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ALCHIMIA

D5.1 Use-Cases preparation

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Abstract

The purpose of this document is to present a detailed report on the preparation of use-cases for the ALCHIMIA project. This report aims to provide a clear and concise overview of the purpose and importance of use-cases in the context of the project, as well as highlight the benefits and opportunities they offer in driving innovation.

Statement of originality

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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Glossary

Abbreviation	Meaning
AI	Artificial Intelligence
FdT	Fonderia di Torbole
EAF	Electric Arc Furnace
KPIs	Key Performance Indicators
HB	Brinell Hardness method
ERP	Enterprise Resource Planning
PLCs	Programmable Logic Controllers
IIOT	Industrial Internet of Things
MQTT	Message Queuing Telemetry Transport
UML	Unified Modelling Language
CI	Continuous Integration
CD	Continuous Deployment
MES	Manufacture Executing System
EMS	Energy Management System
JSON	JavaScript Object Notation
SRA	System Readiness Assessment
TRL	Technology Readiness Level
IRL	Integration Readiness Level

1 Introduction

1.1 Purpose of the document

The purpose of this document is to present a detailed report on the preparation of use-cases for the ALCHIMIA project. This report aims to provide a clear and concise overview of the purpose and importance of use-cases in the context of the project, as well as highlight the benefits and opportunities they offer in driving innovation.

The ALCHIMIA project aims to build a platform based on Federated Learning and Continual Learning to help big European metallurgy industries unlock the full potential of Artificial Intelligence (AI) to support the needed transformations to create high-quality, competitive, efficient and green manufacturing processes.

Use-cases, also known as case studies, represent hypothetical situations that describe how a user or system interacts with a proposed solution. These use-cases are a valuable tool for identifying and understanding the requirements and functionalities necessary for the success of the ALCHIMIA. They allow visualizing how the proposed solution integrates into the existing environment and how different users benefit from it.

In this report, a series of relevant and detailed use-cases will be presented, which have been meticulously prepared as part of the initial phase of the project.

1.2 Scope of the document

The scope of the document encompasses a comprehensive exploration of the readiness of each pilot for the development and deployment activities based on T5.1. The document's primary focus is on preparing and executing pilot projects within two distinct organizations: CELSA Group and Fonderia di Torbole (FdT).

In a comprehensive exploration of the readiness of industrial pilot projects, there are several potential limits or challenges that can be identified. These limits may affect the accuracy, reliability, and effectiveness of assessing the readiness of the pilot projects.

To mitigate these limits, it's important to conduct a thorough and balanced assessment, engage relevant stakeholders, ensure clear success criteria, and remain flexible to adjust the assessment as challenges arise.

1.3 Structure of the document

The document begins with an introduction that provides a brief overview of its content.

In the section entitled "Use-Cases Identification," various use cases for the industrial partners are identified. The subsection "Use-Case Description" delves into the specifics of these use cases. It further includes sub-subsections discussing individual cases at CELSA Group and FdT. Following this, the section "Expected Results" outlines the anticipated outcomes of these use cases.

Moving on to the "Pilot Sites Preparation" section, the technological components and services necessary for the pilots are detailed. This section also includes sub-subsections highlighting the preparations at both CELSA Group and FdT. A roadmap for the pilot implementation is presented, with specific plans provided for both companies. Additionally, the section addresses the potential issues, barriers, and risks associated with the pilot preparation. Subsections within this part explore these factors individually for both CELSA Group and FdT.

The "Description of the Datasets" section offers insights into the structure of the datasets used in the project. It also provides examples to illustrate the dataset's content and organization.

In the "Readiness Evaluation" section, the criteria and standards employed to assess the readiness of the pilot projects are elaborated upon. Furthermore, individual assessment results for each pilot, conducted according to the established criteria, are documented.

The "Implementation" section encompasses various aspects of the pilot execution. It commences with the sub-section regarding factory visits, followed by the methodology employed for the implementation of the pilots. An analysis of the strengths and areas for improvement for each pilot is also included. In response to these findings, proposed action plans to address the identified areas for improvement are outlined.

Finally, the document concludes with the "Conclusions" section, offering a summary of the key findings and outcomes derived from the pilot projects and their evaluation.

2 Use-Cases Identification

2.1 Use-Case description

2.1.1 CELSA Group

Use Case 1 – Full scrap Characterization

Metallic yields, chemical compositions (Cu, Cr, Ni, Mo, Sn, C, P, S in particular), specific energy consumption of each type of scrap are essential characteristics for a good characterization of the different types of scrap used.

Use Case 2 – Scrap Inventory

According to volumes, detection thanks the drones or specific cameras and the internal determination of scraps' densities, a dynamic knowledge of the quantities of different kinds of scrap will be provided.

Use Case 3 – Determine Predictive Results offline

According to the Scrap characteristics (quality and quantity) and the steel grade to produce (Production planning), the model will determine the chemical compositions, the yield losses and the energy consumptions for the chosen scrap mix. The visualization of the results will appear in a specific interface.

Use Case 4 – Optimal Recipe for Steel Grades

The optimizer will have to establish the optimal scrap mix and the optimal process parameters to get the optimal result of the Electric Arc Furnace (EAF) according to the priorities given by CELSA Group (expected results/outputs on economic, environmental, energetic aspects). The model has to indicate the optimal weights and times of introduction for each EAF additive, the optimal energy process parameters (O_2 and CH_4 flowrates, electric voltages and intensities, boring, melting and refining times, optimal moments for scrap charging into the furnace).

The visualization of this model will be done on an interface integrated into CELSA France Supervision and indicators (Power-BI).

Use Case 5 – Dynamic control to Get the Optimal results and follow the CELSA priorities

According to the inputs chosen by CELSA, the optimizer will have to orientate the user on optimal online parameters to achieve the optimal results.

CELSA will have the possibility to fix the priorities/optimal results to reach in the interface, making a balancing between the different relevant criteria (yield loss, energy, CO_2, transformation cost…)

Use Case 6 – Life Cycle assessment of operating practices

The environmental impact of the different scrap types and resources consumed will be estimated.

Use Case 7 – Visualization of optimization results and performance metrics

User interface for visualization of optimization results and performance metrics. The visualization of the expected performances and of the real data must be possible at any time via our supervision system, and recorded in our acquisition system.

Performance indicators of the model will have to be created in order to follow the efficiency level of the model.

