the operations required for disassembly.

   **Performance Indicator Anatomy:** the performance of this KPI is measuref by comparing the use-cases automation before and after Circular TwAIn Project. The automation here refers to the proposed number of perception system and the collaborative robot.

   Total number of sub operations are automatized after CircularTwAIn Project = A_new

   Total number of sub operations are automized before CircularTwAIn Project = A_old

   Total number of sub operations = A_N

   Automation increase A = ((A_new – A_old)/ A_N)*100

   **Involved use-cases:** UC:3, UC:4

3. Description: 30% reduction in time for the de-manufacturing operations of IT equipment by integrating a collaborative robotics application capable of handling disassembling operations.

   **Performance Indicator Anatomy:** Circular TwAIn framework establishes and transmits the de/remanufacturing operation sequences with human and robot classified tags making sure the 30% operational reduction time. Use-Case 4 will be integrating a collaborative robot. The human and robot collaboration work coherently to reach this KPI value.

   Disassembly time for the given PC (similar components and case architecture) before CircularTwAIn framework = t_old

   Disassembly time for the given PC (similar components and case architecture) after CircularTwAIn framework = t_new

   Reduction in time, T = ((t_new – t_old)/t_old)*100

   **Involved use-cases:** UC:3, UC:4

4. Description: 20% reduction in time for the testing and evaluation operations of IT equipment by using AI to assist the worker on the evaluation, inspection and identification of components and sub-components.

   **Performance Indicator Anatomy:** Reduction in time for the testing and evaluation operations of IT equipment means after the Circular TwAIn framework this process will be performed much quicker in term of operation cycle time.

   Assessment time for the PC lot (similar components and case architecture) before CircularTwAIn framework = t_old

   Assessment time for the PC lot (similar components and case architecture) after CircularTwAIn framework = t_new

   Reduction in time, T = ((t_new – t_old)/t_old)*100

   Involved use-cases: UC:1, UC:2

### 3.1.5 Measured KPIs

1. Description: 20% more value generated from the recycled/re-used components through an improved assessment of the component condition and its market value. Performance Indicator:

   **Benchmark:**

   I. 22/23-year mean value of the mix recycling lot.

   II. 22/23-year mean value of the given component.

   III. 22/23-year x value per lot also a value and b value for the reused component and the recycle material recovered from a given lot at entrance.

   IV. 22/23-year market value of the given component in a lot.

2. Description: Automation of more than 25% of the operations required for disassembly.

   **Benchmark**: 22/23-year number of disassembly sub-operations (A_old) have automation components such as robots, perception sensors, etc. Total number of disassembly sub operations (A_N).

3. Description: 30% reduction in time for the de-manufacturing operations of IT equipment by integrating a collaborative robotics application capable of handling disassembling operations.

   **Benchmark:** 22/23-year time required to disassemble PC component (t_old).

4. Description: 20% reduction in time for the testing and evaluation operations of IT equipment by using AI to assist the worker on the evaluation, inspection and identification of components and sub-components.

   **Benchmark:** 22/23-year time required to assessment a lot of PC's (t_old)

## 3.2 BATTERY Pilot

### 3.2.1 Pilot and Use Case introduction

The Circular TwAIn BATTERY Pilot is focused on the circular value chain of e-mobility Li-Ion battery packs.

Automotive battery systems are complex components, and their circular value chain is peculiar: they share with the rest of the vehicle only the central part of the linear value chain (assembly, distribution, usage). Their manufacturing and end-of-life management instead, follow dedicated routes. The current circular value chain for automotive battery systems lacks optimization in the recovery of functionalities and materials from these components. Nevertheless, it already excludes both landfilling and energy recovery as viable options. Nowadays, batteries are managed by a transport and logistic actor which ensures their distribution to an authorized dismantler for discharge and disassembly. Finally, the battery modules or battery cells, core of the whole system, undergo recycling treatments for the recovery of the materials, especially the cathode metals.

The concept behind the Circular TwAIn battery Pilot is to overcome the current value chain by integrating innovative circular economy nodes of the following framework:

- E-mobility battery systems which reach their end-of-life are collected by transport and logistics operators.
- Preliminary tests assess the reusability of the battery without any manipulation. The compliant batteries are directly reused in automotive or stationary domains.
- Those battery packs whose direct reuse is not applicable are disassembled and tested at modules and eventually cells level.
- The units (modules and cells) suitable for reuse are reassembled in second life batteries.
- The units with no residual electric properties compliant for reuse are recycled to recover the raw materials.

This Pilot will implement the Circular TwAIn technologies in 5 Use Cases related to the Batteries de/re-manufacturing:

1. Computer-vision driven collaborative robotics for the disassembly of LIB packs

   Computer vision will greatly aid the operator in all disassembly procedures, both manual and automated. Also, thermal and charge sensors will notify if the battery pack is safe to be dismantled. A video surveillance system will be active during each phase of the process. All of this will be integrated to improve the efficiency of the collaborative dismantling of recurrent LIB packs.

2. Machine learning aided automated disassembly of LIB modules

   Battery modules disassembly requires both manual and automated operations to be performed. Machine learning algorithms will be developed to optimize the disassembly parameters according to the battery model, end-of-life state and of the cells to be detached.

3. AI tool for the characterization of the LIBs state-of-health combining historical and testing data

   A deep characterization of the residual state-of-health and of the remaining useful lifespan of each cell is mandatory to ensure certified quality of reassembled batteries. In Circular TwAIn a mutual data and model driven AI supported methodology to certify the state-of-health and remaining useful lifespan of LIB cells will be developed.

4. AI tool for optimized mechanical recycling of degraded LIBs

   In Circular TwAIn, AI driven optimization algorithms will be developed to drive reconfigurable mechanical recycling technologies in the selective isolation of material streams, in function of the LIB cells materials composition and architecture and of market quotations of target materials.

5. Market oriented holistic decision-support-system for the LIBs de- and re-manufacturing

   The profitability of different LIBs circular economy scenarios is function of many factors, both inner and external to the technological chain. Circular TwAIn will exploit AI to merge data available on the battery in terms of materials composition and state-of-health with data characterizing the market quotations to obtain a decision support system which guides operational choices in function of the most profitable expected scenario.

### 3.2.2 Activities for the next period

Phase 1: Experiment design

Table 3-6: BATTERY Pilot's phase 1 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A1.1 Complete the trial handbook section1 | A general description of the Pilot, its framework, manufacturing process and description of the Use Cases with the AS-IS and TO-BE scenarios. | M6-M9 – Activity Completed | All |
| A1.2 Complete the trial handbook section 2 | Description of Business requirements (list of legal, administrative, and technological requirements for the Use Cases) and use caseUse Casementation (summary of the implementation and validation efforts). | M6-M9 – Activity Completed | All |
| A1.3 Identification of major research questions and Use Cases scenarios | Analise the SotA and identify technologies, risks and issues that may arise during the execution of the Project and use-case scenarios. | M6-M9 – Activity Completed | All |
| A1.4 Selection of battery reference models | Selection of the battery model to be used in all the Use Cases scenarios, to demonstrate the flow connection between the use-cases. | M8-M13 | All |
| A1.5 Collection of batteries | Collection of the selected battery model samples to be used in the Use Case scenarios. | M10-M13 | All |
| A1.6 Selection of suitable sampling devices | Selection of sampling tools and devices to extract data from the Use Case scenarios process flow. | M10-M13 | All |
| A1.7 Procurement of sampling devices | Procurement of the devices selected for the data sampling. | M10-M18 | All |
| A1.8 Installation of sampling devices | Installation of sampling points on the machineries adopted for the implementation of the use-case scenarios. | M10-M19 | All |
| A1.9 Procurement of necessary equipment for Use Case scenario simulation | Procure the equipment required to support the simulation of the Use Case scenarios. | M10-M19 | All |

Phase 2: Pilot set-up and datasets recording

Table 3-7: BATTERY Pilot's phase 2 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A2.1 Definition of sensors and actuators | Define sensors and cameras to be used. Model the data coming from these sensors. | M10-M18 | 10% reduction of battery disassembly time; 20% increase of battery |

| | | | |
|---|---|---|---|
| | | | disassembly tasks automation; 15% reduction of battery testing time; 25% increase of reusable batteries. |
| A2.2 Setting-up of equipment | Set up sensors and cameras in a relevant environment. Capture data samples from them. | M11-M21 | 10% reduction of battery disassembly time; 20% increase of battery disassembly tasks automation; 15% reduction of battery testing time; 25% increase of reusable batteries. |
| A2.3 Battery data structure digitalization | Model the product information and metadata and structure them in an organized format and dataset. | M12-M21 | All |
| A2.4 Battery characterization dataset recording | Record a dataset on product images and components to develop the Use Cases AI modules. | M13-M21 | 10% reduction of battery disassembly time; 20% increase of battery disassembly tasks automation; 15% reduction of battery testing time; 25% increase of reusable batteries. |
| A2.5 Use Case scenarios operations dataset preparation | Record a dataset on product state and components to develop the Use Cases AI modules. | M15-M21 | All |
| A2.6 Market information dataset preparation | Compile a dataset with the historical values of products and materials to develop the Use Cases AI modules. | M15-M21 | 20% more value generated from recycling; 25% increase of reusable batteries. |
| A2.7 Data gathering from external stakeholders | Compile a dataset with the metadata and product information to develop the Use Cases AI modules. | M13-M21 | 20% more value generated from recycling; 25% increase of reusable batteries. |