2.1.2 Fonderia di Torbole

Fonderia di Torbole has evaluate 2 different scenarios:

Scenario 1: is the current way of operation at FdT (EX-post evaluation). This is the starting point for the ALCHIMIA project: in this stage it is necessary to make understand and learn to ALCHIMIA the correlations between input (Use case 1) and output data (Use case 2). In addition in this stage the data collection help us and ALCHIMIA to find correlations and use these data/correlations to predict the final results (Ex ante evaluation as per scenario 2).

Scenario 2: ex-ante evaluaton of the quality output. We will work only with Use case 1 (input data) using the evaluations coming from ALCHIMIA system allowing anticipating final quality measurements (mechanical resistance, integrity, ...), in order to get rid of 3-to-5 hours of lag after production as currently in use.

At the beginning, scenario 1 and 2 (ex-post and ex ante evaluation) will work in parallel in order to verify the robustness of ALCHIMIA. Only after this trial period will be possible to consider only the ex- ante data coming from ALCHIMIA.

Here below the description of the different Use Case:

SCENARIO 1

Use Case 1 – Measurement of Input data

Measurement of input data: inoculant quantity, measurement of chemical composition (%), temperatures, thermal analysis properties during casting (data available at the beginning of the process to set up the casting process. Data are checked on an hourly basis)

Use Case 2 - Measurement of output data: Quality checks only at the end of the process.

Quality checks only at the end of the process. System to evaluate ex-post the conformity of the piece, after 3-to-5 hours of production, based on quality checks (for quality check, see output parameters below – use cases 2.1-2.5 in S1)

Use Case 2.1 - Output measurements: Mechanical property by Wedge compression test

This sampling check is made in order to evaluate the main characteristics that the brake discs must be comply. In fact, the brake disc is a safety part and the mechanical resistance must be respected. The mechanical resistance is made by a wedge compression test. To perform this test is necessary a preparation of a specimen cutting the part and it is necessary around 30' to have the result. This test is carried out 1 time/batch

Use Case 2.2 - Output measurements: Hardness

Hardness is a value that indicates the plastic deformability characteristics of a material. It is defined as the resistance to permanent deformation. Hardness tests determine the resistance offered by a material to being penetrated by another (penetrator). For cast iron the method to check the hardness is according to Brinell method (HB) which provides a ball indenter with diameter 10, 5 or 2.5mm with different load. The check is carried out on a sample basis (1 time/hour)

Use Case 2.3 - Output measurements: Quality internal integrity

The internal integrity is a check carried out by X-Ray machine to verify the absence of defects within the material like porosity, blow holes, defect non visible on the surface with naked eyes. Defects that can affect the safety of the product and depend on the production process.

Use Case 2.4 - Output measurements: Quality external surface (Cementite)

The cementite is a metallurgical problem mainly due the chemical composition or a poor inoculation. Factor that is easily predictable with thermal analysis. Cementite has very high hardness and creates problems in the machining phase and is not accepted on the parts. The check is carried out on sampling base (1time/hour) using a file.

Use Case 2.5 - Output measurements: Natural Frequency

Natural frequency, also known as eigenfrequency, is the frequency at which a system tends to oscillate in the absence of any force.

This parameter is checked by an analyser. The test is very fast. The part is struck by a hammer equipped with a load cell (input) and the signal is detected by a microphone (output). In a few minutes you can have the result without any preparation of the part (no cutting or specimen preparation is requested). The value of natural frequency is mainly connected to the material properties (stiffness of the part / mechanical resistance) and geometry. Since this check is fast (compared to the wedge compression test), we use this method to predict the final results in term of mechanical properties. In fact, the correlation between natural frequency and mechanical resistance is very hight (>90%). In addition is possible correlate on parameter of the thermal analysis (T liquidus) with the frequency results with good correlation.

SCENARIO 2

Use case 1

Prediction model to evaluate ex-ante output data (output parameters are shown in use cases 3-to-7 in scenario 1): ALCHIMIA is supposed to predict the final results starting only from input data

Use case 2

Human prediction check: Verifying the accuracy and robustness of the predictions.

Use case 3

Model performance monitoring and retraining (continual learning) and environmental impact evaluation (LCA based): ALCHIMIA is supposed to monitor model predictions and its performance in real time and in case of loss of performance; a new training must be launched to improve the model.

ALCHIMIA is also supposed to provide information related to environmental impact and to guide optimisation decisions.

2.2 Expected results

There are no relevant changes in the Key Performance Indicators (KPIs) established in the Grant Agreement.

KPI's and their targets have been represented in Table 1.

Table 1. KPIs and target value

OBJECTIVE	KPI	Target value
1. Implement a decentralised AI and Data solution to support the strategy towards the green transition of big metallurgy industries	Prototype of ALCHIMIA Federated Learning and Continual Learning framework	
	Aggregation of ML models from	≥ 3 factories
	Models developed using the FL and CL framework	>10
2. Demonstrate the potential of ALCHIMIA solution automatically and dynamically find the optimal mix needed in steelmaking processes based on recycled scrap metal. Successful replication for automotive parts production	Installation of ALCHIMIA system/factories using ALCHIMIA system	6
	Reduction of electricity consumption	~10 kWh/t
	Increase in metal yield	2%
	Specific to steelmaking use-case	
	Increase in efficiency for other resources than energy and scrap (ferro-alloys deoxidation materials)	5%
	Specific to automotive parts manufacturing	
	Reduction of power-on time	~ 1 min
	Reduction of the tap-to-tap time	~ 3 min
	Less consumption of deoxidation materials due to less over-oxidation at melt tapping	5%
	Savings of total oxygen consumption	0,05
	Increase of productivity in ton of liquid steel per hour	3%
3. Assess the environmental impact of ALCHIMIA solution	Reduction in CO_2 emissions (g CO_2eq / product mass)	> 5%
	Increase in circularity ratio (total scrap mass / product mass)	> 5%
	Reduction in slag formation	2%
4. Guarantee the highest levels of trust, safety and seamless collaboration between workers and AI-powered industrial solutions	Skills Development: Workshops for upskilling workers	> 3
	Workers engaged in ALCHIMIA Training and Education Action Plan	> 30
	Instantiation of High-Level Expert Group (HLEG AI) guidelines in realistic industrial use-cases	≥ 3
	Extension of HLEG AI guidelines for the usage of robotics systems in the manufacturing domain	≥ 1
5. Establish synergies with AI4EU AI-on-demand-platform, GAIA-X, European Common Data Spaces and relevant standards	New services integrated into AI4EU platform	> 2
	New datasets published in AI4EU catalogue	> 5
	New models published in AI4EU catalogue	> 10