Phase 3: Technology Integration

Table 3-8: BATTERY Pilot's phase 3 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A3.1 Integration of the Circular TwAIn framework | Integration the cloud tools of the Circular TwAIn framework in the local systems. This activity takes charge of the development of the core systems needed to disassemble EV Li-ion Batteries. In addition to that, during this activity the components needed to connect with the Circular TwAIn tools will be implemented. | M15-M21 | All |
| A3.2 Data Space and Data model integration | Design and integration of the data models for the disassembling, testing and recycling processes. In this activity data from the EU data market will be retrieved and processed to fit the needs of the work developed during the BATTERY Pilot. | M15-M21 | All |

| | | | |
|---|---|---|---|
| A3.3 Digital twin integration (product, process, human) | Design and integration of models for the digital twins for product, processes and agents. A symbolic model for the digital twins will be generated, along with an ontology to simulate the processes needed to accomplish the goals set in the BATTERY Pilot. | M15-M21 | All |
| A3.4 Integration of AI-Modules | Integration of the AI-Modules in the machineries. During this activity the software developed in activities A3.2 and A3.3 would be included in the local systems, along with every utility component needed to link the different systems. | M17-M21 | All |
| A3.5 Deployment | Deployment and testing of the developed AI-modules and components. This activity will take charge to test the integrity of the components before starting the experimentation process of the Use Cases. | M19-M21 | All |

Phase 4: Experimentation and KPIs measurement

Table 3-9: BATTERY Pilot's phase 4 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A4.1 Execution of Use Cases scenarios | Execute the selected use-case scenarios: Computer-vision driven collaborative robotics for the disassembly of LIB packs; Machine learning aided automated disassembly of LIB modules; AI tool for the characterization of the LIBs state -of-health combining historical and testing data; AI tool for optimized mechanical recycling of de graded LIBs; Market oriented holistic decision-support-system for the LIBs de - and remanufacturing. | M19-M21 | All |
| A4.2 KPIs measurement | Reduction of battery disassembly time by 10% will be compared with the design values;<br>Increase of battery disassembly tasks automation by 20% will be compared with the design values;<br>Increase by 25% of the fraction of reusable batteries over the total collected will be compared respect to the design values;<br>Reduction of testing time by 15% will be compared with the design values;<br>Increase of profitability rate with respect to standard recycling by 20% will be compared with the design values. | M19-M21 | All |
| A4.3 Evaluation algorithms and performance indicator analysis | Study the impact of the AI-modules on the KPIs. Define if/where AI-modules components need to be improved or added to reach the target values. | M19-M21 | All |
| A4.4 Comparison with the benchmarks | Compare the measured KPIs with the target values. | M19-M21 | All |
| A4.5 Compilation of the results and graphical representation | Compile the results and plan the next implementation phase. | M19-M21 | All |

Phase 5: Conclusion and Recommendation

Table 3-10: BATTERY Pilot's phase 5 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A5.1 Preparation of the report | Preparation of the end-of-cycle reports. This preparation consists in the writing and composition of every report and deliverable as well as the final version of the THB needed to divulge and justify the work developed during the current implementation period. | M20-M21 | All |

| | | | |
|---|---|---|---|
| A5.2 Presentation of the results | Preparation and presentation of the results of the development realized during the Pilot implementation process. This activity takes charge of the composition of slides, demos and any additional material needed to divulge the BATTERY pilot's results. | M20-M21 | All |

### 3.2.3 Gantt chart

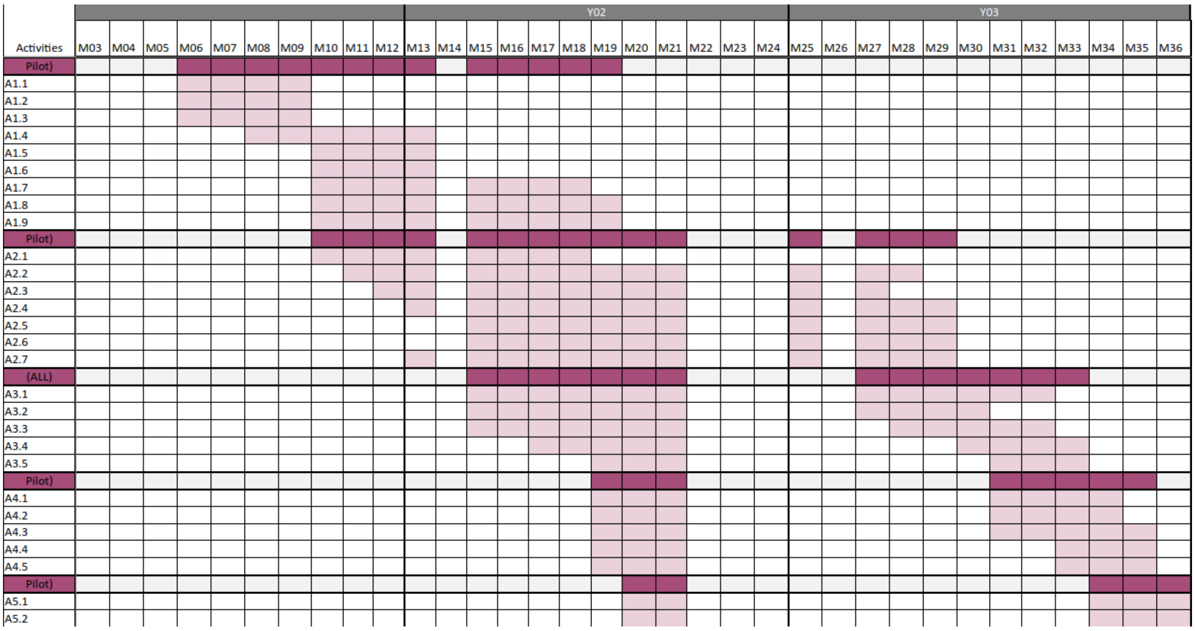



Figure 3-2: BATTERY Pilot's Gantt chart for the first period

### 3.2.4 Identified KPIs

- KPI1: Battery disassembly time

  Battery disassembly time will consider the disassembly procedure of the battery, from pack to modules and from modules to cells.

- KPI2: Battery disassembly tasks automation

  The assessment of the disassembly automation will investigate the amount of disassembly tasks (pack to modules and module to cells) with respect to the total number of disassembly tasks.

- KPI3: Fraction of reusable batteries over the total collected

  The assessment will investigate the amount of reusable batteries inside the battery pack, providing a quantitative evaluation of the batteries reusability.

- KPI4: Testing time

  Testing time refers to the time required to perform a full test for assessment of the batteries SoH.

- KPI5: Profitability rate with respect to standard recycling.

  The assessment of the recycling profitability will consider both data available on the battery in terms of materials composition, state-of-health and material market quotations, and data referred to the cost of recycling operations.

### 3.2.5 Measured KPIs

- KPI1: Reduction of battery disassembly time by 10% will be compared with the design values.

  Average time to perform a full battery disassembly from pack to cells is 1h30(*).

- KPI2: Increase of battery disassembly tasks automation by 20% will be compared with the design values.

  At the state of the art the disassembly is mainly performed manually(*).

- KPI3: Increase by 25% the fraction of reusable batteries over the total collected will be compared respect to the design values.

  On average, only a minor part of the battery cells are reused for the manufacturing of new battery packs(*). At the state of the art the batteries are mainly destinated to the recycling treatment. Moreover, the reusability of the battery is strongly affected by the EoL state and by the type of the adopted disassembly techniques (e.g. destructive techniques are faster but decrease the potential reusability of the battery).

  The baseline of this KPI will be assessed according to the selected battery model.

- KPI4: Reduction of testing time by 15% will be compared with the design values.

  Full test battery testing can takes up to one hour of testing time(*). Testing time increases with the increase of variables investigated and the level of detail of the testing techniques.

- KPI5: Increase by 20% of profitability rate with respect to standard recycling. The design values will be assessed according to the selected battery model and compared with the use case recycling scenario(*).

* Design values strongly dependent on the selected battery model and EoL state.

## 3.3 PETROCHEMICAL Pilot

### *3.3.1 Pilot and Use Case introduction*

Ethylene Oxide (EO) production begins with the introduction of ethylene, ethane, oxygen, methane, and gas phase promoters into a reactor. The mixture formed in the reactor passes through a silver oxide catalyst at temperatures of 200-300°C and 10-30 bar. The Ethylene Oxide/Ethylene Glycol (EO/EG) plant is a production facility with high energy consumption. The EO stripper column is an equipment with intense steam consumption. With the energy optimization to be made in this equipment, it is possible to reduce steam consumption and accordingly to reduce the CO2 emission and unit production cost. The feed stream to the column contains mainly EO, EG and water, and 99.9% of the incoming EO is steam stripped off the top of the column. EO and water are taken from the top by process-specific streams and sent to the EO purification unit, while EG and water are removed as glycol leaks from the downstream side and sent to a flasher to recover the contained glycol. Stripping in this column is accomplished by the steam generated in the stripper reboiler. Recovery of EO is controlled by the temperature profile at the top of the column. The amount of steam is varied to maintain a constant top column temperature. Optimizing the amount of steam used in the reboiler while maintaining the amount of EO recovered in the stripper, will save LS (low pressure steam) and accordingly reduce the CO2 emission and unit production cost.

Within Circular TwAIn Project, PETROCHEMICAL Pilot aims to reduce energy consumption and CO2 emission of the stripping operation. The developed Circular Twain technologies will be implemented in 5 Use Cases.

1. Data acquisition and representation for AI framework

Historical process data will be gathered from Distributed Control System (DCS). Data from inferential sensors will be collected for the optimization of product quality and energy trade-off.

2. Developing hybrid circular twin of the process

A Hybrid Circular Twin (HCT) will be developed to design possible process improvements and future opportunities of current operations. HCT will be a combination of a data-driven Digital Twin and first-order physical model.

3. Use of data analytics, AI and model verification to understand process unit failures

Data analytics and AI will be used to understand process unit failures, to identify abnormal process conditions, avoid unplanned shutdowns and successfully manage unpredictable feed and demands.