OBJECTIVE	KPI	Target value
	Alignment with relevant projects and standards	> 5
	Industrial technologies compatible with ALCHIMIA	≥ 10
6. Communication and exploitation strategy for the adoption of ALCHIMIA results in several sectors	DIHs with the capability of demonstrating ALCHIMIA system	≥ 5
	DIH networks engaged to maximise long-term sustainability	≥ 3
	Projects with synergies	> 15
	Activities with other European partnerships and Horizon Europe Clusters	> 8
	Contributions to standardization bodies and foras	≥ 3
	New/enhanced services or products in each of the participating industrial companies, including the SMEs	≥ 1

CELSA and FdT have chosen some use cases for the project with a direct relevancy in terms of production. The expected results for both industries will focus on a reduction of more than 2,5% in energy consumption and CO2 emissions. The solutions proposed by ALCHIMIA should help to generate savings in the total cost of production of around 2.5% as long as the current quality standards are not lost.

3 Pilot sites preparation

3.1 Technological components and services

3.1.1 CELSA Group

CELSA Spain

The information flows generated by the IT systems, necessary for manufacturing, are organized at different levels. Each of these levels are independent of each other but the information flows between them is bidirectionally. The protocol used for exchanging information between systems is the TCP Stream Socket.

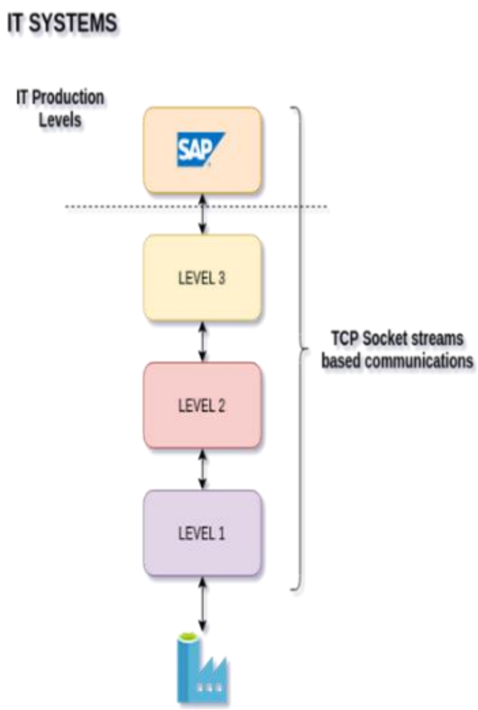

Figure 1. Levels of information flows

The flow of information begins at level 4. Level 4 is the company's Enterprise Resource Planning (ERP) system based on SAP as shown in Figure 1. From level 4 all the data regarding manufacturing orders and production planning are sent to level 3.

Level 3 is the system that contains the historical data of production registrations, raw material consumption, and registration of plant delays as well as micro-stoppages, data related to product quality are recorded through online editors, it also generates reports necessary for making decisions based on the data. This system contains a dedicated database where all the data is stored.

Level 2 is the system where the machine parameters related to all manufacturing products reside. For each machine and product there are specific parameters that must be transmitted for the EAF process to take place. Level 2 also dispose of material tracking monitoring of the plant in real time that allows most of the actions to take place automatically without the intervention of operators.

Level 1 is the plant control system. It is the system that is in contact with the machines that make up the manufacturing process. At this level you will find the necessary automation and process controls.

The plant's Programmable Logic Controllers (PLCs) are from the manufacturer ABB, these controllers are connected to the previous systems. In addition to the information systems described above, the plant has an industrial information system based on Internet of Things and Industry 4.0 technologies.

These technologies are based on sensors coming from the plant such as accelerometers, temperature sensors, and data that is collected from the process and is recorded in the signal analysis and management systems (IBA). The Industrial Internet of Things (IIoT) system is endowed with the ability to exchange any signal with any digitalization platform. The main communication protocols with the control systems are OPC-UA through connected gateways and Message Queuing Telemetry Transport (MQTT) for the exchange with the digitization platforms (Figure 2).

The digitalization level varies between the Melt Shops. At the highest one, the main information available is as following:

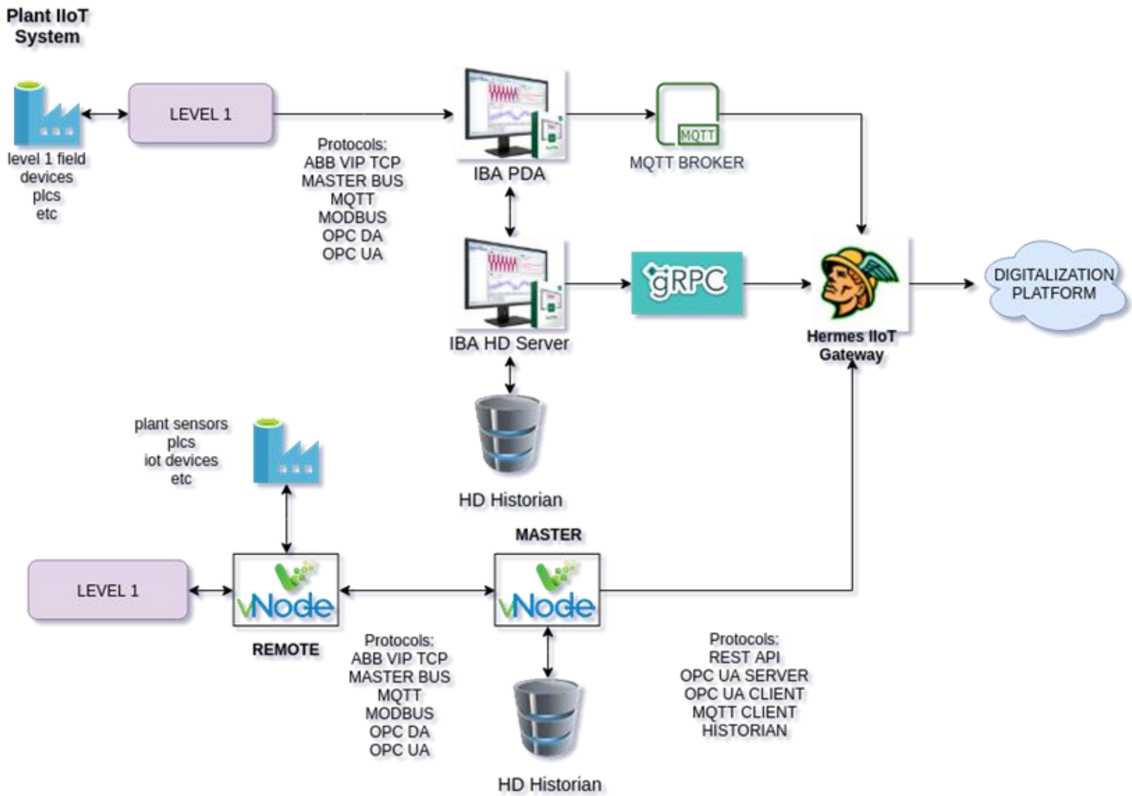

Figure 2. General scheme of Level 1 communications to digitalization platform

CELSA France

The IT infrastructure of the French plant is practically the same as in Spain. There are small differences with respect to the brand of some PLCs or with respect to the sensor data visualisation systems.