4. Developing AutoML module for Process Industry

To help the end users, i.e., operators and managers at the factory and to have a generic framework applicable in other plants, an AutoML module will be developed. AutoML user can identify the portion of data to be used for training and testing, then selected machine learning algorithms are trained by the specified data.

5. Generation of a tool for process optimisation

An AI-App will be developed to optimize the production process to ensure that the unit maximizes production of on-spec product while minimizing any undesired by products.

### 3.3.2 Activities for the next period

Phase 1: Experiment design

Table 3-11: PETROCHEMICAL Pilot's phase 1 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A1.1 Complete trial handbook section 1 | A general description of the Pilot, its framework, manufacturing process and description of the Use Cases with the AS-IS and TO-BE scenarios. | M6-M9 – Activity Completed | N/A |
| A1.2 Complete the trial handbook section 2 | Description of Business requirements (list of legal, administrative and technological requirements for the Use Cases) and Use Case implementation (summary of the implementation and validation efforts). | M6-M9 – Activity Completed | N/A |
| A1.3 Determination of the sampling point location | A new sampling point is required to monitor the EO concentration in the bottom stream of the EO stripper. The location of the sampling point will be determined. | M12-M15 | 5 % decrease in steam consumption<br>5 % decrease in $CO_2$ emissions<br>5 % decrease in unit process cost |
| A1.4 Selection of the suitable sampling device | Stripper bottom stream is composed of mainly water and small amount of EO. Closed sampling system is required in order not to lose EO from the sample. | M16-M18 | 5 % decrease in steam consumption<br>5 % decrease in $CO_2$ emissions<br>5 % decrease in unit process cost |
| A1.5 Procurement of the sampling device | Closed sampling system will be procured. | M18-M21 | 5 % decrease in steam consumption<br>5 % decrease in $CO_2$ emissions<br>5 % decrease in unit process cost |
| A1.6 Installation of the sampling device | Installation of a sampling point at the bottom of C-205 absorber column. | M25-M26 | 5 % decrease in steam consumption<br>5 % decrease in $CO_2$ emissions |

| | | | |
|---|---|---|---|
| | | | 5 % decrease in unit process cost |
| A1.7 Taking samples from the operation | Laboratory analysis will be carried out to measure EO with a new sampling point and device. | M27-M30 | 5% decrease in steam consumption in the EO stripper<br>5% decrease in CO2 emissions of EO stripper<br>5% decrease in the unit cost of EO stripper |
| A1.8 Representation of the data from field components | Data representation for AI framework. | M12-M15 | 5% decrease in steam consumption in the EO stripper<br>5% decrease in CO2 emissions of EO stripper<br>5% decrease in the unit cost of EO stripper |
| A1.9 Definition of the necessary equipment and process streams of the DME process | Necessary equipment and chemicals/streams required for DME process will be identified. | M19-21 | 5 % decrease in steam consumption<br>5 % decrease in CO2 emissions<br>5 % decrease in unit process cost |
| A1.10 Integration of real CO2 data on DME simulation | The amount of CO2 in the top stream of D-205 will be analysed and these data will be used in the DME simulation. | M25-M28 | 5 % decrease in steam consumption<br>5 % decrease in CO2 emissions<br>5 % decrease in unit process cost |
| A1.11 Defining a workflow | Defining a workflow for the comparison of different ML algorithms. | M25-M28 | 5% decrease in steam consumption in the EO stripper<br>5% decrease in CO2 emissions of EO stripper<br>5% decrease in the unit cost of EO stripper |

Phase 2: Pilot set-up and datasets recording

Table 3-12: PETROCHEMICAL Pilot's phase 2 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A2.1 Determination of related tag names of the physical sensors | Significant parts of the data from sensors available in the plant will be marked according to the categories needed. By collecting the tagged data, the training set will be created, and the model will be trained. | M9-M12 | 5 % decrease in steam consumption;<br>5 % decrease in CO2 emissions;<br>5 % decrease in unit process cost; |
| A2.2 Produce abundant datasets for each data type, enabling data combination | Producing abundant datasets for each data type, enabling data combination | M9-M12 | 5 % decrease in steam consumption;<br>5 % decrease in CO2 emissions;<br>5 % decrease in unit process cost; |
| A2.3 Gathering laboratory analysis data | The EO content in the EO stripper bottom and CO2 content of the top of D-205 will be analysed and analyses results will be used in DT. | M30-M32 | 5 % decrease in steam consumption;<br>5 % decrease in CO2 emissions;<br>5 % decrease in unit process cost; |
| A2.4 Pre-processing of the gathered laboratory data | Laboratory analyses results will be prepared for DT. | M31-M33 | 5 % decrease in steam consumption;<br>5 % decrease in CO2 emissions;<br>5 % decrease in unit process cost; |
| A2.4 Produce abundant datasets for each data type, enabling data combination | Producing abundant datasets for each data type, enabling data combination. | M30-M33 | 5 % decrease in steam consumption;<br>5 % decrease in CO2 emissions;<br>5 % decrease in unit process cost; |

Phase 3: Technology Integration

Table 3-13: PETROCHEMICAL Pilot's phase 3 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A3.1 Design and run AI training based on the datasets | Determination of machine learning algorithms suitable for the dataset. Random forest, supervised etc. | M12-M18 | 5 % decrease in steam consumption;<br>5 % decrease in CO2 emissions;<br>5 % decrease in unit process cost; |
| A3.2 Development of C205 first-order model | The first order model (input-output transfer function) of C205 stripper will be modelled in order to optimize the EO purity. | M11-M15 | 5 % decrease in steam consumption;<br>5 % decrease in CO2 emissions;<br>5 % decrease in unit process cost; |
| A3.3 Calibration of the first-order model with process data | The hyperparameters of transfer function of C205 that was modelled beforehand will be optimized using process data. | M16-M20 | 5 % decrease in steam consumption;<br>5 % decrease in CO2 emissions;<br>5 % decrease in unit process cost; |
| A3.4 Data Space and Data model integration | Determining the data space, adapting the catalog contract representation entities in the data model to the data. | M26-M28 | Availability of a Digital Twin where what-if analysis and simulations can be handled |
| A3.5 Digital twin integration. | Transmission of sensor data to databases and installation of applications on servers. | M27-M29 | 5 % decrease in steam consumption;<br>5 % decrease in CO2 emissions;<br>5 % decrease in unit process cost; |
| A3.6 Design of different and relevant dashboards shown to the operators according to the plant | Determining the dashboard type based on the data type. | M29-M31 | Availability of a Digital Twin where what-if analysis and simulations can be handled |
| A3.7 Deployment of the CircularTwAIn framework | Installation of the application to be developed on end user servers as Docker containers. | M30-M31 | Availability of a Digital Twin where what-if analysis and |

| | | | |
|---|---|---|---|
| | | | simulations can be handled |
| A3.8 Exploration of the degradation trend of the collected sensor data (from the plant) | The calendar/time based preventive maintenance will be transformed to predictive maintenance. Data that is collected right after the maintenance will be used as "healthy" condition data. The data right before the next maintenance will be used as "faulty/used" condition data. | M18-M21 | >90% accuracy in detecting anomalies related to the EO/EG plant |
| A3.9 Training a ML model | Data will be compared to see the trends that occur, if a degradation trend is found within the data, a model will be trained to estimate the condition of the plant, whether maintenance is needed or not. | M19-M21 | >90% accuracy in detecting anomalies related to the EO/EG plant |
| A3.10 Monitoring the condition of the plant using real-time sensor data | Monitoring the condition of the plant using real-time sensor data fed to the predictive maintenance model. | M20-M21 | 5 % decrease in steam consumption<br>5 % decrease in CO2 emissions<br>5 % decrease in unit process cost<br>>90% accuracy in detecting anomalies related to the EO/EG plant<br># of AI models trained and tested for process optimization >= 3 |
| A3.11 Displaying the condition of the EO production plant and its parts in the digital twin. | The dashboards created by TEKNOPAR will use user authorization and show only the relevant parameters to the operators/engineers and executives. The warnings about the plant may be shown to maintenance operators on the plant. | M32-M35 | Availability of a Digital Twin where what-if analysis and simulations can be handled |
| A3.12 Detection of abnormal conditions | If any shutdowns occur or have occurred on the plant, the data before said shutdown will be used as indicators of a shutdown condition. | M32-35 | >90% accuracy in detecting anomalies related to the EO/EG plant |
| A3.13 Developing the loading data GUI using the data type | Developing the loading data GUI using the data type that end user plans to use (currently .xlsx). | M11-M15 | Availability of a Digital Twin where what-if analysis and |

| | | | |
|---|---|---|---|
| | | | simulations can be handled |
| A3.14 Selection of the needed preprocessing algorithms | Selection of the needed pre-processing algorithms based on the needs of the problem. | M15-M17 | 5 % decrease in steam consumption;<br>5 % decrease in CO2 emissions;<br>5 % decrease in unit process cost |
| A3.15 Developing data set analysis section | Developing data set analysis section that is relevant with the row/column names of the data that is loaded. | M15-M17 | 5 % decrease in steam consumption<br>5 % decrease in CO2 emissions<br>5 % decrease in unit process cost |
| A3.16 Selection of training algorithms | Selection of training algorithms that is compatible with the sensory data acquired from DCS/PHD. (Regression/Classification). | M17-M18 | 5 % decrease in steam consumption<br>5 % decrease in CO2 emissions<br>5 % decrease in unit process cost |
| A3.17 Selection of important learning performance metrics | Trained models comperision using different metrics, such as F1 score, Area Under the Curve, TP, TP, TN, FN, etc. | M17-M19 | 5 % decrease in steam consumption<br>5 % decrease in CO2 emissions<br>5 % decrease in unit process cost |
| A3.18 Ensuring that the model can be saved and is able to work network-wise | The trained models will be saved in the format determined by the library and will have the ability to be predicted by a separate service. Since the service will be available in the web application, it will be accessible over the network. | M27-M35 | 5 % decrease in steam consumption<br>5 % decrease in CO2 emissions<br>5 % decrease in unit process cost<br>>90% accuracy in detecting anomalies related to the EO/EG plant |
| A3.19 Merging the codes that were developed to create a complete AutoML GUI | The codes that were implemented, AI algorithms that were developed and the models that were created will be merged to create a complete AutoML GUI. | M30-M32 | Availability of a Digital Twin where what-if analysis and simulations can be handled<br># of AI models trained and tested for process optimization >= 3 |