CELSA Poland

The equipment in the Polish plant is much older than in the other two plants. As a result, this factory is less digitised. Training of technicians from Poland is currently taking place in the other more digitised plants of the group and the corporate IT department is implementing the first digitisation milestone, which is the datalake.

Digital Solutions	CELSA Spain	CELSA France	CELSA Poland
Enterprise Resource Planning (ERP)	Yes	Yes	Yes
Manufacture Executing System (MES)	Yes	Yes	Yes
Energy management system (EMS)	Yes	Yes	No
Signal analysis and management systems (IBA)	IBA	ARCHESTRA	Yes
Programmable Logic Controllers (PLC)	ABB	Siemens	Yes
Industrial Internet of Things (IIoT)	Yes	Yes	No

Table 2. Digital Solutions by plant

3.1.2 Fonderia di Torbole

FdT has already the technological system/instruments able to detect input and output (like spectrometer for chemical analysis and Itaca for Thermal analysis for input data and other different instruments to check the quality of the part as output data). Most of this data are collected by SAP system and data will be shared on Webservice platform/VPN connection.

In order to have the availability of all data in SAP system we are evaluating a new thermal analysis software and the system to share the data.

3.2 Roadmap

This section of the document describes the roadmap for organizing case studies preparation activities, development activities, deployment activities, and the training of the use cases participants.

The main activities listed on the roadmap are common for all case studies but will be deepened and performed according to the specific case study needs, constraints, and time schedule. The common roadmap steps focus on:

1. **Site visits**: organizing site visits in the factories and engaging all relevant stakeholders and actors for:
    a. identifying and design the use cases of each plant, producing very detailed specifications for each one;
    b. identifying the current status of the infrastructure of each plant;
    c. identifying software and hardware components that are missing in the infrastructure and the time schedule for their acquisition or development;
    d. identifying topics and methodologies for participants training;
2. **Development activities**: all the activities related to the implementation of software, considering the selection of required libraries, main components, algorithms, composing the decision support system;
3. **Deployment activities**: all the activities related to the installation of hardware and software components composing the formulated decision support system architecture;
4. **Training phase**: training of stakeholders and use cases participants on the use of the decision support system, and for supporting the potential continuous development phase.

Site visits have been and will be organized according to the needs of the partners involved in each WP and related task. In the preliminary phases of the project, the site visits had the objective of clarifying the main characteristics and functioning of each plant, and involved process, of identifying any necessary and currently missing components (hardware and software) for the development of the platform. Secondly, the visits had the objective of deepening the operational needs of stakeholders, operators and participants, in order to identify a set of functional and non-functional requirements required for the ALCHIMIA platform.

The data collection campaign was and is one of the main objectives of the project, for exploiting the potential of Artificial Intelligence and Federated Learning approaches. In this context, the site visits have been and will be necessary for the identification of the fundamental measurement points for the development of the models, for identifying similarities and differences between plants of the same industrial company, the identification of any bottlenecks linked to the already present communication and data collection standards in the plant, and for identifying and solving barriers linked to the acceptability of the proposed solutions.

Future visits will be aimed at (i) identifying and solving any risks and barriers related to the development, implementation, and distribution of the solutions, (ii) training the operators for using the solutions proposed by the project, (iii) installing and testing the versions of the software, (iv) final tests and evaluation of the results.

For the development and deployment activities, we refer to the work developed during WP2, and in particular Task 2.4, where a High-Level Architecture has been proposed for developing and deploying hardware and software solutions of the ALCHIMIA platform. A schematic view is depicted in Figure 3 where, in order to exploit a Federated Learning approach, two different platform types will be available: (i) a central server and (ii) several local clients, one for each plant. The work done during the task gives precise indications on what are the necessary steps for the preparation, development, and deployment of the platforms.

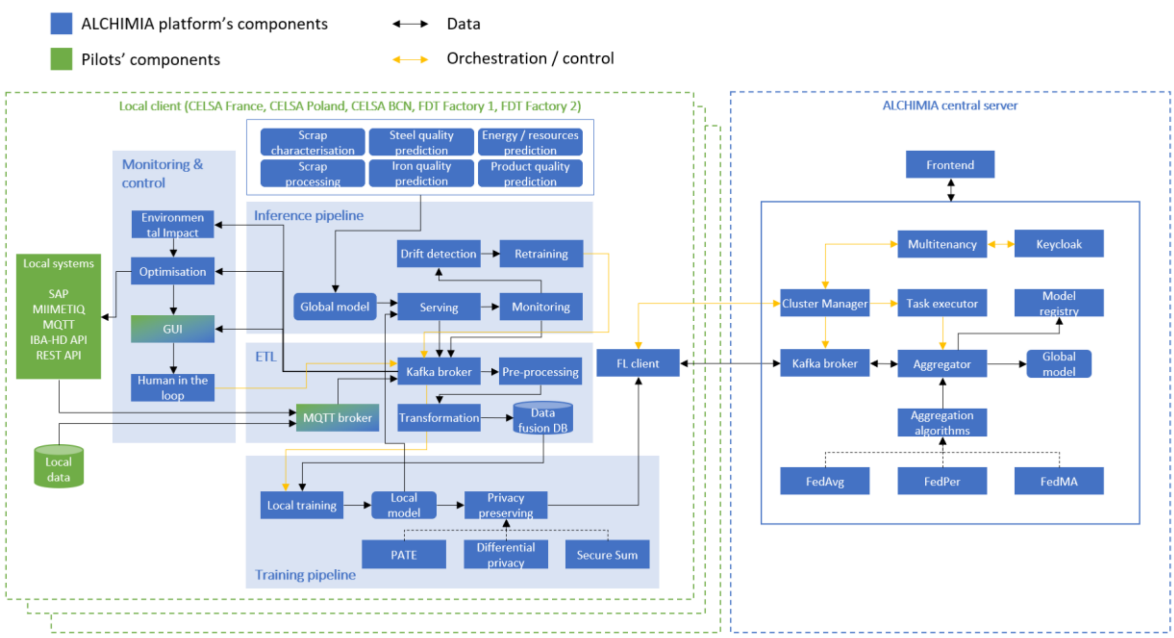

Figure 3. Architecture design proposed for the ALCHIMIA platform.