| | | | |
|---|---|---|---|
| A3.20 Test the tool preliminary capabilities | Tests to compare the lab results with the estimated EO purity will be performed. | M32-35 | 5 % decrease in steam consumption<br>5 % decrease in CO2 emissions<br>5 % decrease in unit process cost |
| A3.21 The development of the plant's first order model | Modelling the whole plant (EO absorption, EO stripping, CO2 removal) will be useful in optimizing EO purity. This would also be used as an input to circularity of CO2 output (Aspen engineering suite model). | M12-M18 | 5 % decrease in steam consumption<br>5 % decrease in CO2 emissions<br>5 % decrease in unit process cost |
| A3.22 The selection of the optimization model's sampling method. | Different sampling methods are available for optimization models (random, strat, lhs etc.). Thus, the most optimal sampling method for the application should be selected. | M17-M19 | 5 % decrease in steam consumption<br>5 % decrease in CO2 emissions<br>5 % decrease in unit process cost<br># of AI models trained and tested for process optimization >= 3 |
| A3.23 The evaluation of the optimization problem by a number of ML algorithms. | Training of ML algorithms for the optimization problem and working towards the solution of the problem. | M19-M21 | # of AI models trained and tested for process optimization >= 3 |
| A3.24 The addition of time stamps to lab results. | Date and timestamps associated with the completion of laboratory results, that are meta data associated with laboratory results. | M25-M26 | Availability of real-time performance data to capitalize on AI algorithms |
| A3.25 Test of the optimization model | Use of optimization data not used in training to test the accuracy of the machine learning model. | M33-M36 | >90% accuracy of trained model |

Phase 4: Experimentation and KPIs measurement

Table 3-14: PETROCHEMICAL Pilot's phase 4 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A4.1 KPIs measurement | Steam consumption of EO stripper will be compared with the design values. | M21 / M35 | 5 % decrease in steam consumption<br>5 % decrease in CO2 emissions |

| | | | |
|---|---|---|---|
| | $CO_2$ emission will be calculated based on the saving in steam consumption.<br><br>The difference in the operating cost of EO stripper will be determined comparing before and after the implementation of the AI tool. | | 5 % decrease in unit process cost |
| A4.2 Evaluation algorithms and performance indicator analysis | Study the impact of the AI-modules on the KPIs. Define if/where AI-modules components need to be improved or added to reach the target values. | M20-M21 / M34-35 | 5 % decrease in steam consumption<br><br>5 % decrease in $CO_2$ emissions<br><br>5 % decrease in unit process cost<br><br>>90% accuracy in detecting anomalies related to the EO/EG plant<br><br># of AI models trained and tested for process optimization >= 3 |
| A4.3 Comparison with the benchmarks | Comparing the measured KPIs with the target KPIs. | M20-M21 / M34-35 | 5 % decrease in steam consumption<br><br>5 % decrease in $CO_2$ emissions<br><br>5 % decrease in unit process cost |
| A4.4 Compilation of the results and graphical representation | Compile the results and plan the next implementation phase. | M20-M21 / M34-35 | 5 % decrease in steam consumption<br><br>5 % decrease in $CO_2$ emissions<br><br>5 % decrease in unit process cost |

Phase 5: Conclusion and Recommendation

Table 3-15: PETROCHEMICAL Pilot’s phase 5 actions

| Activity | Description | Temporal Planning | Associated KPIs |
|---|---|---|---|
| A5.1: Preparation of the report | Preparation of the end-of-cycle reports. | M20-M21/M34-36 | 5 % decrease in steam consumption<br><br>5 % decrease in $CO_2$ emissions;<br><br>5 % decrease in unit process cost |

| | | | |
|---|---|---|---|
| A5.2: Presentation of the results | Preparation and presentation of development outcomes obtained during the Pilot implementation process. | M21 / M36 | 5 % decrease in steam consumption<br><br>5 % decrease in CO2 emissions<br><br>5 % decrease in unit process cost |

### 3.3.3 Gantt chart

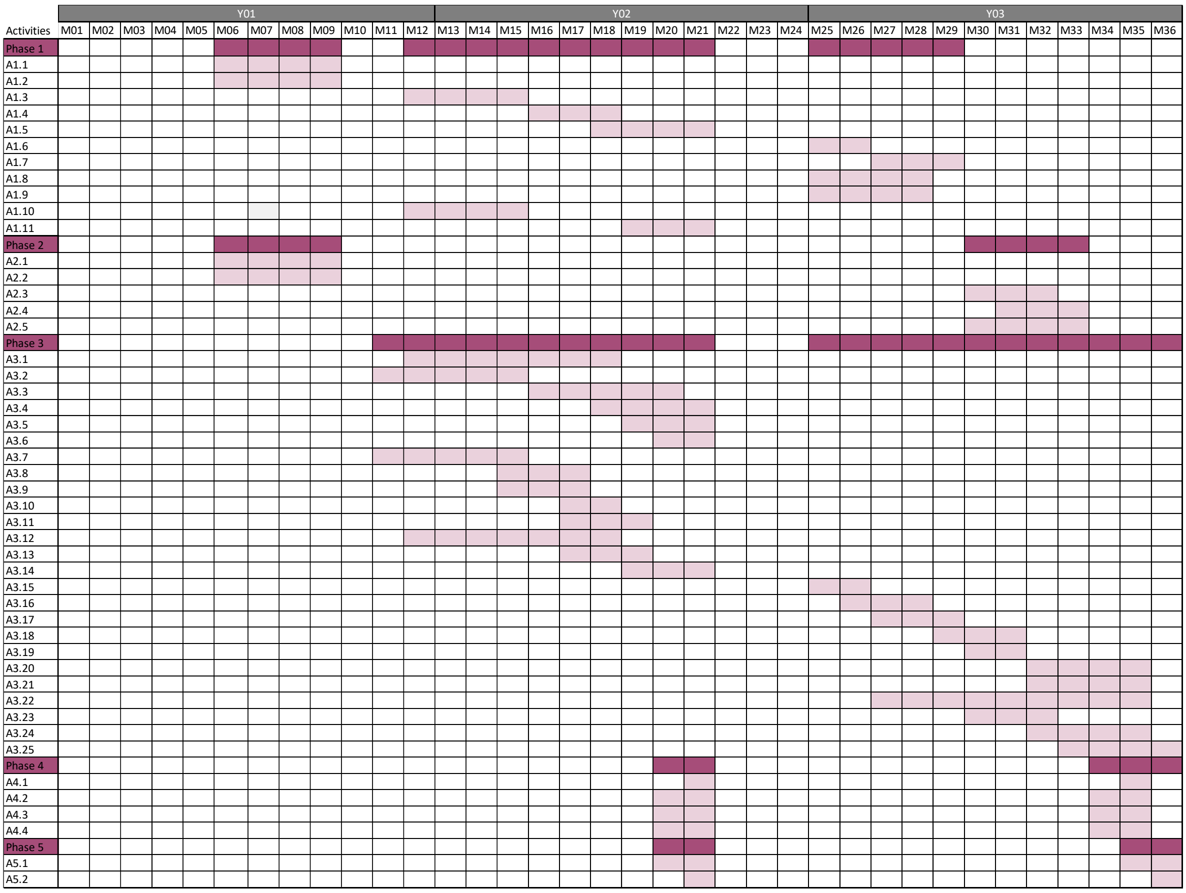



Figure 3-3: PETROCHEMICAL Pilot's Gantt chart for the first period

### 3.3.4 Identified KPIs

- Availability of real-time performance data to capitalize on AI algorithms; Real-time estimated performance is calculated through first-order models of the plant and the formula is:Estimated EO output of the first order model of the plant/ Expected (or maximum) EO Output. Since the data gathered from the DCS is mostly linear, the optimization models will run each 5 minutes to predict estimated EO/CO2 output.
- Availability of a Digital Twin where what-if analysis and simulations can be handled.
- >90% accuracy in detecting anomalies related to the EO/EG plant; In an ethylene oxide plant, for example, an anomaly condition could be an unexpected rise in temperature or pressure in the reactor vessel, which could indicate a problem with the cooling system or a blockage in the reactor. Other examples of anomaly circumstances include unexpected changes in flow rates, unusual readings on monitoring instruments. Anomaly conditions in ethylene oxide plants can be hazardous, posing significant safety risks to employees and the environment. As a result, it is critical to have anomaly detection systems in place to detect and identify anomalous conditions as soon as possible, as well as robust safety procedures in place to mitigate any potential risks.
- # of AI models trained and tested for process optimization >= 3

- 5% decrease in steam consumption in the EO stripper (it will be measured by actuator that can adjust flow rate)
- 5% decrease in $CO_2$ emissions of EO stripper (It will be calculated based on the reduction in steam)
- 5% decrease in the unit cost of EO stripper (It will be calculated based on the reduction in steam)

### 3.3.5 Measured KPIs

- Currently steam consumption is 31.1 ton per hour, with the implementation of to be developed system 5% decrease in steam consumption in the EO stripper is aimed. Steam consumption of EO stripper will be compared with the design values.
- Currently steam consumption is 13.3 ton $CO_2$ per hour, with the implementation of to be developed system 5% decrease in $CO_2$ emissions of EO stripper is aimed. $CO_2$ emission will be calculated based on the saving in steam consumption.
- 5% decrease in the unit cost of EO stripper; the difference in the operating cost of EO stripper will be determined comparing before and after the implementation of the AI tool.
- >90% accuracy in detecting anomalies related to the EO/EG plant.
- *# of AI models trained and tested for process optimization >= 3.*

# 4 Conclusion and Future Outlook

This deliverable presents the methodology and planning for the coordination of the pilots in Circular TwAIn Project. These pilots all represent circular scenarios in very different sectors and with different levels of maturity. The goal of this document is to unify and coordinate the execution, development and integration of the Circular TwAIn technologies in this heterogeneous landscape.