More in details, a bullet point representation of the common activities included in the roadmap for Development, Deployment and Training activities is as follow:

1. Site visits for:
    a. Discussing of objectives and possible use case
    b. Deepening knowledge on process behaviour
    c. Identifying missing sensors and methodologies for data collection and data access
    d. Identifying similarity and differences between plants of same industrial company
    e. Deploying the future versions of the software and for finalizing online tests
    f. Training of operators and software users

2. Development activities:
    a. Definition of functional and non-functional requirements for the ALCHIMIA platform (done during task 2.4)
    b. Design of high-level architecture of the ALCHIMIA platform (done during task 2.4)
    c. Definition of Hardware and software requirements (done during task 2.4)
    d. Development of Unified Modelling Language (UML) diagrams for defining class diagrams, component diagrams, deployment diagrams and sequence diagrams (done during task 2.4)
    e. Development of services for interfacing and provide plant data to the ALCHIMIA platform
        i. FdT: development of web services for data interface
        ii. CELSA Spain-France, datalake access, methodologies, validation and integration.
        i. CELSA Poland, to be discussed after the ALCHIMIA solution implementation in CELSA Spain-France
    f. Offline development and first prototype of process models and, algorithms for outlier detection and correction
    g. Offline implementation of monitoring and Control systems
    h. Development of ALCHIMIA central server
    i. Development of software for local clients

j. Development of ETL components and interface with existing data sources in each plant
k. Development of training pipelines and related components for the federated learning
l. Inference pipelines
m. Monitoring and control, including Graphical User Interfaces

3. Deployment activities:
    a. Installation of calculation platforms in each plant
    b. Implementation of Continuous integration and continuous deployment (CI/CD) strategy and related architecture
4. Training courses on:
    a. Architecture, modules, graphical user interfaces and their use
    b. Modelling methodologies aimed at continuous development
    c. Optimization methodologies aimed at continuous development

3.2.1 CELSA Group

The roadmap for the CELSA Group has been developed for each plant, as each requires certain specifications, procedures, and timelines.

CELSA Spain

<u>26-27/09/2022 - Kick Off-meeting:</u>

a. Discussion of objectives and possible use cases
b. Visit to the Barcelona plant with a focus on the overall plant layout and process

<u>26-27/06/2023 - Visit to understand the expectations with Cardiff:</u>

c. Understand the work methodology of the plant
d. Forecast how ALCHIMIA will affect the role of each person involved in the process
e. Understand the expectations of the internal costumers and how it could be taken into account in each use case

<u>07/07/2023 - Technical Plant Visit of Barcelona Plant with SSSA:</u>

f. Scrapyard plant visit and related modelling information and methodologies
g. Identification of missing sensors

h. Technical discussion on datalake access

Possible future visits for:

i. E.g. First software version installation and online tests

j. Training of personnel

k. Final solution installation

CELSA France

7-8/03/2023 - Technical plant visit of Boucau Plant:

a. Visit to the Boucau plant with a focus on the scrap management and the overall production process
b. Deepening production planning and use cases
c. Discussion on scrap management tools and procedures
d. Presentation of the computerized structure
e. Discussion with ATOS, EXUS, BFI and SSSA respectively on reference architecture, data consolidation and orchestration tools, and modelling tools

5-7/06/2023 - Visit to understand the expectations with Cardiff:

a. Understand the work methodology of the plant
b. Forecast how ALCHIMIA will affect the role of each person involved in the process
c. Understand the expectations of the internal costumers and how it could be taken into account in each use case

CELSA Poland

25-26/05/2023 - Visit to understand the expectations with Cardiff:

a. Understand the work methodology of the plant
b. Forecast how ALCHIMIA will affect the role of each person involved in the process
c. Understand the expectations of the internal costumers and how it could be taken into account in each use case

Further technical visits are going to be conducted once implemented the solution in CELSA Spain and France.

3.2.2 Fonderia di Torbole

Plant visits:

- 16/11/2022
    1. Visit to plant and processes
    2. Deepening of objectives and use cases
    3. Technical discussion on data collection, current status, and requirements
- 16-17/05/2023
    1. Production plant visit and update on data collection
    2. Surveys to understand the expectations of the people involved in the process and forecast how ALCHIMIA will affect their role
- Next site visits
    1. First deployment of the software and online tests
    2. Following deployment of the software, tests and results assessment

Today Fonderia di Torbole checks different parameters at the beginning of our process (input data) and at the end of the process on the physical part (output data). Only at this stage we know if the parts (brake discs/brake drums) are compliant or not with the standards.. This mean that we need to wait 3-5 hours after the production to see the final result. (**Ex-post evaluation**).

Up to date only the T-liquidus coming from thermal analysis is used to predict frequency and mechanical resistance.

Further parameters could be employed to predict the quality parameters. ALCHIMIA system should find more correlation between input (inoculant quantity, chemical composition, temperatures, thermal properties during casting) and output data related to the quality of the final product in order to predict **Ex-ante** the final result. To complete and in order to have the availability of all necessary data for ALCHIMIA, the next steps should be the following:

- Data availability and format: At today not all the data are available in SAP (i.e., thermal analysis). We are evaluating a new software / instrument able to connect with SAP. Forecast for the implementation 07/2024. Today the correlation is not in automatic way but is manually.
- Data collection: to correlate the data with more accuracy is necessary to involve the operators. In addition, at today not all checks are carried out on an hourly basis. Our idea, for the next step is to increase some final checks (i.e., mechanical

resistance) in order to have a good correlation between input and output data with the same frequency sampling.

- Implementation of the PC desktop able to manage the ALCHIMIA platform.
- Data sharing: Data will be shared by Webservice platform/VPN connection. The implementation will be done after connecting the thermal analysis to SAP

3.3 Issues, barriers and risks

3.3.1 CELSA Group

In terms of steel production in CELSA, some issues have been considered:

- Due to long changeover time the production focuses on high lot sizes
- The schedule window at the Melt Shop and later processes is short. A longer planning horizon at demand and sales planning is needed.
- Agreeing on the decision criteria between different business operation units.
- Agreeing on the daily production schedule between the Melt Shop and the Scrap Yard.
- Lack of capacity to ensure maintenance and continuous functioning of sensor infrastructure in CELSA France.
- Scrap market is a sellers market which makes any sort of planned scrap buying prohibitively expensive. At some point, ALCHIMIA will not be able to prescribe what sort of scrap might be needed.

Two main technological barriers have been faced: the lack of interface and communication between management systems (e.g., MES and EMS), and to identify measurement points and appropriate placement of sensors/meters.

3.3.2 Fonderia di Torbole

The main possible Issues and barriers highlighted in the ALCHIMIA project are the following:

- General: in some case is difficult to modify the habits
- Operators: is required more attention in the data collection in the right frequency
- Operators: distrust of the AI based models
- Operators: necessity of a dedicated training
- Company not available to share data/info

- System not compatible with ALCHIMIA interface
- IT dept. not available to modify the current structure
- FdT is TISAX certified (conformed with ISO 27001 for data confidentiality policy). Therefore, the cloud use depends on the TISAX (and customers) constraints.

The main risks highlighted in the ALCHIMIA project are the following:

- Incorrect data acquisition or incorrect data correlation between input and output
- Wrong data mainly in the thermal analysis due to breakage of the thermocouple
- Wrong evaluation of the defect in the final control
- Timing not in line with the time schedule of the project
- Data sharing not possible due to confidentiality information
- Sharing platform not available or not compatible with ALCHIMIA interface

4 Description of the Datasets

CELSA Group

4.1 Dataset structure

In the following section, the structure and meanings of the CELSA Group dataset will be detailed. The format used in the dataset is JavaScript Object Notation (JSON) files.

Table 2. Dataset concept description

Identification	Unique identifier for each heat, ensuring each entry is uniquely referenced
Production_Data	Measurement attributes: Steel grade and liquid steel weight. The "steel grade" refers to a standardized classification or designation that defines the composition and properties of a particular type of steel. The "liquid steel weight" refers to the mass or weight of molten steel. It is typically measured in tones
Start/end time	Specific data for each furnace: Electric Arc Furnace, Ladle Furnace, Continuous Casting Machine as the main electric consumers during the process.
Plant	Identification number of each plant
Scrap	In CELSA's production, steel is made from scrap instead of iron ore.
Aggregations	Raw materials and inputs to adjust the final composition of the steel
EAF parameters	Measurement attributes: Characteristics: de-slagging time, liquid steel weight and tapping slag Global heat media consumption Additives consumption Slag composition Oxygen content measurement at tapping of liquid steel Furnace refractory lifetime (breakdowns, electrodes and burners)
Ladle parameters	Characteristics (initial weight and temperature start) Energy consumption Additives consumption (at tapping and during refining) O2 concentration Temperature
Chemical analysis	Concentration of chemical elements

4.2 Examples

CELSA's dataset example:


```
[ 1 item
  0 : {
    _id : { 1 prop }
    general : {
      identification : {
        id : 247132
        heat : 247132
        id-in-heat : 0
        total-billet-number : 0
        good-billet-number : 0
        good-billet-weight : 0
        eaf-team : value
        eaf-number : 1
        lrf-number : 1
        ccm-number : 1
      }
      caracteristics : {
        production-date : { 1 prop }
        steel-grade : HM-275
        steel-liquid-weight :
        eaf-start-time : { 1 prop }
        eaf-end-time : { 1 prop }
        lrf-start-time : { 1 prop }
        lrf-end-time : { 1 prop }
        ccm-start-time : { 1 prop }
        ccm-end-time : { 1 prop }
        sy-start-time : { 1 prop }
        sy-end-time : { 1 prop }
        scheduled-steel-grade : HM-275
      }
      plant : cms01
      scrap : { 1 prop }
      name : heat - cms0
      __type__ : heat
      _updated : { 1 prop }
      _created : { 1 prop }
    aggregations : { 1 prop }
    eaf : {
      caracteristics : { 3 props }
      global-heat-media-consumption : { 5 props }
      additives-consumption-eaf : [ 2 items ]
      slag-composition : [ 0 items ]
      celox-tapping-liquid-steel : [ 1 item ]
      furnace-refractory-lifetime : [ 1 item ]
      breakdowns : [ 2 items ]
      electrodes : [ 0 items ]
      burners : [ 7 items ]
    }
    ladle : {
      caracteristics : { 6 props }
      energie-consumption-at-ladle-furnance : [ 2 items ]
      additives-consumption-at-tapping : [ 5 items ]
      additives-consumption-during-refining : [ 12 items ]
      liquid-steel : [ 2 items ]
      o2-concentration : [ 2 items ]
      temperature : [ 4 items ]
      slag-composition : [ 0 items ]
    chemical-analisis : {
      chemical-analisis-master : { 50 props }
      heat-chemical-analisis : [ 4 items ]
    }
```

Fonderia di Torbole

The dataset template is available at the beginning of the project in Excel format, with manually correlating the data.

After the implementation of all the system integrated in SAP, the data will be available in automatic way through WEB service platform.

5 Readiness Evaluation

5.1 Description of the criteria and standards used to assess pilot readiness

A System Readiness Assessment (SRA) is a structured and comprehensive evaluation process used to determine whether a complex system or project is prepared and capable of transitioning from its development or testing phase to its operational phase. The main goal of an SRA is to ensure that all necessary components, processes, and functionalities are in place for the system to function effectively, efficiently, and reliably in its intended operational environment.

Defining a SRA often involves utilizing concepts such as Technology Readiness Levels (TRL) and Integration Readiness Levels (IRL) to assess the system's readiness for deployment. These concepts provide a structured framework for evaluating the maturity of technologies and the integration of components within a system. The SRA methodology provides decision-makers a snapshot of a system's holistic state of maturity and quantifies the System Readiness Level Index of component-to-component integration during system development, using a scale from 1 to 9, with 9 signifying the highest level of readiness.