To that end, following the outputs of WP2, a Trial Handbook has been developed and fulfilled with the collaboration of all the pilots: the THB carries all the information related to the Use Cases and how they will be implemented. Since these THBs contain confidential information about industrial business and processes, they will be used as internal documents of the consortium. However, a template of the THBs is provided in Annex I to illustrate the information collected from the pilots, the collection of requirements and the planning of activities. These THBs will be used as the main communication document for the coordination of the pilots, allowing an easy communication with the technical partners. Finally, these documents also detail what steps and actions will be taken in the pilots to implement the technologies.

In this deliverable the implementation plan and list of actions is summarized for each one of the three pilots, providing an outline of the roadmap for the first iteration of the implementation phase. A Gantt chart is provided for each Pilot, showcasing the activities for this first period and the outline for the second one.

This document and the action plans will be revised and updated in D6.3 “Methodology and Tools for Industrial Pilots WP6 coordination - 2nd version” due in M27, where the first implementation plan and the stablished KPIs will be analysed.

# Annex I: THB template

# Table of Contents

# Definitions and acronyms

| | |
|---|---|
| *Actor* | *Entities involved in the Use Case that do not participate directly in the project* |
| *KPI* | *Key Performance Indicator. Metric that summarizes the key parameters in the process* |
| *Pilot:* | *Sector and local environment where Circular Twain technologies will be demonstrated* |
| *Use Case* | *Applications of Circular Twain technologies in each pilot* |
| *Scenario* | *A scenario describes how a specific user perceives the use case and interacts with the technologies to achieve a goal* |
| *AI* | *Artificial Intelligence* |
| *CA* | *Consortium Agreement* |
| *DoA* | *Description of Action* |
| *EC* | *European Commission* |
| *EL* | *Ethical and Legal* |
| *EPIA* | *Ethics Impact Assessment* |
| *EU* | *European Union* |
| *GA* | *Grant Agreement* |
| *Mx* | *Month x* |
| *PPE* | *Personal Protection Equipment* |
| *PC* | *Project Coordinator* |
| *TC* | *Technical Coordinator* |
| *WP* | *Work Package* |
| *THB* | *Trial Handbook* |
| *TechHB* | *TechHB* |
| *V&V* | *Verification & Validation* |

# Introduction

The Trial Handbook is intended to provide up-to-date information about Circular TwAIn pilot experiments performed in WP6 in order to monitor their progresses and assess their impact. Each chapter focuses on the collection of specific data, starting from the general description of the pilots, to the description of the use cases, their potentialities and barriers at technical and economic level and their effective implementation and validation. The document allows an easier and faster update and/or /modification of the information and the collection of new data after the experiments 1st iteration needed for WP6 deliverables.

Each experiment leader has to fill the THB according to the specific time-to-time requests with the support of the involved stakeholders in the trial (e.g., Technology Providers) and WP2/WP6 Leaders and is responsible for the quality of the provided information.

The WP2 and WP6 Leaders will revise the contents and will ask for possible clarifications and improvements before the final submission.

All the experiments for a pilot will be collected in a single document because:

1. otherwise we will end up with a lot of documents that will be more difficult to manage;
2. some of the experiments will depend on the others, and it will be easier to cross-reference.

The document is structure as it follows:

- A general description of the pilot, its framework and manufacturing process.
- A list of use cases for the pilot, with three independent chapters for Use case
    - Experiment overview: provides a description of the use case with the AS-IS and TO-BE scenarios.
    - Business requirements: provides a list of legal, administrative and technological requirements for the use case
    - Implementation: provides a summary of the implementation and validation efforts.

# 1 Pilot Definition

| **Pilot** |
|---|
| *Pilot name and short ID in Circular Twain project*<br><br>IDs: BATT, WEEE, PETRO |
| **Process name** |
| *Industrial process name* |
| **Contact person** |
| *Contact person for information regarding the pilot* |

*This section is used to provide a structured and formal view of the process to partners and people with different backgrounds. To correctly complete this definition, please fill out the information as much and as thoroughly as possible.*

*The goal of this exercise is to summarize:*

- *Comprehensive knowledge about the execution of the industrial process and full ecosystem including suppliers and customers (full circular economy process).*
- *Relevant indicators that could be improved with the use of Circular Twain technologies.*
- *Sensors and/or actuators that can be used for the interaction between the physical and digital systems.*
- *The existence of historical data or open datasets relevant to the pilot.*
- *The existence of formal knowledge, models or simulations relevant to the pilot.*
- *Provide information pertaining to the human involvement in the complete process. For instance, human historical health data, risks and targets.*
- *Provide data related to the component and product wise specifications, cost/economy, and processing.*

*Use this section to describe the process as it is, without the technologies that will be added during the project execution. This information will be used to model the use cases and extract the requirements.*

## 1.1 Pilot description

*Overall pilot description. Include the partners involved and their roles.*

## 1.2 Business factors

*Overall description of the business needs and factors.*

Eg:

Interest in new technologies

Increase automation

Provide a safer work environment

## 1.3 Actors involved in the Pilot

*Entities related to the system being modelled. If the entity role is assumed by one of the Circular Twain partners, please specify so.*

| Actor name | Actor ID | Actor role | Actor description | Data provided |
|---|---|---|---|---|
| **(Eg) Transport Agency** | WEEE.AC.1 | Translate WEEE to the disassembly facility | Logistics agency that moves items in and out of the facilities. | *Batch ID* |
| | | | | |

## 1.4 List of steps

*List of steps of the manufacturing process (Inclusion of a descriptive flowchart of the process is highly encouraged)*

Eg (WEEE Pilot):

- WEEE pickup, transportation and reception
- Visual inspection
- Cleaning
- WEEE Re-manufacturing
- WEEE De-manufacturing
- Testing
- Transportation of waste
- Selling of remanufactured items.

### *1.4.1 Definition of steps*

*(Repeat this table for each one of the steps provided in the last field)*

| **Step name and ID** |
|---|
| *Name and ID of the step in the previous field*<br>*Eg: Visual inspection – WEEE.S.2* |
| **Description** |
| *Description of what is happening in this step, interaction or operations with workers, etc. Reference to the actors list or other steps if possible. Include information regarding* |

| |
|---|
| *lead/processing times, equipment used (including specifications), quality control methods (Gauges, inspection procedures, audits) if available, documentation and procedures.* |
| **Inputs / Outputs** |
| *Inputs and outputs of the step. Please reference them with the other listed steps or actors if possible. Specify if the step is of continuous (by item or by batch) or discrete nature. Specify the information about the material inputs regarding size, quantities, qualities, etc., and also considering uncertainty and variations.*<br>*Eg (Visual inspection):*<br>*Inputs: a PC from a given received pallet (step 2)*<br>*Outputs: a PC; information regarding the system and components* |
| **Specific KPIs** |
| *Relevant KPIs for this step.  Indicate units and measurement process.*<br>*Eg:*<br>*Process time (Pieces / min). Computed with the mean value of 100 executions.*<br>*Material flow (l / m). Measured with a Flow Meter at the exit of this stage* |
| **Human intervention** |
| *Define any human intervention in this step, as well as any actions that have to be performed by a human and the equipment used during said interaction. Include also the available data relative to the worker(s).*<br>*Eg: Visual inspection performed by a worker equipped with PPEs (glasses and gloves). Available data: Age, Sex, Experience, Work Related Injuries history, etc.* |
| **Existing / Possible sensors and data** |
| *Sensors and other data sources in the manufacturing plant that can be used to gather data. This should summarize all the information available for the execution of this step. Should more sensors be added during the execution of the project, please include them here. If possible, specify data formats and sizes as well.*<br>*Include as well any environmental sensors or aspects that may affect the process at this step (temperature, humidity, etc.).*<br>*Eg:*<br>*Existing data:*<br>*Component information: Data of the component being de-manufactured. Includes information about the source of waste, date of pickup, computer model, etc.*<br>*Temperature sensors:* |
| **Existing / Possible actuators** |
| *Actuators or other cyber-physical systems that can be used to interact with the production process. Should more sensors be added during the execution of the project, please include them here.* |

| |
|---|
| *Eg:*<br>*Existing systems:*<br>*Flow control valve: Actuator that can adjust the step input*<br>*GUI: Graphical user interface used to display alerts and interact with the workers.* |
| **Other relevant information** |
| *Include any additional information of this step: pictures, videos, simulations, mathematical equations or models, reference papers, etc.* |

## 1.5 Circularity and data sharing

*Specify the circularity flows in the business or pilot. Provide a material flow diagram if possible.*

Eg (WEEE Pilot):

- Circularity stream 1: Re-manufacturing and reuse of equipment
- Circularity stream 2: Reuse of components
- Circularity stream 3: Recycling of rare materials (RE, gold, etc.)

### *1.5.1 Circular value chain and stakeholders*

*Provide a clear outline of the circular value chain (the peer-to-peer network of organisations playing the role of Data Providers and Data Consumers)*

*Identify the network of stakeholders with the indication of the relevant beneficiary. If it is a role not played by a beneficiary, please give a generic name and some indications on how this actor will be involved (simulated, private agreements, other projects, in-house personnel, subcontractor, affiliated entity)*

### *1.5.2 Data sources*

*Identify the data sources provided by stakeholders (both as inputs to advanced applications and outputs to it) with the indication of the relevant beneficiary. Data files and data sets should be carefully described with their confidentiality level, access, and usage rights / apps. An estimation of their size and the definition of the queries necessary to extract them is also to be added.*

### *1.5.3 Data Sharing Workflow*

*Identify the business logic (PUSH PULL) according to which the data sharing needs to be implemented. Please be consistent with the stakeholders and data sources when defining the business logic.*

## 1.6 Framework

*A clear overview of the "framework conditions" considering variables such as social/economic/legal and ethical ones is necessary to effectively adopt a transformation in the company business and successfully implement an innovation that can be replicable and scalable even in other contexts.*

*The following sections are focused on framework conditions linked to the Pilot.*

### *1.6.1 Social Framework*

*Identify the main barriers linked to the social framework that characterizes the current situation of the company's sector and the technology related to the trial. If possible, describe how the selected social aspects affect the activity performed at the company. Select those that mostly affect the experiment from the following list and, if possible, justify.*

- *Region-specific and (local) cultures hamper the implementation of new solutions*
- *Conservativeness in business practices (e.g. waste management industry)*
- *Lacking or uncertain customer need*
- *Other: specify*

### *1.6.2 Economic Framework*

*Identify the main economic barriers affecting the activity performed at the company linked to the trial (e.g. high hardware/software and development costs, solution integration barriers into the company processes, skills acquisitions – resources, competences, technology, high investment risk, other…).*

### *1.6.3 Legal and ethical framework*

*Give a description of the legal and ethical framework related to the technology involved in the experiment, identifying the relevant regulatory sources, such as legislations, standards, sector-specific policies, company practices/policies and Ethics Committes' Opinion. Also, non-binding sources are relevant.*

| Regulatory Source | Relevant content | Legal and/or ethical issues concerned | Other |
|---|---|---|---|
| *Brief reference of the regulatory source (name, date, number, type, etc.)* | *Summary or extract of the content/articles/rules of this regulatory source relevant to your experiment* | *Why this source is relevant to your experiment? Please briefly describe the legal and/or ethical issues raised by the experiment.* | *Any other useful details* |
| | | | |
| | | | |

## 1.7 Pilot KPIs

*(Overall KPIs for the entire process)*

Eg (WEEE Pilot):

20% more value generated from the recycled/re-used components through an improved assessment of the component condition and its market value;

Automation of more than 25% of the operations required for disassembly;

30% reduction in time for the de-manufacturing operations of IT equipment by integrating a collaborative robotics application capable of handling disassembling operations;

20% reduction in time for the testing and evaluation operations of IT equipment by using AI to assist the worker on the evaluation, inspection and identification of components and sub-components.

# 2 Selected Use Cases: Use Case A

## 2.1 Experiment Overview Chapter

This chapter gathers all the key overall information of the pilot experiment, to allow a comprehensive understanding of the trial, and it mainly addresses Phase 1 - "Scenario analysis", of the Circular TwAIn Requirements Engineering Methodology for the requirements and scenario recollection. This phase consists of drawing the as-is and to-be scenarios including bottlenecks, objectives and KPIs among others. Accordingly, this chapter includes general information of the experiment, framework conditions information and fully depicts the initial business scenario, with current weaknesses and bottlenecks, business objectives and impact areas, as well as the expected results and KPIs.

The AS-IS and TO-BE business and innovation scenarios reported in this Chapter will be summarized in D2.2.

### 2.1.1 General description and motivation

*Give a general description of the experiment, including:*

- *Motivation - problems, gains and pains;*
- *Experiment concept;*
- *Challenge - specify the need for Artificial Intelligence, Digital Twins and Data Space for material/process/product data, considering sustainability aspects;*

*(between 1 and 3 pages)*

### 2.1.2 Objectives & Benefits

*Describe the main objectives and benefits that the implementation of the experiment is expected to provide at a business level. Highlight the expected benefits towards sustainability, product quality, productivity, reduction of costs, effectiveness of processes, benefit in production, improvement in company image, or other tangible benefits.*

*(between 1 and 2 pages)*

### 2.1.3 Experiment Team

*Provide a brief description of all the involved stakeholders in the experiment and their role. If possible, refer to the Actors defined in the Pilot definition:*

- *end-user – specify all the company functions involved;*
- *technology providers;*
- *other involved party.*

*Quickly describe how the collaboration is expected to occur. If not all the parties have already been identified, provide a brief description of the expected partner for the success of the experiment (e.g. "a solution provider able to…").*

*(between 1 and 2 pages per stakeholder)*

### 2.1.4 AS-IS Scenario

*Give a comprehensive description of the activities as currently performed for the selected use case. If possible, refer to the Pilot definition Steps listed in Section 1.*

*(between 1 and 2 pages)*

### *2.1.5 Weaknesses and bottlenecks*

*Describe the current problems connected to the AS-IS scenario and the possible causes. Then, fill the provided table synthetizing the main weaknesses and bottlenecks, specifying the affected business areas.*

*(between 1 and 2 pages)*

| Weaknesses & Bottlenecks | Description | Business Impact Area |
|---|---|---|
| *Name of the weakness/bottleneck* | *Description of the weakness/bottleneck* | *Which business area is affected by the weakness/bottleneck (e.g. production, marketing & sales, R&D, ..)? How?* |
| | | |

### *2.1.6 TO-BE Scenario*

*Give a comprehensive description of the expected solution, listing all the possible targeted scenarios. Clarify how the activities will be performed after the implementation of the experiment and specify the use of AI technologies/applications, Digital Twins and Circular Industrial Data Space for material/process/product data. Images/flow diagrams are welcome.*

*If possible, describe multiple scenarios from different perspectives, eg, Use of the tool from the worker's perspective / Use of the tool from the business owner perspective*

***Scenario 1***

*…*

***Scenario 2***

*…*

*(between 1 and 3 pages)*

### *2.1.7 Expected results and KPIs*

*Describe the main expected results after the implementation of the experiment.*

*Then, fill the following table synthetizing the business objectives, connected to the business impact area, and identify potential KPIs that will be considered and monitored throughout the duration of the experiment.*

*KPIs should be identify considering 3 levels:*

- *Strategic level: long term – pilot experiment level*

- *Tactical level: medium term – phase objectives level*
- *Operational level: short term – task objectives level*

*Different KPIs can be linked to the same Business Objective and/or Business Impact Area.*

*(between 1 and 3 pages)*

***Scenario 1***

| Business Objectives (BO) | Business Impact Area | KPIs | | |
|---|---|---|---|---|
| | | Description / Level | AS- IS Value | TO-BE Value |
| *Description of the Business Objective* | *Which business area will be affected by the BO?* | *Description of the KPI and connected level (Strategic – Tactical – Operational)* | *Value measured before starting the experiment* | *Targeted value.* |

## 2.2 Requirements

This chapter gathers all the business requirements of the use case.

It mainly addresses *Phase 2 - "Business/Technological Requirements, elicitation and analysis*" and *Phase 3 – "IT Requirement Specification"* of the Circular TwAIn Requirements Engineering Methodology for the requirements recollection. Phase 2 consists of identifying the mentioned requirements, their classification, priorization and grouping. Phase 3 is oriented to the identification of IT requirements covering business requirements and the AI-focused IT architecture design. Accordingly, this chapter includes information of each requirement, including a brief description, the priority, the area of application and the type of requirement. In addition, the connected business processes and the application areas are described.

The Business Requirements reported in this Chapter will be summarized in D2.2.

### *2.2.1 Business Processes*

*A business process is an activity or set of activities that will accomplish a specific organizational goal. Business Processes have to be identified per each of the Scenarios identified in Chapter 1, including the business objective and the related tasks/activities. Please refer to the steps/activities defined in section 1.4.*

**Scenario X – *[Name of the scenario]***

| **#1 Business Process** | **Business Objective** |
|---|---|
| *[Describe briefly the BP that will be affected by the scenario]* | *[Identify the particular business objectives of Chapter 1, which meet by the business process]* |
| **Activity/Activities** | |
| *[Identify the collection of related and structured activities or tasks that in a specific sequence meet a particular business objective]* | |

….

| **#n Business Process** | **Business Objective** |
|---|---|
| *[Describe briefly the BP that will be affected by the scenario]* | *[Identify the particular business objectives of Chapter 1, which meet by the business process]* |
| **Activity/Activities** | |

*[Identify the collection of related and structured activities or tasks that in a specific sequence meet a particular business objective]*

### 2.2.2 Business Requirements

*Identify the main business requirements linked to the experiment, including the name of business requirement, a short description, the priority (critical, preferred or optional), the area of application and the type (functional /non-functional). Moreover, each requirement is linked to the business process and its business objective.*

| Req # | Business Requirement | Description | Priority | Application Area | Functional Requirement? | Business Process | Business Objective |
|---|---|---|---|---|---|---|---|
| *00* | *[Name of business requirement]* | *[Short description of the business requirement]* | *[- Critical<br>- Preferred<br>- Optional]* | *[Area of application of Business Requirement]* | *[- Functional<br>- Non-Functional]* | *[Identify the business process linked to the BR – See previous section]* | *[Identify the business objective linked to the BR]* |
| *01* | *[Name of business requirement]* | *[Short description of the business requirement]* | *[- Critical<br>- Preferred<br>- Optional]* | *[Area of application of Business Requirement]* | *[- Functional<br>- Non-Functional]* | *[Identify the business process linked to the BR – See previous section]* | *[Identify the business objective linked to the BR]* |
| *02* | *[Name of business requirement]* | *[Short description of the business requirement]* | *[- Critical<br>- Preferred<br>- Optional]* | *[Area of application of Business Requirement]* | *[- Functional<br>- Non-Functional]* | *[Identify the business process linked to the BR – See previous section 1]* | *[Identify the business objective linked to the BR]* |