1. Technology Readiness Levels:

Technology Readiness Levels are a standardized set of stages used to assess the maturity of a technology or component. They help gauge how advanced a technology is in terms of its development, testing, and integration. TRLs are numbered from 1 to 9, with each level representing a specific stage of technological advancement. The higher the TRL, the more mature and well-tested the technology is. Here's an overview of TRLs:

- TRL 1-3: Basic research and concept development.
- TRL 4-6: Technology development, testing, and validation in a laboratory or controlled environment.
- TRL 7-9: Integration and testing of the technology in a relevant operational environment, leading to actual system deployment.

In the context of SRA, TRLs are used to assess the individual technologies, components, or subsystems that make up the larger system. The goal is to ensure that each technology is sufficiently mature and tested before integration into the final system.

2. Integration Readiness Levels:

Integration Readiness Levels are similar to TRLs but focus specifically on the integration of various components or subsystems within a system. IRLs assess the readiness of different parts of the system to work seamlessly together. The integration process involves combining components and ensuring they interact as intended without causing conflicts or failures.

Like TRLs, IRLs are typically numbered, and each level represents a specific stage of integration readiness:

- IRL 1-3: Initial planning and concept of integration.
- IRL 4-6: Integration design and development, including testing in a controlled environment.
- IRL 7-9: Integration testing in a relevant operational environment, leading to full system deployment.

The Key Components considered to be part of the SRA are:

1. Functional Testing: The assessment involves verifying that the system's core functions and features work as intended. This includes checking that interfaces, algorithms, and interactions among various components are functioning correctly.
2. Performance Evaluation: The system's performance metrics, such as response time, processing speed, and capacity, are assessed to ensure they meet predetermined standards.
3. Integration Testing: This involves testing how different modules or components of the system work together to achieve the overall objectives. It identifies any issues related to interoperability and compatibility.
4. Security and Reliability: The assessment includes evaluating the system's security measures to protect against unauthorized access and its reliability in terms of uptime and resilience to failures.
5. Scalability: The system's ability to handle increased load or demand is examined to ensure it can accommodate future growth without compromising performance.
6. User Acceptance Testing: If applicable, users or stakeholders participate in testing to validate that the system meets their needs and expectations.
7. Documentation Review: All necessary documentation, including user manuals, technical specifications, and operational procedures, is reviewed to ensure completeness and accuracy.
8. Risk Assessment: Potential risks and vulnerabilities are identified and assessed to determine whether mitigation measures are in place.
9. Training and Support: The availability of training resources and support mechanisms for end-users and maintenance personnel is evaluated.

10. Change Management: Procedures for managing changes or updates to the system after deployment are reviewed.
11. Compliance and Regulations: If the system needs to adhere to specific regulations or standards, compliance with those requirements is assessed.

These criteria and standards serve as benchmarks against which the project's various aspects are measured.

FdT

For the first stage of the project the data will be collected manually, and the Input/output will be synchronized manually in offline mode. At this stage it will be possible to evaluate if the ALCHIMIA system is able to manage the data. In addition to verify if the system runs correctly with right correlation end EX-Ante evaluation.

After the implementation of all instruments/software, the data will be available in line and collected in automatic way. In this stage will be possible to evaluate the full system with the relevant output and KPI.

5.2 Individual assessment results for each pilot

In Table 5 is referenced the parameters that the two industries will use for the validation of the use cases.

Table 3. Individual assessments for each industrial case

USE CASE	DESCRIPTION	Individual assessments
CELSA UC 1	Full scrap characterization	Metallic yields
		Specific energy consumption of each type of scrap
CELSA UC 2	Scrap inventory	Quantities of different kinds of scrap
CELSA UC 3	Predictive results offline	The chemical compositions, the yield losses and the energy consumptions for a scrap mix chose
CELSA UC 4	Optimal Recipes for Steel grades	Optimal weights and times of introduction for each EAF additive
		Optimal energy process parameters
CELSA UC 5	Dynamic control	CELSA will have the possibility to fix the priorities/optimal results to reach in the interface making a balancing between the different relevant elements (Yield loss, energy, CO_2, Transformation cost…
CELSA UC 6	Life Cycle assessments of operating practices	Comparison with existing data
CELSA UC 7	Visualization of optimization results and performance metrics	Power-BI
FdT UC 1	Measurement of input data	Inoculant quantity, measurement of chemical composition (%), temperatures, thermal analysis properties during casting (data available at the beginning of the process to set up the casting process
FdT UC 2.1	Output measurements: Mechanical property by Wedge compression test	Wedge compression test to evaluate ex-post the conformity of the piece, after 3-to-5 hours of production, based on quality checks.

USE CASE	DESCRIPTION	Individual assessments
FdT UC 2.2	Output measurements: Hardness	Hardness is defined as the resistance to permanent deformation. Hardness tests determine the resistance offered by a material to being penetrated by another (penetrator). For cast iron the method to check the hardness is according to Brinell method (HB) which provides a ball indenter with diameter 10, 5 or 2.5mm with different load.
FdT UC 2.3	Output measurements: Quality internal integrity	The internal integrity is a check carried out by X-Ray machine to verify the absence of defects within the material like porosity, blow holes, defect non visible on the surface with naked eyes.
FdT UC 2.4	Output measurements: Quality external surface (Cementite)	The cementite is a metallurgical problem mainly due the chemical composition or a poor inoculation. Factor that is easily predictable with thermal analysis. Cementite has very high hardness and creates problems in the machining phase and is not accepted on the parts.
FdT UC 2.5	Output measurements: Natural Frequency	Natural frequency, also known as eigenfrequency, is the frequency at which a system tends to oscillate in the absence of any force. This parameter is checked by an analyser. The part is struck by a hammer equipped with a load cell (input) and the signal is detected by a microphone (output). Since this check is fast (compared to the wedge compression test), we use this method to predict the final results in term of mechanical properties. In fact, the correlation between natural frequency and mechanical resistance is very hight (>90%). In addition is possible correlate on parameter of the thermal analysis (T liquidus) with the frequency results with good correlation.

6 Implementation

6.1 Factory visits

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The visits to the plants located in Spain, France and Poland have achieved the main purpose of these visits: an approximation to the specific reality of each of the factories. The visits to the plants have also allowed to level the expectations between the different partners of the project but also with regard to the internal customers of each plant, who are the ones who will ultimately use the solutions developed by the ALCHIMIA's project.

FONDERIA DI TORBOLE

The factory visits are a very important point to understand deeply our processes. The main aspect seen during the visit are the following:

- Process step (raw material area, melting shop, final control,...)
- Quality checks in the different areas
- Current system to evaluate the quality of the final product
- Explain what the ALCHIMIA system is supposed to do
- Understand how the ALCHIMIA system could be integrated into our process

A first visit was made by SSSA on 22/11/2022 and a second visit by SSSA and Cardiff University on 16-17/05/2023.