### 2.2.3 Ethical and Legal Requirements

*Identify the main **Ethical and Legal (EL) requirements** linked to the experiment, including the name of EL requirement, a short description, the priority (critical, preferred or optional), the area of application and the nature (Ethical/Legal). Moreover, indicate to what Circular TwAIn tool the requirement is linked.*

| Req # | EL Requirement | Description | Priority | Application Area | Nature | Circular Twain Technology Asset | Business Process | Business Objective |
|---|---|---|---|---|---|---|---|---|
| **00** | [Name of EL requirement] | [Short description of the EL requirement] | [- Critical<br>- Preferred<br>- Optional] | [Area of application of EL Requirement ] | [- Ethical<br>- Legal] | [Indicate to what AI Circular TwAIn technology tool the requirement is linked. | [Identify the business process linked to the EL Requirement – See Section 1] | [Identify the business objective linked to the BR] |
| 01 | [Name of EL requirement] | [Short description of the EL requirement] | [- Critical<br>- Preferred<br>- Optional] | [Area of application of EL Requirement ] | [- Ethical<br>- Legal] | Indicate to what AI Circular TwAIn technology tool the requirement is linked. | [Identify the business process linked to the EL Requirement – See Section 1] | [Identify the business objective linked to the BR] |
| 02 | [Name of EL requirement] | [Short description of the EL requirement] | [- Critical<br>- Preferred<br>- Optional] | [Area of application of EL Requirement ] | [- Ethical<br>- Legal] | Indicate to what AI Circular TwAIn technology tool the requirement is linked. | [Identify the business process linked to the EL Requirement – See Section 1] | [Identify the business objective linked to the BR] |

### 2.2.4 Ethical Procedures and experiment-specific features

*Please provide information related to:*

*i) **HUMAN INVOLVEMENT**: the involvement and participation in the experiment activities of individuals, volunteers and stakeholders (for example for usability tests, for validation workshops, etc.) external to the research staff. In other words, this information regards the participation in the experiment operations of human beings, different from the AI REGIO team (with subsequent privacy and ethical implications). In such a case, more information about the informed consent and recruitment procedures are asked, such as:*

*how these individuals/participants are identified and selected*

*which are the inclusion and exclusion criteria for this recruitment*

*which methods are used to recruit them (for instance face-to-face personalised e-mails, telephone, social media, website, etc.)*

*ii) **PERSONAL DATA COLLECTION AND/OR PROCESSING**. This point regards the privacy, regulatory compliance and ethical implications in case of collection and/or handing of personal data is foreseen in the experiment. This includes, for instance, questions on specific and "sensitive" tools and techniques like:*

*The use of the video-surveillance (CCTV and intelligent visual surveillances)*

*The use of the technologies for access control (authentication, authorisation)*

*The use of biometric identification*

*iii) **ARTIFICIAL INTELLIGENCE**: this point regards the check on the applicability of the Ethics guidelines for trustworthy AI developed by the High-Level Expert Group on AI, as well as the classification or not of the AI application/tool that you plan to use as high risk application/system 1*

*Please summarize in the next table the experiment-specific features from the legal and ethical point of view:*

<table>
<tr><th colspan="5">Ethics Impact Assessment</th></tr>
<tr><th>#</th><th>Name</th><th>Criterion info</th><th>YES/NO</th><th>Notes</th></tr>
<tr><td rowspan="5">1</td><td rowspan="5">EXTERNAL HUMANS</td><td>Involvement and participation of individuals, volunteers and stakeholders external to the research staff</td><td></td><td></td></tr>
<tr><th colspan="2">Only If external humans involved</th><th>Description</th></tr>
<tr><td colspan="2">External humans' identification and selection</td><td></td></tr>
<tr><td colspan="2">Inclusion and exclusion criteria for recruitment of external humans</td><td></td></tr>
<tr><td colspan="2">Methods used to recruit external humans</td><td></td></tr>
</table>

[1] *"High-risk" AI-system "under the AI Act means "**a significant potential in an autonomously operating AI-system to cause harm or damage to one or more persons in a manner that is random and goes beyond what can reasonably be expected**; the significance of the potential depends on the interplay between the severity of possible harm or damage, the degree of autonomy of decision-making, the likelihood that the risk materialises and the manner and the context in which the AI-system is being used". To determine whether an AI-system is high-risk, the Report suggests to take into account also the sector in which significant risks could arise and the nature of the activities to be undertaken".*

| # | Name | Criterion info | YES/NO | Description |
|---|---|---|---|---|
| | | Clarify whether vulnerable individuals/groups will be involved | | |
| | | Informed Consent Procedures (Informed Consent Form and Information Sheet) | | |
| | | Is necessary to obtain an opinions/approvals by ethics committees and/or competent authorities for your planned activities with humans? | | |
| **#** | **Name** | **Criterion info** | **YES/NO** | **Description** |
| 2 | PERSONAL DATA COLLECTION AND/OR PROCESSING | Confirmaton of compliance with GDPR and respective national legal framework(s) | | |
| | | Confirm of appointment of a Data Protection Officer (DPO) and that the contact details of the DPO will be made available to all data subjects involved in the research | | |
| | | Processing of sensitive personal data and related justification | | |
| | | Anonymysation/pseudonymisation techniques and other technical/ organisational measures that will be implemented to safeguard the rights and freedoms of the data subjects/research participants | | |
| | | Security measures that will be implemented to prevent unauthorised access to personal data or the equipment used for processing must be provided | | |
| | | Informed consent procedures (consent form and information sheet) in regard to data processing | | |
| | | Confirmation of compliance with GDPR and/or with the laws of the country in which the data was collected in case of international transfer of personal data (from the EU to a non-EU country and/or from a non-EU country to the EU) | | |
| | | Need to conduct a data protection impact assessment under art.35 General Data Protection Regulation 2016/679 | | |
| | | In case of profiling, confirmation that adequate information will be provided to the data subjects and that adequate safeguards for his/her rights will be taken | | |
| | | In case of further processing of previously collected personal data, confirmation of the lawful basis of it | | |

| | | | | |
|---|---|---|---|---|
| | | *Use of the video-surveillance (CCTV and intelligent visual surveillance)* | | |
| | | *Use of access control techniques* | | |
| | | *Use of biometric identification tools* | | |
| ***3*** | ***ARTIFICIAL INTELLIGENCE*** | *Check the applicability of the Ethics guidelines for trustworthy AI developed by the High-Level Expert Group on AI and of the related Assessment List for Trustworthy AI (ALTAI)* | | |
| | | *High-level risk application according to the proposal for a Regulation on Artificial Intelligence (AI Act)* | | |

### 2.2.5 Technical Information

*The following section include technical information related to the current experiment status.*

#### 2.2.5.1 Trial technologies

*In case any such technologies have been already prioritized by the industrial pilot, they should be highlighted.*

##### 2.2.5.1.1 AI Applications Need

*Reference to the Circular TwAIn AI technology(-ies) that will be used in the experiment. The full list is provided for reference.*

**Application Modules for Collaborative AI***:* AI-based collaboration on the local shopfloor to support the operator on the local shopfloor, e.g., performing de-or remanufacturing operations:

- ☐ Product recognition through machine vision
- ☐ Parts recognition through machine vision
- ☐ Automatic deduction of disassembly procedure
- ☐ Demonstration-based parts disassembly procedure learning (Robot Teaching)
- ☐ Human-robot collaboration in disassembly (Robot Execution)
- ☐ Robotized disassembly, Part management process optimization, Advanced data analysis.

**Application Modules for Seamless Data Sharing** for the global/value chain level to support trusted data sharing across the entire circular value chain:

- ☐ Analytics of the current and future market situation
- ☐ Orchestration of intelligent supply chains
- ☐ Diagnoses and determination of the optimal re-manufacturing circle
- ☐ Re-construction of missing product life-cycle data

##### 2.2.5.1.2 Digital Twins Need

*Reference to the DTwins that will used in the experiment. The full list is provided for reference.*

- ☐ DTwins for materials and products to follow the lifecycle of goods (LCA simulation)
- ☐ DTwins for process and production to model and simulate Industrial Assets (RAMI AAS)
- ☐ DTwins for Humans (workers) to follow the Collaborative Intelligence paradigm

##### 2.2.5.1.3 Data Space Need

*Define the highly relevant sources of data and information to train and feed the human-AI applications:*

- *the (de-)manufacturing process*
- *the product to be de- manufactured*
- *the human operation*

#### 2.2.5.1.4 Human-Machine Collaboration aspects

*Provide a short explanation of the Human-Machine collaboration in the experiment*

- *role (why this collaboration exists, e.g. to reduce mistakes made by humans, to make the work faster, safer, …)*
- *type ("Humans Assist Machines" vs. "Machines Assist Humans")*
- *benefits (which KPIs are improved by using this collaboration)*

### 2.2.6 User Requirement Specifications

*This section identifies the ICT specifications to be covered by the Circular Twain solution considering the initial results of T2.2 and T2.3 to be reported in D2.2 and the initial reference implementations coming from technical WPs.*

#### 2.2.6.1 Actors

*The following* ***Error! Reference source not found.*** *shows the main actors identified in the textual descriptions of the application scenarios as described in the previous chapter.*

| *Actor Name* | *Business Scenarios* |
|---|---|
| *Actor1* | *Scenarios* |
| *Actor2* | *Scenarios* |
| | |
| | |
| | |
| | |
| | |
| | |

*This table did not explicitly consider the system administrators that will also been involved.*

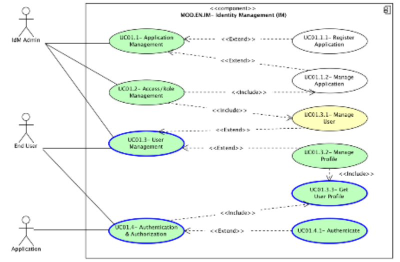
#### 2.2.6.2 Features Analysis

*This section is aimed to identifying the features of the system, providing the initial bounds of a particular system solution. For that, a description of what the system is going to do is provided by using natural language and UML technique. Moreover, use cases involved on each feature are identified and described, providing information related to system behavior, that is, how actors and the system interact to realize the identified feature.*

*The following table represents the notation followed by the use case included in the sections below. This will be used as a criterion to prioritize functionalities and implementation effort.*

| | |
|---|---|
| | *Identified as essential requirement* |
| | *Identified as desirable requirement* |

| | |
|---|---|
| | *Identified in at least one use case application* |

| Feature analysis summary | | | | | | | |
|---|---|---|---|---|---|---|---|
| ID | Name | Objective | Actors IDs | ***External interfaces*** | Requirement adressed | Related Application | ***Involved Use cases*** |
| *FTR.01 1* | *Identity management* | *Natural language description of the feature.* | *Link with the actors identified in section 1.3* | *Interaction with external systems* | *Link with the requirements identified in previous sections* | *Link with the scenarios identified on Chapter 1* |  |
| | | | | | | | |

*Below, indicate how the use case will use the features indicated in the list by creating an user journey or flow of events.*

*Example of User Journey, update by each experiment leader:*

| ***UC.01.1 Application Management*** | |
|---|---|
| ***Objective*** | *Register and manage applications able to share the Identities.* |
| ***Initiation*** | *On demand* |
| ***Flow of Events*** | • *IdM Administrator registers and configures a new application*<br>• *IdM Administration manages existing applications*<br>• *IdM Administration manages existing access/role granting at application level*<br>• *IdM Administration manages existing access/role granting at user level*<br>• *The system provides feedbacks on the result of the process* |

#### *2.2.6.3 Deployment Infrastructures*

*Identify all the IT infrastructures to be involved in the pilot scenario, including hardware components, communication protocols, potential bandwidth limitations, specific security mechanisms and restrictions, etc.*

*Notice that here the focus should remain on the assets (HW/SW) available for experimentations; we do not need to collect/disclosure sensitive information on IT/OT systems.*

| ***Topic*** | ***Requirement*** |
|---|---|
| *Deployment* | *[Circular TwAIn solutions could be deployed in external cloud or on premises?*<br>*If using on-premises deployment, specify the availability of cloud management solutions:*<br>*Identify the cloud management solutions (e.g. OpenStack, VMWare,..).*<br>*identify the cloud approach: public cloud (deployed in external host provider, e.g. MS AZURE), private cloud (deployed in company's data center).*<br>*Identify any potential constraint related to the deployment of a cloud based solution.]* |
| *Wireless and wired network* | *[Specify the availability of a wireless/wired network at shop floor level for demonstration purposes.*<br>*Identify any potential limitation (e.g. bandwidth limitations) or restriction.]* |

| | |
|---|---|
| *Security levels* | *[Specify the security level required: (e.g. VPN, trusted IPs, trusted MAC addresses …)]* |
| *Network topology* | *[Describe the network topology in use in the pilot side, specifying the connection between the different elements (including security aspects).]* |
| *Network communication* | *[Identify any potential limitations to be taken into account by the AI REGIO solutions (e.g. on socket base, on port base, …)]* |
| *Data protection* | *[Identify any potential data protection requirement coming from your internal policies.]* |
| *Data base management* | *[Specify if there is any restriction, due to internal policies, regarding database managers (e.g. no restriction to deploy open source database as MYSQL, POSTGRES SQL, etc., only SQL Server/Oracle are possible, etc.)]* |
| *Other* | *[Provide any other information on potential restriction due to your data center policies that should be taken into account when designing/deploying the Circular TwAIn solutions.* |

## 2.3 Implementation and Results

This chapter focuses on the experiment plan, its implementation and the achieved results, together with a preliminary Exploitation Plan and Lessons Learnt. In particular, it addresses Phase 4 - "Deployment" and Phase 5 – "Requirement validation, assessment and lessons learned", of the Circular TwAIn Requirements Engineering Methodology, which reflects the trial action plan and include the assessment of coverage and completion of business requirements, considering testing and prototyping. Accordingly, this chapter includes a detailed experiment action plan, describing the different trial phases (plan – prepare – execute – evaluate), technical implementation description, achievements and results, outcomes, including barriers.

The version of chapter 3 will contain the implementation of the 1st Iteration of the experiment including the mid-term results, barriers and lessons learnt. Additionally, it will contain the detailed implementation plan of the 2nd Iteration of the experiment.

### *2.3.1 User Requirement Specifications*

*Experiments are run in two iterations in order to start testing and verifying first results and to adjust activities according to the collected barriers and lessons learnt.*

#### *2.3.1.1 1st iteration Plan (M21)*

*Provide a comprehensive description of the experiment phases describing the foreseen activities and the main milestones in the 1st iteration.*

*Fill the table and then detail the mentioned activities in the box below.*

| Activity | Period | Responsible |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

Main expected outputs of the 1st iteration:

*Detailed activities description.*

***Phase 1 "XX": MX-MX (Responsible)***

*Task 1.1: Title of the task*

…

##### *2.3.1.1.1 Implementation and results of the experiment*

*Provide an overview of the development status of the experiment compared to the 1st iteration plan.*

- *Was everything achieved?*
- *What was not achieved and why?*

- *How it affects to the overall experiment plan?*

*(between 2 and 3 pages)*

##### *2.3.1.1.2 Description of results*

*Describe the results achieved thanks to the implementation of the experiment by providing a detailed description of the system built, technology developed, etc.*

*(between 2 and 5 pages)*

##### 2.3.1.1.3 Barriers faced

*Fill in the provided table with the different problems/difficulties/challenges that have appeared during the implementation of the experiment and the solutions applied to face them.*

*(1 page)*

| Barrier/ Difficulty/ Challenge | Description | Solution Applied |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

##### 2.3.1.1.4 Lessons learned

*Provide a detailed description of the lessons learned from the implementation of the experiment.*

*(1 page)*

##### 2.3.1.1.5 Measured KPIs

*Describe the main achieved results after the implementation of the experiment, based on the KPIs identified in Chapter 1. Fill the following table synthetizing the business objectives, connected to the business impact area, and the KPIs that are being considered and monitored throughout the duration of the experiment.*

*In some cases it may not be possible to provide values, as some task of the experiments are still ongoing or about to start. In this cases, please:*

- *Provide mid-way KPIs.*
- *Indicate that is "no value yet".*

*Important remark: This information might be used in public deliverables.*

*(between 1 and 3 pages)*

***Scenario 1***

| Business Objectives (BO) | Business Impact Area | KPIs | | | |
|---|---|---|---|---|---|
| | | Description / Level | AS-IS Value | TO-BE Value | ACHIEVED Value |
| *Description of the Business Objective* | *Which business area will be affected* | *Description of the KPI and connected level (Strategic – Tactical – Operational)* | *Value measured before starting the experiment* | *Targeted value.* | |

| | | | | | |
|---|---|---|---|---|---|
| | *by the BO?* | | | | |

**Table 1 – Achieved results – KPIs**

#### *2.3.1.2 2nd iteration Plan (M36)*

*Provide a comprehensive description of the experiment phases describing the foreseen activities and the main milestones in the 1st iteration.*

*Fill the table and then detail the mentioned activities in the box below.*

| Activity | Period | Responsible |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

Main expected outputs of the 2nd iteration:

*Detailed activities description.*

***Phase 1 "XX": MX-MX (Responsible)***

*Task 1.1: Title of the task*

…

##### *2.3.1.2.1 Implementation and results of the experiment*

*Provide an overview of the development status of the experiment compared to the 1st iteration plan.*

- *Was everything achieved?*
- *What was not achieved and why?*
- *How it affects to the overall experiment plan?*

*(between 2 and 3 pages)*

##### *2.3.1.2.2 Description of results*

*Describe the results achieved thanks to the implementation of the experiment by providing a detailed description of the system built, technology developed, etc.*

*(between 2 and 5 pages)*

#### 2.3.1.2.3 Barriers faced

*Fill in the provided table with the different problems/difficulties/challenges that have appeared during the implementation of the experiment and the solutions applied to face them.*

*(1 page)*

| Barrier/ Difficulty/ Challenge | Description | Solution Applied |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

#### 2.3.1.2.4 Lessons learned

*Provide a detailed description of the lessons learned from the implementation of the experiment.*

*(1 page)*

#### 2.3.1.2.5 Measured KPIs

*Describe the main achieved results after the implementation of the experiment, based on the KPIs identified in Chapter 1. Fill the following table synthetizing the business objectives, connected to the business impact area, and the KPIs that are being considered and monitored throughout the duration of the experiment.*

*In some cases it may not be possible to provide values, as some task of the experiments are still ongoing or about to start. In this cases, please:*

- *Provide mid-way KPIs.*
- *Indicate that is "no value yet".*

*Important remark: This information might be used in public deliverables.*

*(between 1 and 3 pages)*

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