6.2 Methodology for implementation

The methodology chosen for *T5.1 Detailed specification of scenarios and end-user sites preparation* is based on the Agile methodology, which is well-suited for dynamic collaboration. This methodology emphasizes flexibility and iterative development. The cornerstone of this approach involves holding regular collaborative meetings. During these meetings, project partners show their progress, seek clarifications, and collectively outline the next steps for use case definition and specifications. In this way, an understanding is reached between the owners of the pilots and the partners responsible for system development to prevent integration problems in the future.

In addition to the regular meeting, visits have proven to be essential for comprehending the various phases of the manufacturing processes and gaining deeper insight into the elements that the system must address, as well as the different functionalities it must provide to the users.

To facilitate collaboration among the various partners, a GitHub repository[1] has been created to maintain version control over the different specifications that the system needs to present, as well as the use cases. During the specification definition, the work carried out in tasks *T2.1 Requirements' analysis, use-cases definition and KPIs* and *T2.4 Reference architecture design and specification* has been considered to ensure that all specifications are coherent and compatible. These tasks have been organized with following steps:

1. Specification of pilots' use case: This step consists of identifying the actors and the external systems that will interact with ALCHIMIA system. In addition, the data characterization is required to understand different data aspects as volume, viability, latency, etc. The specification is the first step to agree the vision of all partners.
2. Definition of system requirements: Once the use cases of the pilots are set. Both, functional and non-functional requirements must be defined. Thus, a clear understanding of what the system must accomplish and how is provided.
3. Logical system overview: High-level description of how different components, processes and interactions within ALCHIMIA system based on previous steps helps to detect complexities in the future.
4. Architecture description using 4+1 methodology: At this step the pilots' use cases are specified, the functional and non-functional requirements are defined, and the logical overview of the system is described. All this information is used to describe the system using 4+1 view model. This methodology provides logical, development, process, physical and use case views which are valuable for documenting and communicating the architecture of systems from different perspectives.
5. Component's APIs specification: The final step consists of document the components APIs, brokers and data model of the system.

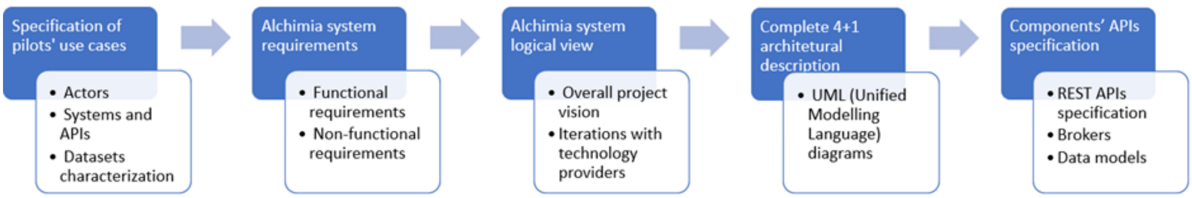

Figure 4 Process summary

[1] https://github.gsissc.myatos.net/GLB-BDS-ALCHIMIA/Platform-design/tree/uml_diagrams

6.3 Analysis of strengths and areas for improvement for each pilot

Analysing the strengths and areas for improvement for an industrial pilot using the Agile methodology involves looking at both the positive aspects and potential areas where the process can be enhanced. Here's a breakdown:

Strengths:

1. Flexibility and Adaptability: Agile methodologies allow for changes in requirements and priorities, making them suitable for industrial pilots where variables can change rapidly.
2. Iterative Development: Agile promotes iterative development cycles. This means that industrial pilots can deliver incremental improvements, allowing for continuous testing and validation. This is especially valuable in steel industries where the products are complex.
3. Stakeholder Collaboration: Agile emphasizes collaboration among team members and stakeholders. For an industrial pilot, this ensures that the perspectives of various departments and stakeholders are considered, leading to better alignment and reduced chances of misunderstandings.
4. Early Detection of Issues: Frequent testing and reviews in Agile methodologies help in the early detection of issues or deviations from the intended outcomes. This is crucial in industrial pilots, where identifying and addressing problems early can prevent costly mistakes down the line.
5. Customer-Centric Approach: Agile methodologies prioritize delivering value to the customer. In an industrial pilot, this means focusing on meeting the specific needs of the end-users and adapting the pilot accordingly.

Areas for Improvement:

A. Integration with Existing Processes: Industrial pilots often need to integrate with existing systems or processes. Agile teams need to ensure that integration challenges are anticipated and addressed, and that the pilot aligns seamlessly with the broader operational context.

B. Resource Allocation: Agile teams require dedicated resources and frequent involvement from stakeholders. In industrial settings, where resources might be constrained, finding the right balance between daily operations and pilot execution can be a challenge.

C. Scaling Agile Practices: Scaling Agile from a small team to an industrial context can be complex.

D. Corporate Resources: Corporate departments and services from large industries are sometimes disconnected and independent from the industrial site.

Coordination of the tasks, roles and resources from each site can be challenging. In addition, the differences between each industrial site, even in the same company, can provoke discrepancies with the approach of the project and working methodology.

E. Lack of knowledge about Agile Practices: Traditional industries usually use traditional working methodologies. Since Agile Practices are mostly used by developers, it could be difficult for the people from industry to understand the approaches.

7 Conclusions

The use-case definition proposal for both industrial partners of this project, Fonderia di Torbole and CELSA Group, have been defined in accordance to the KPIs of the project. The expected results for both industries will focus on a reduction of around 2,5% in energy consumption and CO_2 emissions.

The roadmap is based on site visits, development of activities related to the implementation of ALCHIMIA solution, deployment activities and the training phase with the main goal of the development workshops for upskilling workers.

Regarding issues and barriers, the main difficulties could be modifying the current habits in both industries, some incorrect data acquisition or incorrect data correlation between inputs and outputs and a distrust of the AI based models.

The criteria and standards used to assess pilot readiness will be developed with a SRA, which mixes TRL with IRL to assess the system's preparation for deployment. The individual assessment for each use case is related to specific KPI's from each industry.

All members of the consortium are aware that any project has the great challenge of moving from theory to practice. A good definition of the use-case can help to anticipate possible risks and mitigation plans, therefore, a comprehensive risk control is also being developed in the project management of the project.